The compatibility of lean and innovation - The coevolution of lean management and innovations in the automotive industry

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Dedication

For my father.

Note of Thanks

I would like to take this opportunity to thank Prof. Dr. Andreas Pyka, Head of the Institute for Innovation Economics at the University of Hohenheim, who gave me the opportunity to do this work under his leadership.

I would particularly like to thank my husband, Stephan Pischl, and siblings, Dr. Verena Wörndle and Günter Lorber, for the unrestricted, loving and versatile support during my dissertation.

Foreword

In the automotive industry, original equipment manufacturers (OEMs) face the challenge of being innovative and lean at the same time. This ambidexterity influences their research and development strategy as well as their production system strategy. Considering that until today no consistent definition exists of innovation within the literature, a multidimensional approach is used in this work, which focuses on three main objectives to analyse the compatibility of lean and innovation. Within the theoretical background, innovations are characterised based on their origin (generated or adapted innovation), type (process, product or organisational innovation), and intensity (incremental or radical innovation). Embedding this characterisation into the lifecycle theories of industries, technologies, and products displays the resulting complexity and leads to the drawing of connections between state decisions (laws and regulations) and society (megatrends), thereby creating a holistic theoretical framework in which OEMs have to align their production system strategy.

The **first objective** of this work is to create a deeper understanding of the ambidexterity of the patent structure within the automotive industry focusing on OEMs and their production systems. The coevolution of lean und innovation is analysed in a long-term view using a statistical patent analysis. Until today, the question of whether companies should set their priorities in explorative or exploitative inventions to generate innovations has not been clarified explicitly. Therefore, a model combining ambidexterity (exploitation and exploration) with leagility (lean and agile) is defined and tested to obtain an enhanced understanding that the combination of being agile and being lean plays a key role within a lean production system and has a main influence on innovation.

The **second objective** is to propose how a production system can successfully cope with external/adapted (incremental and radical innovation) innovation using lean principles. A model focusing on the target orientation of new concepts, methods, and technologies is defined and tested to obtain an enhanced understanding that lean must be integrated into the selection and evaluation process of innovations projects within the production system to ensure target orientation and make it possible to cope with innovation successfully.

The **third objective** is to demonstrate how lean principles can be successfully integrated into innovation projects using augmented reality (AR) in assembly training. Modern workplaces equipped with large screens provide new employees with 2D and 3D information about the current task. Workers receive additional visual or haptic information through pick-to-light systems to prevent picking mistakes or smart tools, such as a screwdriver with torque and rotation angle monitoring. Over the last years, a various range of AR systems have been proposed. This shows that assembly training with head-mounted displays using AR and taking lean principles into consideration are as good as being trained by a trainer, which provides an enhanced understanding that lean principles must be integrated in process and product innovation projects to achieve the optimal output and ensure smooth implementation in the production system.

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List of abbreviations

A

AR · Augmented Reality

B

BMW · Bayerische Motoren Werke

C

CIP · continuous continuous improvement process

E

EPO · European Patent Office

H

HMD · Head-Mounted-Display, Head-Mounted-Display

J

JIT · Just-in-time

N

NPE · Nationale Plattfrom Elektromobilität

R

ROI · Return on Investment

T

TPS · Toyota Production System
TQM · Total Quality Management
TRIZ · Theory of Inventive Problem Solving

V

VDA · Verband der Automobilindustrie
VPS · Value Added Production System
VW · Volkswagen

1. Introduction

When current developments within markets, industries, and societies are examined, it becomes obvious that established market-based mechanisms are overridden by these developments. Current ‘megatrends’[1]such as digitisation, individualisation, and urbanisation create markets where individual successful companies dominate the entire market (ATZ Heavy Duty worldw, 2019). Companies do their utmost to be number one and secure a global monopoly position in rapidly changing environments. This makes it almost impossible for number two, especially in already tight markets, to wiggle at the monopoly position even if the product is good. This leads to the fact that change cannot just be understood as technological progress anymore; instead, we are talking about a radical change in the economy and society, resulting in new challenges and market mechanisms that cannot be comprehended fully yet (Wells and Nieuwenhuis, 2012).Such change processes have increased in rapidness in recent years and, as a result, speed has become a decisive competitive advantage in the economy. To become number one, the innovative potential of companies is a crucial factor and results from a company’s capability to deal with rapidly changing markets, understanding of the new market mechanisms, and fulfilling of varying customer needs (Wells and Nieuwenhuis, 2012).The automotive industry serves as an example industry in this work to elucidate transformation/change processes and to demonstrate that reconciling innovation and robust, stable processes and systems play an essential role in staying competitive.

Because the automotive industry is undergoing one of the largest transformations in history (Kessler and Buck, 2017), it represents an excellent example to analyse the current industrial, economic, and societal developments through showing how the pressure to change today—and therefore to innovate—results from four megatrends: digitisation, urbanisation, sustainability, and individualisation (Townsend and Calantone, 2013). Recommendations for action for companies, managers, and society can be derived from this transformation analysis. By keeping in mind that the transformation of the automotive industry started with the introduction of assembly line production in 1913, developing the luxury car into a mass-produced product in countries and regions such as North America, Japan, and Western Europe

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[1] The term “megatrends” was coined by the futurologist John Naisbitt (1982). Megatrends are deep currents of change encomapssing several decades, in contrast to short-term product and fashion trends encompassing of a maximum of 5 years. A megatrend affects everyone and encompasses all levels of society: economy and politics, as well as science, technology and culture. Their powers of change even manage to transform entire societies, because they change and penetrate forms of civilization, technologies, and economy as well as value systems. By combining several individual trends megatrends are changing the world slowly but fundamentally and can often not be clearly distinguished from one another. (Burkhart and Hanser , 2018; Krys, 2017; Naisbitt, 1982)

(Maxton and Wormald, 2004), the long and ongoing history of change within the industry can be seen. Today, the transformation can be observed in new drive technologies that are about to make their breakthrough (sustainability); car manufacturers as well as suppliers that are becoming mobility service providers (individualisation); and new, innovative business models that are conquering the market (digitisation), resulting in a mobility of the future that is networked, shared by people in autonomous and electric vehicles. In the next years, but already beginning today, the electric engine will replace the combustion engine (Bakker and Farla, 2015).An enormous need for action derives from urbanisation as well as the altered awareness of the environment, values, and demographic development, which should not only be seen as drivers but also even more so as catalysts of the transformation. This puts companies in the position to invest in their old business model, which will enable them to generate a large part of their profits in the foreseeable future; furthermore, they are simultaneously faced with the task of promoting the transformation of their products, processes, and business models. Dealing and balancing the internal demands as well as coping with external geopolitical changes make flexibility and dealing with complexity a crucial factor to survive the ongoing transformation successfully. The mobility shift will be so profound that new regulations of the automotive industry and corporate transformation alone will not be enough. The political and regulatory environment for the automotive industry is changing faster and more unexpectedly than ever before. Brexit, the US election, or quotas for e-cars in China are current examples (Kolk and Levy, 2004; Lin and Ho, 2016; Driffield and Karoglou 2016; Xiao, Zhou and Hu, 2017). Politics, business, trade unions, and consumers must work together to launch a new policy (Maxton and Wormald, 2004).

At the centre of the investigation of this work is the question of the transformation potential engendered by global structural change and the resulting perspectives on the example of the automotive industry. Because of its differentiated and efficient structure of technology, product and product-related services, and its ensuing problem-solving competence, the automotive industry is the point of departure in this work, particularly to demonstrate the enormous opportunities in accelerating the global challenges. Especially against the background of current crisis (e.g. diesel scandal), it is necessary to look ahead and focus on the opportunities that still exist. To ensure, offer, and guarantee long-term mobility, a far-reaching transformation of the economy and society will be necessary. Only by coping with societal, cultural, and political change processes in addition to performing technological and economic adjustments can the transformation that will be necessary both from the perspective of innovation and that of adapting existing structures be achieved successfully. This leads to the main question of this dissertation: How can a compatibility between being innovative and being efficient (lean) be achieved?

1.1.Introduction to the topic and definition of the problem

The connection between science and progress has been known since antiquity[2], and the obvious link between technological progress and economic well-being is beyond question (Grupp, 2013). The concepts of knowledge gain and prosperity increase are seen as intertwined. It is not just societies that act, develop, and deal in this continuum of science and progress/technology but also globally operating companies (figure 1).

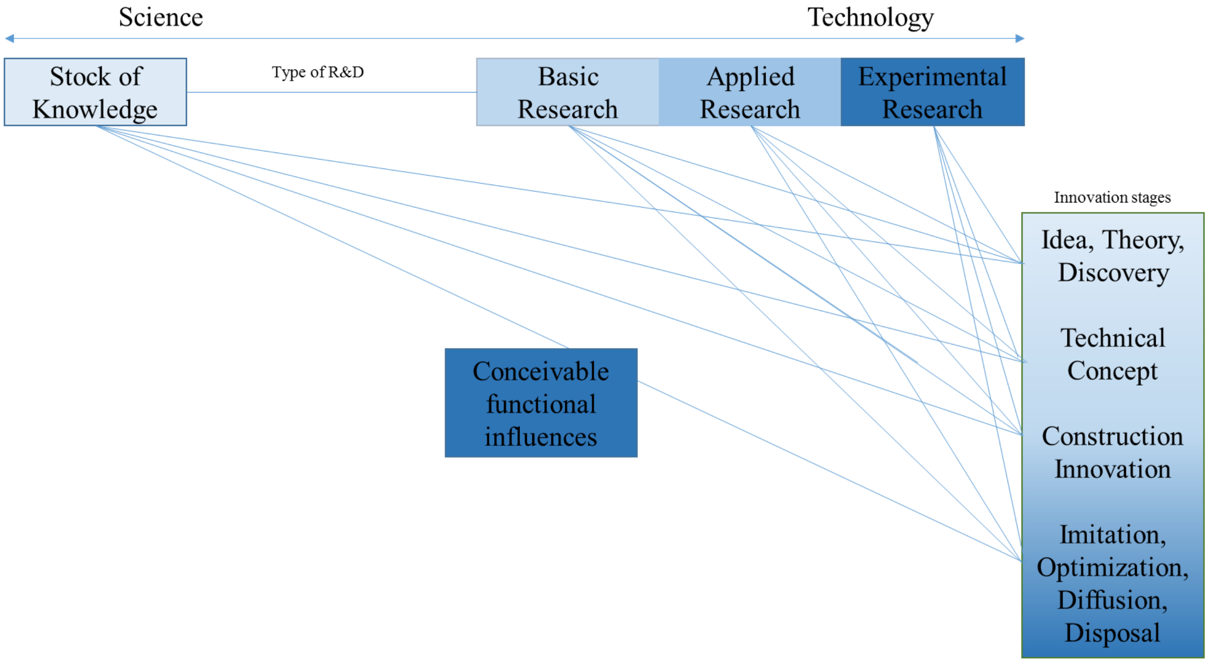

Figure 1: Reference scheme of coupled progress functions (own representation based on Grupp, 2013).

Keeping this continuum in mind, it is essential to understand how crucial innovations are for companies to gain knowledge and encourage technological progress. Companies are caught in the acquisition of knowledge through trying out something entirely new on the one hand, while sticking to their established and standardised production process on the other.

In this dissertation it is essential to create a deeper understanding of these areas of tension and demonstrate their compatibility. Therefore, this study indicates the importance of innovations for a company with a lean production system as well as how companies can face the challenge

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[2] E.g.: Alchimedes (287-212 vor christus) determination of pi and invention of state-of-the-art war weapons
Galileo Galileis (1564-1642) heliozentrisches weltbild, neue errungenschaften in der navigation der schiffahrt

of being lean and innovative simultaneously using theoretical and empirical evidence. Furthermore, the interrelations of lean and innovation in the context of the automotive industry are presented.

A peculiarity of this work lies in the shared perspective for observing the production of the new at several levels (micro, meso, and macro), keeping in mind that 'there is no cheap way to successful innovation' (Anderson and Hein 1987, S. 73). The three levels/perspectives of macro, meso, and micro are derived from the field of evolutionary economics (Dopfer, Foster, Potts 2004), and they are used in this study to create a multiple and holistic perspective. Researchers assume that both individual companies and entire industries regularly have problems when the old rules of the game are overturned by new business models or technical innovations (Enders, König, Hungenberg, Engelbertz , 2009).

At all three levels, the descriptions of an economic system containing rules, their structure, and their process by Dopfer, Foster, and Potts (2004) help to understand and explain the resulting interplay of change and complexity. The microstructure is the smallest unit and displays how the rules are conducted at the lowest individual level. While the meso structure investigates the collusion of the micro units on a higher level, the macro further consists of the population structure of the systems of the meso. Thus, micro cannot be summed into macro but micro can be summed into meso and meso into macro. However, an untraditional way to explain innovative change, starting from the micro level with new rules, results in change at the meso level, and this work uses structural shifts leading to changes in aggregate sizes on the macro (Albrecht Enders xx). Moreover, by explaining the macro level first and then breaking it down into the meso and micro levels, this study develops an understanding of the environment as well as the reasons that old top dogs often fail to adapt to changes in the new environment, sooner or later being overtaken by newcomers. Based on this logic, the compatibility of lean and innovation are analysed using the architecture described above. This study will show that that the complexity that can be found at the respective level makes it necessary to put a meso level in between.

At the first level (industry), in a long-term view, this work illuminates the roles that lean and innovation play in research and development (R&D) in the automotive industry—the macro-level view. At the second level (company), it shows how companies are caught between the standardisation of processes, achieving a strategic vision, and staying competitive in the market by fostering prosperity increase through innovation—the meso-level view. At the third level (project), this work answers the main questions of how companies can use lean principles to create a successful innovation project and how innovation can be used to conduct a successful lean project—the micro-level view. The objectives and structure of this work are defined analogously to this fundament in sections 1.2 and 1.3, respectively.

1.2.Objectives of the study

The **first objective** of the study is to create a deeper understanding of the ambidexterity of the patent structure within the automotive industry, focusing on OEMs and their production systems, which are assigned to different states in lean evolution. The goal is to shape the macro perspective of the whole industry to be able to deduce essential factors, outcomes, and arguments for the meso level.
Deduction: Companies in the automotive industries are caught in a field of tension between being innovative and being lean.

The **second objective** is to identify how a production system can successfully cope with incremental and radical innovation using lean principles on a company level. Especially when selecting an evaluation for innovation projects, it is essential to answer the question of whether the innovation is going in the right direction and supports the vision and targets of the company. The goal is to form the meso perspective on the example of one company to obtain a deeper understanding of how units collude on a higher level and what the rules are for the interplay within the company.
Deduction: Lean must be integrated into the selection and evaluation process of innovation projects within the production system to ensure competitiveness.

The **third objective** is to analyse how lean principles can be successfully integrated into innovation projects. Use cases serve as empirical validation to demonstrate the compatibility of lean and innovation in conducting innovation projects that take lean principles into consideration. The goal is to create an understanding of the micro perspective, and specifically how the interplay of rules works on an individual project level and the balance that can be found between lean and innovation.
Deduction: Lean must be integrated into innovation projects to achieve the optimal output and conduct a smooth implementation.

Central topics of investigation in the present analysis are thus the balance of lean and innovation in the automotive industry as well as their structural and knowledge-related impacts on the macro, meso, and micro levels. Accompanying structural change processes, such as the change and influences on the productions system as well as the state influence, are included in the flow of reasoning only to the extent necessary.

Furthermore, limitations that accompany the analysis are only discussed to the necessary extent for this work, but do not reflect the main focus as well.

1.3.Structure of the study

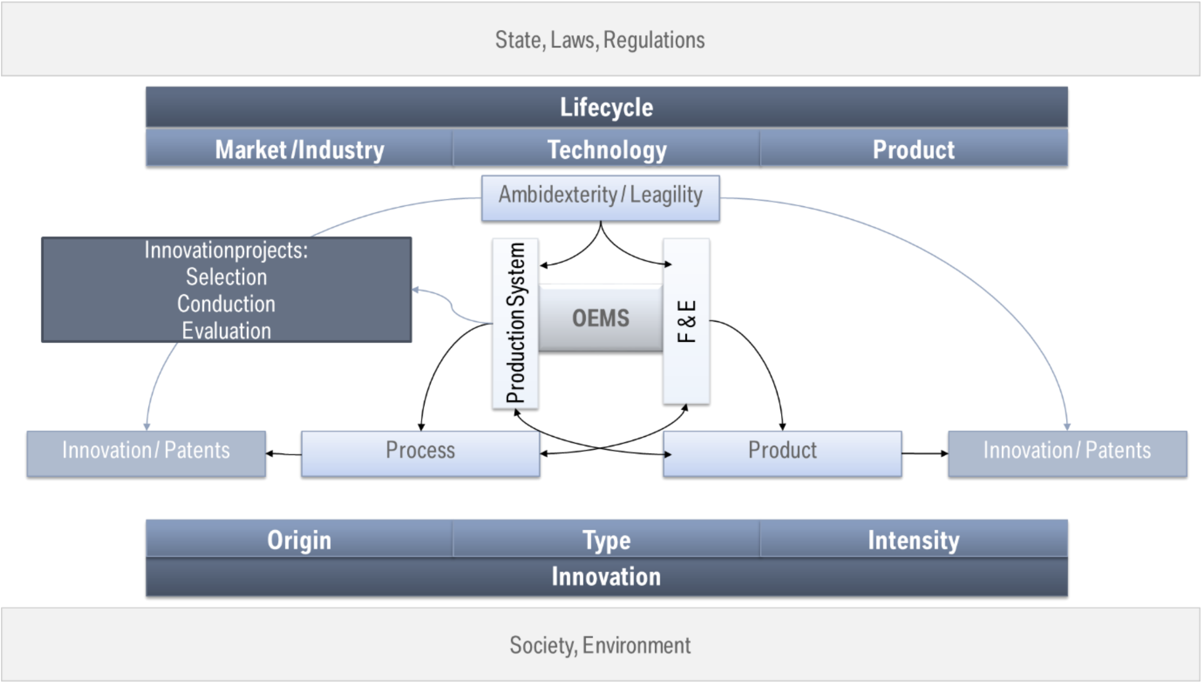

Figure 2: Picture of the content.

Chapter 1 is devoted to a thematic introduction, including the initial situation. An introduction to the topic is provided and the existing problems are defined, resulting in the establishment of the study’s objectives and determination of the limitations of the investigation, as well as the procedure and structure of the analysis.

In **Chapter 2**, the study is situated in a larger theoretical framework. The combination of the topics of life cycle theories, knowledge and innovation networks, complexity, as well as insights into the ambidexterity of organisations are within the focus of this chapter. The theory of innovation and knowledge is the first pillar of the scientific foundation, which focuses on the multidimensionality of the innovation concept as well as the presentation of knowledge as the driving force for change. These considerations serve to conceptualise the second pillar of the scientific foundation: the evolution of industries with complex products, in complex production processes, with complex social systems, resulting in complex network structures. The emergence of lean management and innovation management in the automotive industry is explained as a determinant and driving force for ambidexterity. Based on the presentation of the developmental principles of lean and innovation, focusing on agility and the linkage with ambidexterity, the theoretical foundation is discussed in detail. The integration of technology in products and the specific properties of complex products result in significantly different patterns in product and technology life cycles compared to simple products. In particular, the role of state and demand as additional co-evolutionary determinants arise from the essential development drivers due to the technical and product-related dynamics in the life cycles. A foundation is created for understanding the importance of lean principles and methods for innovation and vice versa. From this insight emerges the need for a multi-level study of the automotive industry. Industry development is viewed as a network dynamic in which organisations leverage external connections to meet the complexity and change demands.

Based on the scientific-theoretical foundation, Chapters 3, 4, and 5 are devoted to the practical field of this investigation. The necessity of transformation gives the industry the task of balancing exploration and exploitation across the product and technology lifecycle. This study analyses these requests for ambidexterity to the industry at three levels, namely macro, meso, and micro.

In **Chapter 3,** the macro level under consideration, displayed by the ambidexterity and innovation patterns in the automotive industry resulting in an empirical (patent) analysis, is discussed. In addition, the transformational impulses that characterise the industrial structure are presented as well as the necessity of examining ambidexterity in the automotive industry is explained. It is shown how the theoretical impulses are empirically validated through a comparison of explorative and exploitative patent structures of companies, resulting in a description of the impact of the framework on a lean production system and vice versa.

In **Chapter 4,** the meso level under consideration is discussed, which is related to the selection and evaluation process of innovation projects within the production system and the link to ambidextrous and structural requirements. The selection and evaluation of an innovation project is seen as a crucial factor for success. With the establishment of a maturity model, considerations of the overall system- and target configuration at local/temporal operational decisions are allowed, ensuing the vision and goal definition of the project as well as its direction.

Chapter 5 focuses on the micro level under consideration, where the structural design of innovation projects and link between ambiguous requirements are discussed. The final synthesis summarises the findings and links them. Two use cases are employed to investigate the multitude of questions that arise in connection with the compatibility of lean and innovation on a micro level. Thus, strengths and weaknesses of the two different forms—namely lean principles used in supporting an innovation and innovation used to support lean principles/methods, in particular with regard to their suitability for learning processes—can clearly be demonstrated.

The dissertation concludes with **Chapter 6,** which summarises key findings and derives implications for practice, policy, and research. Based on a critical reflection on the approach, further approaches for research are presented.

2. Theoretical Background

The focus of this chapter is to classify the relevant concepts and locate them in one scientific framework. The main goal is to explain the theories of innovation concentrating on the origin, type, and intensity of innovations: Section 2.1 is examining innovation and change; Section 2.2. discusses industry-, technology,- and product-lifecycle theories and their influence on innovation; Section 2.3. reflects upon ambidexterity and the impact on innovation; Section 2.4. reflects upon complexity in the context of innovation; Section 2.5 unites these insights in a theoretical fundament to generate the link to innovation and lean management.

2.1.Innovation, its link to change and resistance influenced by type, origin, and intensity

First, a common understanding of innovation must be created, followed by a discussion of the drivers of change. Based on the fact that research on innovation is multidisciplinary (Corsten et al. 2006), there is no consistent definition of innovation. However, examining the different research fields, all definitions of innovation have the generation (process) and introduction (launch) of something new in common (Vgl. Schumpeter 1934; Schumpeter 1939; Schmookler 1966; Kline und Rosenberg 1986; Herkema 2003; Chen et al. 2004; OECD 2005).

Fred Gault (2016) created a **general definition of innovation** that is applicable in all economic sectors: “An innovation is the implementation of a new or significantly changed product or process. A product is a good or a service. Process includes production or delivery, organisation, or marketing processes. A new or significantly changed product is implemented when it is made available to potential users. New or significantly changed processes are implemented when they are brought into actual use in the operation of the institutional unit, including the making of product available to potential users.” (Gault 2016, p. 24)

Gault’s definition considers basic facts for the theoretical fundament of the present study. First, it differentiates between the types of innovation (see subsection 2.1.1.); second, it sees innovation as the realisation and launch of an invention on the market (Schumpeter 1939; see Section 2.1); and third, it deals with the implementation of the product and therefore with the different resulting lifecycles (i.e., industry, market, product, and technology; see Section 2.2.).

Following Schumpeter’s (1939) definition of innovation, it is essential to distinguish between invention and innovation. While an invention reflects ideas, concepts, and prototypes before its launch onthe market, innovation is the realisation and launch on the market, and thus the capitalisation of the invention. Thus, invention is the process of creating something new (e.g., the Stage-Gate process by Cooper [2008]), whereas innovation is the output or launch of something new (e.g., organisational innovation, product innovation, supply chain innovation, process innovation, marketing innovation and business model innovation by Kahn [2018]). In successfully performing the innovation process and creating an output, the mindset of the organisation plays a critical role (Kahn, 2018). Associating, questioning, observing, experimenting, and networking were found by Dyer, Gregerson, and Christensen (2011) to be fundamental skills that spur innovation. Moreover, research on the Toyota Production System (TPS) showed that networking (transferring knowledge from one unit to another) is a valuable unit of analysis for explaining competitive advantage (Dyer & Nobeoka 2000). The example of the TPS shows that openly shared knowledge, the prevention of free riding, and the efficient transfer of tacit and explicit knowledge are the key factors for creating a highly interconnected network with strong ties. These ties create the competitive advantage because, most importantly, knowledge is seen as the property of the network and not of the firm (Dyer & Nobeoka 2000).

For a more holistic view, the focus in the following paragraphs lies on **innovation** being described **as a process**, in which the acquisition, sharing, and assimilation of knowledge aim to create new knowledge (Herkema 2003; subsection2.1.2). The modern economy is a highly complex system of distributed knowledge. Every individual action leads to changes in socially distributed knowledge, without these changes being completely manageable for all individuals—not even for the one that caused the change (Herrmann-Pillath, 2002). In the theoretical background, **change processes**, such as innovations, structural change, technological change, institutional change, economic growth or, in general, the economic development of an industry, crucial roles in elucidating the subject of the convergence of lean and innovation.

Innovation has shaped modern society since its inception, but it is changing its character today. Innovation was long seen as left to chance, the brilliant ideas of individuals, and the creative practices of separate areas (Hutter, Knoblauch, Rammert & Windeler 2016). This can best be described with one of the most famous innovation incidents in history—the discovery of penicillin. In the Nobel lecture that Alexander Fleming (1945) gave in Stockholm, it would have been easy for him to say that he had come to the conclusion, based on serious literature studies and deep thought, that moulds produce valuable antibacterial substances. However, he preferred to tell the truth, namely that the history of penicillin began with an ‘accidental observation’ (Fleming, 1947).The change of character in innovation can be seen as two sides of a medal. Innovation is still seen as a coincidence, as researchers and engineers like to show, but it can also be the result of a process clearly managed by management (Gassmann and Sutter, 2013). Moreover, economics innovation today is increasingly driven on purpose, in relation to many others, and in the context of general demands for strategic manufacturing (Hutter, Knoblauch, Rammert & Windeler 2016). However, there is still a discussion that real innovation cannot be planned and controlled deterministically (Gassmann and Sutter, 2013).Coincidence and chance are constant companions of innovations, but today, innovations are coordinated as processes, distributed across different instances and reflected with reference to the actions and knowledge of the actors in other areas(Townsend and Calantone 2013). This leads to the question of whether innovation must be seen as controlled coincidence with innovators often being repeat offenders (Gassmann and Sutter, 2013).

The concept of **reflexive innovation** attempts to clarify, explain, and answer this question. Reflexive innovation, as described by Hutter, Knoblauch, Rammert, and Windeler (2016), refers to the interplay of these practices, orientations, and processes, observing, shaping, and controlling the course of an innovation in terms of its various institutional implications, discursive justifications, and the shapes and patterns of other innovations. It is not only a targeted but also a continuously renewed knowledge of innovation, which is supported by action practices. Hutter et al. (2016) differentiated between semantics of the new (the goal and purpose of social action), the pragmatics of creative action (as part of the routine of action), and the grammar of the innovative regime (as systematically created social structures for the production of the new; Hutter et al. 2016).

However, when discussing innovation it is necessary to keep in mind that it often does not take place without **resistance**. Furthermore ‘Innovation has to reckon with resistance’ (Hauschildt et al 2016, p. 31). Schumpeter already noted the following in the first edition of his theory of economic development: ‘The most modern enterprise has a persistence resistance against changes’ (Ders. 2006 [1912]: 108f.).

Changes, novelties, innovations in organisational matters (**internal resistance**) have to deal with several problems (Hauschild, 1998).They …

> … provoke resistance (Wilkesmann 1999, p.11) by others putting forward ‘rational’ arguments, especially of a technical, economic, legal, and ecological nature;
>
> … meet barriers to innovation (Mirow 2010) asa result of ‘not knowing’ and ‘not wanting’;

… have an acceptance problem (Meffert 1976, p. 77) created by a fear culture that does not allow mistakes, and therefore does not provide a basis for systematically developing and promoting future ideas.

… harbour conflict potential (Thom 1980, p. 391) by letting interpersonal conflicts inhibit creativity;

… call opponents (Witte 1973) antagonists and bring forward objectors as actors of the resistance (Markham, Green & Basu 1991), due to divergent power claims.

However, the following question arises: Is it still possible to expect internal innovation resistance in companies with highly standardised innovation processes and established innovation cultures? Resistance seems unlikely today because of modernisation and institutionalisation of innovation. With the integration of innovation into the business enterprise, the new is desirable and thus no longer encounters resistance (Blättel-Mink 2006, p.59 f., referring to Schumpeter 2005 [1947], p.213 ff.).The devaluation of established know-how with the need for players to renegotiate the distribution of scarce resources might be a possible reason for resistance in organisations. In particular, in the case of a highly novel and uncertain character of an innovation idea, a high potential for resistance is assumed (Jaworski and Zurlino 2007).

Resistive responses occur mainly during the innovation process, prior to the decision to launch or implement, because organisational members will hardly be able to oppose a successful new product or process. Thus, resistance depends on time and the different process steps (Pongratz & Trinczek 2005).

Internal or organisational resistance is not the only problem companies face today; there is also a form of **external resistance** that arises from society and the right point of time for the implementation/launch of the innovation. Therefore, one must understand the technical system itself with all its driving forces. The technical environment should have reached a certain level of maturity before an innovation is successfully adapted. Companies have to make sure that no products and services are offered that do not meet the needs of customers. In addition, the social system in which one wishes to launch the new idea, product, or process must be understood.

Deciding which products and services are purchased and consumed also depends on what is considered appropriate and desirable within society and the social association. Economic change can occur as a result of the emergence of taboos that cover certain goods and products. Economic activity in modern capitalist economies is governed and structured by social and cultural values as well as binding legal norms (Böhme 1997).The path from sacrilege to an exercise or process usually begins with horror, outrage, and violent protests. A good example is the introduction/adaption of denim jeans after the Second World War in Germany or Europe. First, the product only led to rejection in the European market. After the rejection phase, emotional barriers decreased and curiosity as well as willingness—still mixed with caution—increased. Gradually, an increasing number of people were convinced about denim jeans. Finally, a broader acceptance, getting used to, and normalisation occurred. A small denim jeans business quickly developed into a worldwide textile company that is known today under the brand name Mustang (Siegfried 2016).

However, the great influence of moral ideas is even more evident when morally problematic products and services are traded in markets. In this regard, the impact of moral change can also be seen as fundamental to economisation (Kley 2018).

Nonetheless, ‘at present, we are seeing a further shift in the relationship between innovation and society: innovation is crossing its barriers and growing into the dominant driving force of future society’ (Rammert, Windeler, Knoblauch, & Hutter, 2016, p. 3). Today, not only must manufacturers comply with labour standards and environmental regulations but also observe social conventions and decency. For goods that are classified as worthy of protection or even as disreputable or dangerous, economic requirements and moral ideas regularly come into conflict when companies or countries are dealing with them. Speculating on food, offering erotic services, or producing weapons show that entrepreneurs must use specific strategies to legitimise their actions and pursue their economic goals. The trade in such products is often subject to special moral restrictions (Kley 2018).

To create a deeper understanding of the technological forces as well as the social influence, this study uses the derivation of general principles for economic change (Schmap, 2012) with a view on the macro, meso, and micro levels of industry as the cornerstones of the following analyses, based on a theory of economic evolution that explains change (novelty) and stability (preservation).Evolutionary economics not only deal with the macro-meso-micro perspective but are also concerned with economic change and the resulting essential basic problem of fundamental knowledge (Herrmann-Pillath, 2002), as well as the coordination and growth of knowledge (Dopfer, 2007); therefore, evolutionary economics serves in all chapters as a reference framework for the results of the analyses. Technical innovations alone are not able to solve complex problems fully. Only a change of mentalities and altered practices, resulting from education, social inclusion, good work, and new ways of thinking together with the right technology can create change. This means that the potential of new technologies can only be developed if they are embedded in changes in social practices (Rogers 2003). This follows the suggestion of Kurt Lewin (1947) that a system cannot be understood until the attempt to change it.

Therefore, the micro and macro perspectives serve to show the structural aspects of change on the meso level, on which the economic system is based (Dopfer, Foster, Potts, 2004). Thus, the prevailing complexity at all levels must not be neglected. Both micro perspectives for economic development, based on complex structures of rules that form systems such as companies, and macro perspectives for economic development, based on complex structures of rule populations such as industries or the entire economy, display complexity at the meso level (Dopfer, Foster, Potts, 2004).

In sum, the tripartist micro-meso-macro level, with the existing complexity at all levels, is not neglected, and neither is the fact that innovation—defined as knowledge creation, dissemination, and a fundamental instrument for change processes—is the basic concept that operates and influences each level/perspective.

2.1.1. Innovation Type—Product, Process, and Organisation and the Influence on and of the Human Factor

The **type** dimension of innovation concentrates on the output that is created by the launch of an innovation. Thus, innovation is differentiated into technical (**product and process innovation;** Chenavaz [2012]) and administrative (organisational) innovation (Afuah 1998).[3] Product innovation is defined as the creation of a totally new product, or at least a significantly altered one, that is available for potential users (Gault 2016). Process innovation is defined as the implementation of a totally new or at least significantly altered production or delivery process, including equipment, software, or technique (OECD/Eurostat 2005). For both types of innovation, the improvement of quality to enhance competitiveness plays a critical role. Improving the overall product quality or functionality to enhance product diversification is the aim of product innovation (Pan and Li, 2016), whereas reducing the costs of production by improving the overall quality of the production process and maximising the efficiency of resources are the aims of process innovation (Li and Ni, 2016). Product innovation has been

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[3] Gault (2016) differentiates between product and process innovation (process innovation = production innovation, organizational innovation and marketing innovation)

proven to be a fundamental source of firm growth (Besanko, Donnenfeld and White, 1987; Lambertini, 2006), Lambertini and Orsini 2015), but a rich line of research has shown that for sustainable growth, the relationship between process and product innovation is crucial.[4]

Within dynamic models of process and product innovation, both forms of innovation are performed sequentially (Utterback and Abernathy, 1975). Producing a new product at a very low rate of process innovation in the beginning follows an increase in process innovation with a decrease in product innovation to the point of a dominant design, followed by the stimulation of technology and costs. However, the increase in customer needs caused by individualisation has led to an increase in the complexity of product architecture and structure. Moreover, with product lifecycles becoming shorter, product portfolios becoming more complex, technology gaps between firms decreasing, and digital convergence among product features increasing (Coad and Rao, 2008; Jacobs and Swink, 2011; Kamath and Roy, 2007), sequentially performed product and process innovation can no longer fulfil the responses to customer requirements. Thus, instead of performing product and process innovation sequentially, companies should perform them simultaneously to enhance their performance (figure 3).With the development of a new product, the enhancement of the production process must start simultaneously in iterative circles.

However, with the simultaneous performance of product and process innovation, the company structure as well as administrative processes must also be innovated, making **organisational innovation** necessary. ‘An organisational innovation is the implementation of a new or significantly changed organisational method in the business practice, workplace organisation or external relations of the institutional unit’ (Gault 2016, p. 8).Process and organisational innovation cannot be distinguished incisively, but for this work, newly or enhanced business models, marketing strategies, and the reorganisation of company structures are seen as organisational innovation, whereas newly or enhanced production or delivery processes are seen as process innovations. Organisational innovation is an underlying process in which product innovation and/or process innovation are matched with existing business models,

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[4] Cf.:

- Mantovani (2006): Dynamic model to study complementarity between market enhancing product innovation and cost-reducing process innovation in a monopoly setting;
- Chenavaz (2012): Product and process innovation model to determine the optimal product price, the product and process innovation investment strategy, given a time-varying demand conditions;
- Choi, Narasimhan and Kim (2016): new paradigm, wherein product and process innovations are pursued concurrently instead of sequentially.

marketing strategies, and company structures to ensure the holistic growth of a company (Choi, Narasimhan, and Kim 2016).

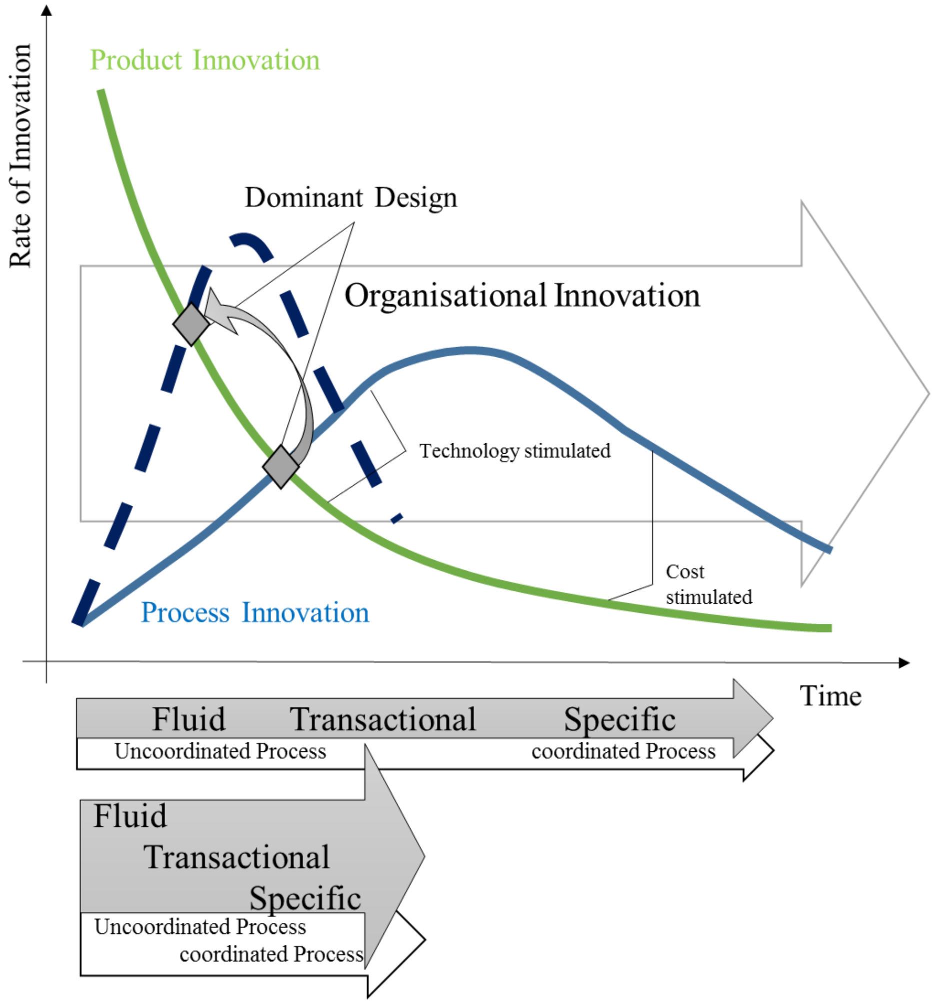

Figure 3: Interaction between innovation types (own representation, based on Utterback and Abernathy [1975] and Choi, Narasimhan, and Kim [2016])

Because of the previously discussed change processes and the resulting internal and external resistance, the fact that innovation is characterised by complexity and uncertainty must not be neglected. Compared with production processes where familiarity is reproduced, innovation always develops something new every time (De Jong, Kemp, Folkeringa, and Wubben, 2003). Moreover, the consequences of an action are not entirely predictable. Thus, the next step can only be determined if the results of the previous one are available. This may mean that a step is performed several times in loops (iterative or circular; Gunday, Ulusoy, Kilic and Alpkan, 2011).

Human factors should never be ignored when discussing innovations. Developing innovations is not routine for any company. Creating something new requires dealing with the hitherto unknown. In addition, creativity cannot be forced. Therefore the establishment of innovation processes is a crucial management tool to support ideas and their implementation (Damanpour, Walker and Avellaneda, 2009).

To take up the question posed above, namely innovation as a controlled coincidence (Section 2.1), the first answer can be given. On the one hand, a coordinated and well-structured innovation process space is created by defined processes in the form of standards, the provision of services, the support and guidance of the same ,and everything not having to be reinvented, which means that participants can direct their creativity toward the creation of new things and necessary improvement. On the other hand, an innovation process promotes the targeted use of creativity and prevents innovations in everyday business life from perishing. By giving a certain amount of structure an innovation process offers orientation but at the same time must be flexible enough to react to the unforeseen. This creates opportunities in the employee suggestion system and in the continuous improvement process that avoid waste through the untapped potential of employees.

However, with the simultaneous performance of product and process innovation, the standardised innovation process must meet the requirements for product as well as for process innovation. Defined processes in the form of standards, the provision of services, and the support and guidance of the same for product innovations might not be useful in process innovation, and vice versa. For example, to achieve the economic success of an innovation, a smooth transfer of the innovation into the business areas such as marketing or production is required. These business areas differ between process and product innovation.

Moreover, ‘Lean Innovation’ is currently attempting to translate the successful principles of lean thinking into the innovation process (Schuh, 2007). The goal is the sustainable rationalisation of the entire innovation process and the mastery of complex product and project programmes (for more details, see subsection 2.4.3).

2.1.2. The Origin of Innovation—Generation and Adaption and the Influence on and of the Human Factor

As already discussed, it is essential for companies to focus on competitiveness through innovation, especially because of the positive effects on manufacturing performance. The origin of creating something new can be distinguished in adoption and generation. **Innovation generation** is defined as new to the world, whereas **innovation adoption** is defined as new to the user/company or, as in other streams of research, called innovators versus imitators (Damanpour and Wischnevsky, 2006). Whereas former research on adoption (imitator) and generation (innovator) is seen as a binary choice within companies (Pérez-Luño et al., 2007a,b; Zhou, 2006; Lieberman and Montgomery, 1988; Damanpour and Wischnevsky, 2006), this work goeswith the suggestion of Perez-Lunos, Wiklunds, and Cabreras (2011) that companies do not engage in generation or adoption solely, but instead **adopt and generate simultaneously**, emphasising one or the other to different degrees.

Therefore, adoption or generation is not a binary choice but a matter of the degree of engagement, which also resembles the logic of the ambidexterity of exploitation and exploration (Section2.3). As innovation is seen as a knowledge creation process, adoption and generation go along with different ways to enhance the knowledge base in a company (Grossman and Helpman, 1991). Whereas knowledge in innovation adaption is in possession of various or at least one player in the market already, in innovation generation a genuinely new product or process is created, which means genuinely new knowledge is established that has not been created by one or various players on the market before (Mahmood and Rufin, 2005).

What does this development mean for the organisation and structure of companies to successfully generate and adopt innovation? Every innovation in the innovation process is individual compared with a production process, where every output is the same and thus plannable. Moreover, strict control over planning, budgeting, and scheduling are known to prevent or inhibit innovation. Thus, companies are advised to refrain from these practices. Deviations from plan specifications should be allowed and welcomed, because the fulfilment of only the prescribed task will not lead to innovative ideas. In addition, the chance of discovering new solutions and innovation is diminished by strict process planning and the necessary flexibility is limited (Kanter 2006).

The **adaptation of innovation** is based on the basic principle that it does not always have to be a fundamentally new idea—exploiting existing potentials can be enough. This means exceeding the existing by perfecting the product, business model, and sales behind it. Almost the same aspects can be applied to the principle of imitations, with a difference being that imitation is not just copying, but rather a creative process of learning from other products and adapting them (Leitner 2016).

Today, most common diffusion theories are based on the works of the American sociologist and communication scientist Everett Rogers, and focus on the merits of having an innovation for the potential adapter as well as which properties hinder an adaptation of the innovation.

Rogers (1962) considered the nature of the innovation to play a central role in the diffusion process. Acceptance or adaptation by an increasing number of users or companies and the associated spread in society is called the **diffusion of innovation** (Rogers 1962). The possibility of being able to forecast and explain the spread of innovations is of great interest to companies, because of growing competition in saturated markets in combination with ever faster changes in needs (Bodensteiner, 2011).

Factors that are responsible for the success and failure of innovations are relevant to comprehend the diffusion of an innovation. **Success factors of diffusion** are whether the innovation offers advantages in terms of technical performance, efficiency, and value for money, but also in terms of social prestige, which encourages a commitment to innovation and foster the diffusion (Hagerstrand, 1968; Mahajan, Muller, & Bass, 1990). A high compatibility of the innovation with existing needs, technologies, or social practices also has a positive effect on the adaptation behaviour (Peres, R., Muller, E., Mahajan, V. 2010, Rogers 2003). The diffusion of innovation can best be seen in the example of smartphones, which combine the advantages of telephones, computers, and calendars, thereby offering the user more advantages. If a new mobile phone is compatible with other devices, it fosters compatibility with existing needs as well. Moreover, the ability to test innovation can help reduce uncertainty and convey information about its benefits (Peres, R., Muller, E., Mahajan, V. 2010). This is one reason why flagship stores of smartphone manufacturers are often designed in a way that customers can try out and test the products easily and quickly. The stores have a concept of walk in and try out with experts in the background of the sales area. When preferences become observable, because the innovation finds its way into the personal environment of the potential user, this can also have an effect. For example, if a friend uses a new cell phone and the benefits become highly obvious (Peres, R., Muller, E., Mahajan, V. 2010).

A complexity of innovation that goes beyond the user's understanding, however, hinders the innovation process and resembles **failure factors of diffusion**. The perceived risk of a product purchase can be seen as such a failure factor. The perceived risk of a product purchase increases the need for information, especially when the first purchase of a product has consequences that cannot be clearly estimated beforehand, including negative consequences. The consumer is faced with a feeling of risk during the purchasing decision (Bauer, 1960).

In the case of smartphones, this applies, among other things, to older people who grew up with other technologies and can therefore not fully estimate the technology itself as well as the resulting consequences of the purchasing decision.

Some companies also refrain from innovation because their product is perfect and popular (for example, Coca Cola) or they rely on tradition and quality. These companies and industries apply the principle of ‘**No Innovation**’. They take advantage of the fact that they have not changed their product for years and use it as a marketing strategy (Leitner 2016).

Similar to this is the principle of **pseudo-innovation**. Many companies adapt their products easily, such as in design, and sell them as an innovation. This follows the logic of fully exploiting existing potential. When new ideas that could fail or revolutionise the industry are missing, companies often use old ideas in new packaging or gimmicks that sound good mainly in commercials to foster sales and growth. They use this strategy because they are afraid of degrowth and zero growth caused by the lack of innovation capabilities (Leitner 2016). This raises the following almost philosophical questions: Do companies have to grow at all? Would it not be easier and better to maintain stability, perfect the products, and just do the job well?[5] (Pelz and Mahlmann 2015).

Apart from the growth discussion, the adaption of innovation has a positive effect on the degree of vertical integration, supplier relations, and enterprise resource planning (Bates, Flynn & Flynn 2009). The generation of innovation has a positive impact on growth on the market (Cefis and Marsili, 2003), revenue growth, and higher output levels (Koellinger, 2008). For both origins of innovations, market processes, involving the consumers and the competitors, determine the payoffs. An innovator only gains sustainable profits as long as the innovation (product and/or process) is not adopted by a competitor completely. Game theory research shows that these companies outpace their direct competitors, stay profitable on the market, and take over market shares from their rivals (Teece, 1986, 2006).

As the question of ‘innovation or no innovation’ refers to a company’s strategy and is therefore answered on a managerial level, whether the company does have the right mind set and people to foster growth, change, and innovation still has not been fully answered yet. The role of **psychological factors of the individuals** involved in the innovation process and the generic culture within the company are crucial in the generation and adaptation of innovations. Nearly all business units need to be involved in the development and implementation of a new technology. This leads to changes on their side, due the required cooperation and resourcres. The transmission of new things is always associated with risk and uncertainty (so-called risk

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[5] Pelz and Malham (2015) answer these question: Due to rising material and personnel costs that cannot be compensated, to the necessary extent, by price increases and productivity increases, companies are returning to a growth strategyto survive. Factors like eliminating borders, the growing world economy and the ‘growth’ mantra of global financial markets contradict the principle of zero growth. The motto is: A company that doesn't grow dies.

behaviour; Rammert 2008, 295) and creates a field of tension between hope for success and fear of failure (so-called performance motivation; Mohr, 1977), as employees move around in innovation projects. New combinations of different knowledge stocks that are necessary to promote innovative approaches, can only be reached through exchange between employees of different departments and with business partners (exchange culture and information sharing) (Kanter 2006). As previously mentioned, resistance and unwillingness to change must be overcome, which makes an optimisation culture as well as the right mind-set of employees some of the most vital factors for change (Judge et al.,1999).Wanberg et al. (2000) and Oreg (2003) identified various dispositional factors (e.g., self-esteem, optimism and perceived controllability, and need for routine, short-term orientation, and cognitive rigidity) associated with successfully managing situations of change or a generally increased willingness to change. Only the willingness to change will make it possible to adapt or generate innovations successfully; otherwise, the launch of every new idea or product will be hindered.

2.1.3. Intensity of Innovation and its Impact—Radical, Incremental, and Disruptive Innovations and Their Influence on and of the Human Factor

Not only the origin but also the intensity dimension of innovation have an impact on the performance of a company. Innovations can be distinguished by the intensity level in incremental, radical[6], and disruptive innovations.

Incremental innovation is seen as the improvement, refinement, and reinforcement of current processes, products, and organisational structures (Chandy & Tellis, 1998; OECD, 2005). Hence, incremental innovations build on the knowledge, functionalities, components, and structure that is already there (Van de Ven et al., 1999, p. 171), and make it harder for competitors to enter the market by enhancing the dominance and stability of already existing companies (Kemp and Rotmans, 2005, p.43).

Radical innovations are seen as substantial breakthroughs, and have a discontinuous character (Pyka, 1999) involving different perspectives, such as technical and social (Linton 2009), technology and market (Chandy and Tellis 1998), as well as the influence on components and on the connection between them (Henderson and Clark 1990). Focusing on the technical, social, and market perspectives, radical innovation is the change/creation of a process or product that

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[6] Cf. Synonyms in former research (Kristiansen and Gersten, 2014):

- incremental = *sustaining*, *variation* und *continuous*
- radical = *breakthrough*, *pioneering*, *non-routine* und *non-programmed*

entails a fundamental increase in customer benefits or newly social systems, such as patent systems. However, the impact on components has an effect on the architecture of the innovation because the impact on the component itself changes the dominant design, which also leads to a change in linked components and functionalities, resulting in a new architecture of the product (Henderson and Clark 1990). Creating new products and processes helps companies to gain or maintain their competitive advantage. The creation is only possible if the company is able to combine their current knowledge base with external knowledge to build a specific and tacit knowledge base that cannot be observed or imitated by others easily (Lichtenthaler, 2009). Thus, investment in a company's capability to absorb and transform external knowledge is essential to develop radical innovations and remain on the market long term (Fores and Camison, 2016). The benefit of gaining external knowledge by involving suppliers or institution must be differentiated into the predesign and commercialisation phases. In the predesign phase, the involvement of suppliers or external institutions is least beneficial, because of high uncertainty, cost intensive investment in new technologies, and human capital that might be easily imitated and launched on the market by competitors earlier. The involvement of suppliers during the commercialisation phase instead is moderately beneficial, because of lower uncertainty as well as the necessity to invest in new technologies or human capital (Song and Thieme 2009). Radical innovation is associated with a huge improvement in performance and technology change. Sometimes it can resemble the shift from already existing product executions or through solving complex problems (of great importance) in a way that existing products have failed to do. This often requires a more sophisticated technology, which is the result of advanced expertise. However, radical innovation is not enough to trigger the necessary transformation within companies and markets. This is where disruptive innovation comes into play.

Disruptive innovation has been one of the defining themes of recent years as it goes significantly further in terms of scope and impact of change than any previous innovation and ties in with concept of 'creative destruction' of Joseph Schumpeter (1942). By changing customer behaviour, inventing new markets, and fundamentally disrupting existing rules of the game, disruptive innovations attack the status quo (Christensen, Raynor and McDonald, 2015). It initially comes with a lower performance than other products (measured by the valuation metrics) used in an industry; thus, in contrast to incremental and radical innovation, disruption is seldom intended and most of the time of no particular interest to existing users or customers (Christensen, Baumann, Ruggles, and Sadtler, 2006). Furthermore, disruptive innovations are being adopted by a market that is currently not saturated or not served at all. In other words, they serve a market segment that did not exist before and does not necessarily have to be based on radical technological innovations (Markides, 2006; Dan and Chieh, 2008; Christensen, Raynor and McDonald, 2015).

Start-ups, for example, often disrupt or even displace existing companies, because existing companies, public authorities, and other organisations can usually not disrupt themselves, but are disturbed. New players with new business models are able to open up new markets established companies were not even aware of. They have an influence on the market and technology lifecycle, because existing business model or an entire market is replaced by a rapidly growing innovation (for more details see subsection 2.2.1.). Simply put, disruptive innovations, often based on new technologies, make existing products or services obsolete (Markides, 2006).

Being able to generate knowledge internally leads to the maximisation of the potential of the existing knowledge base (Bierly & Chakrabarti, 1996) and enhances the company’s established position on the market short term (Lavie, 2006), as was already discussed in subsection 2.1.2.However, especially for the establishment of the right form/intensity of innovation (**incremental, radical, or disruptive**), the respective area and topic as well as your own organisational culture are crucial (Schneider, Günther and Brandenburg, 2010).

Several **personal factors** of employees have been found to influence the generation of knowledge, the intensity of innovation, as well as an organisational culture that is able to perform change positively. The locus of control, creativity, as well as problem-solving skills have been proven to have an influence on innovation (Hippel, 1994; Isaksen, Dorval, and Treffinger, 2010; Weissberg, (2006).

The degree of conviction that one can influence and design certain events and situations through one’s own actions is the characteristic feature of **internal control beliefs** (**locus of control, feasibility, and convictions**). To actively intervene in situations, see oneself as the initiator of events, and make every effort to influence tasks, people, and events in the sense of one’s own goals, are characteristics attributed to people with pronounced internal control beliefs. At the experiential level, internal control beliefs are often associated with feelings of self-efficacy, which can in turn support proactive work behaviour and intrinsically motivated work engagement (Lefcourt, 1976; Deci and Ryan, 1987; Bandura, 1982). As already mentioned, employees who just fulfil their daily tasks will not play an active role in the creation of incremental, radical, or disruptive ideas.

Creativity means the ability to not only consider known and already considered possibilities in problem solving, but also to develop new situation-related solutions from the network of individual and potentially relevant experiences (Kuhl, 2001). In particular, when dealing or fostering disruptive innovation ideas, creativity is a critical personal factor. It is generally assumed that entrepreneurs are more creative and innovative compared with comparable individuals (McClelland, 1987, Chell, Haworth and Brearley1991, Goebel, 1991, Miner, Smith and Bracker, 1994, Müller & Gappisch, 2002; Williams and McGuire, 2008).

Closely related to creativity is **problem-solving orientation**, which requires experience, ingenuity, and the ability to innovate. Having a differentiated perception and comprehension as well as regarding new or complex work requirements as fundamentally manageable are characteristics people with a problem-solving-orientation are said to have. It is essential for problem-oriented individuals to deal with a variety of job responsibilities, be able to expand their knowledge and experience, and improve their existing skills, because of the large amounts of individual information that can be quickly surveyed and processed or used in difficult decisions or negotiations (King, 1985). Ingenuity and creativity help to invent something new and recombine the familiar in ways that have never been there before (Goebel, 1991; Hooper, Jukes and Stubbs, 2000; Hagen and Larssaether, 2000; Skarp and Gadde, 2008).

In addition to the specific characteristics of a person (e.g., locus of control, creativity, and problem-solving orientation), the process characteristics, particularly how these properties are implemented and conducted, are of particular importance to create successful innovations (see Personality System Interactions [PSI] Theory by Kuhl[7]).

2.1.4. Influence of Type, Origin, and Intensity of Innovation on Society, Politics, and Laws on the Example of the Automobile

Nevertheless, innovations have far-reaching implications for all sectors of the economy and society. It is a permissible conclusion that innovations are overestimated in the short term and underestimated in the long term. To ensure efficiency and productivity an innovation process is absolutely essential, in which errors and unnecessary loops, caused by missing or incorrect information, are eliminated. Moreover, the impact on **society, politics, and laws** in the

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[7] Personality System Interactions (PSI) The theory is Kuhl's Theory of Willful Action Control. At the heart of PSI is the action management model. It explains individual behavior through the interaction of various psychophysiological brain processes - and makes the cause of behavioral control measurable for the first time through a differentiated psychological test procedure.

successful generation and adaption of (radical or incremental) innovation (process, product, and organisation) must not be underestimated. Driven by different influences, structural change is taking place. This continuous process started more than 100 years ago and is sure to accelerate further. One of the most important questions is which economic and social effects will be connected with the innovation and is there a need for laws and regulations to be introduced? The development of the first automobile shows impressively what effects and impacts an innovation has on the economy, society, politics, laws, and the environment and is therefore discussed as an example as follows.

The imperial patent number 37.435, registered on January 29, 1886 by Carl Benz, represents the starting point of the incessant triumph of the motor car, despite the fact that people were mainly travelling by horse-drawn carriage or train by then. First seen by contemporaries as a tricycle with a stinking and rattling single-cylinder engine, with no roof and three wheels, cars back then were uncomfortable, very loud, and priceless for most people. Yet, today, they are an indispensable part of our lives and impact all relevant fields of life, and it is estimated that up to 2 billion cars have been built worldwide (Möser, 2002).

Impact on the economy: With car cities, such as Los Angeles, that were planned for the automobile, as well as all countries with a highly developed economy having a high car density, the economic importance of the auto industry is enormous. It is seen in many countries as one of the key industries; for example, more than 700,000 people in Germany work for major car manufacturers such as Volkswagen (VW), Daimler, Bayerische Motorenwerke (BMW), as well as suppliers such as Bosch and Conti. This is one of the most impressive examples, showing the connection between knowledge gain and prosperity increase resulting out of technological progress (Holweg 2008, Wells 2012).

Impact on society: The epitome of personal freedom and prosperity are attributes that are attributed to the automobile, because cars make people flexible and create independence. The mass distribution of the car ultimately paralyses its own mobility, which can be seen especially in metropolises today. The automobile makes individual mobility available to a large extent, without which there would be no economic growth and social development. It made day trips or weekend journeys—resembling freedom—possible, developed new housing areas and huge shopping centres with equally huge parking decks on the green field, and fostered the separation of living and working in cities. This resulted, especially in cities, in a huge parking problem that is not solved as of today, despite the planning of our cities being geared to the needs of drivers and neglecting pedestrians. However, not only have the changes in social structures of daily life been massive; the automobile has also managed to create an attitude towards life, with special cars such as the Volkswagen Beetle or the Trabant expressing a special life feeling and thus standing for social development (Reichhart and Holweg, 2008, Wells, 2012).

Impact on regulations, laws, and politics (traffic): No new technology, no matter how revolutionary and helpful it is, would be introduced today at such a blood toll. Despite the number of fatalities dropping drastically, with innovations such as traffic lights over the years, in Germany alone around 4,000 people are killed every year in traffic accidents, plus tens of thousands are injured (Güttner, Sommer-Dittrich,2008). Over the last decades, accidents have been the reason for several innovations, such as small fences on the edge of the sidewalk, bridges to overpass, and traffic lights to structurally separate streams that used to share the urban space (Güttner and Sommer-Dittrich, 2008, Wells, 2012). With the approach of autonomous driving, moral beliefs are also becoming even more crucial. By supplementing people’s self-determined actions with autonomous artificial systems and the question of who should survive an accident, lawyer or homeless person, mother or child, man or woman, the automobile will continue to have a major influence on politics, laws, and regulations in the future (Scholz and Kempf, 2016).

Impact on the environment: The electric era is approaching with the age of fossil fuels coming to an end. Greener propulsion technologies will change cars and the industry—and possibly the relationship of the customer with the car. With new players on the market, the new powerhouse of global sales is no longer in Western Europe or the USA but in Asia (Güttner and Sommer-Dittrich, 2008; Nakicenovic and Schulz, 2011).

2.2.Life cycle theories and the implications on innovation

The key drivers of economic development and economic growth are closely linked to the impact of technological advances. It is necessary to understand in which cycles industries, products, and technologies evolve and exit from the market and what the connection to innovation is. In this section, innovation activity and its influence on industrial evolution are examined, first in the competitive context of companies and second in terms of their technological and—above all—nonmarket relationships. Within the literature, the terms technology, industry, and product lifecycle have been used synonymously or interchangeably (Taylor & Taylor, 2012).Considering knowledge creation and diffusion within the industry, it is necessary to understand how industries, technologies, or products change over time and how customers, competitors, and the market react. In particular, growth should not only be understood as purely economic but also as social and intellectual growth, in the sense of scientific progress and innovative ability.

2.2.1. The Industry and the Market Life Cycle

Taking product innovation into account to obtain a deeper understanding of the **industry lifecycle,** it is important to compare/plot the number of producers against time to measure how product innovations diffuse (Klepper and Gort, 1982; Kleppers, 1982). The industry life cycle follows an evolutionary logic, starting with the exploration phase surrounded by high levels of uncertainty and many firms entering the market; followed by the growth phase with stabilised product design, specialised production equipment, and already reducing numbers of entrants as well as the shake out of producers; and ending with the mature phase with slowing growth and further decline of entrants (Taylor & Taylor, 2012).The development path of an industry is not always as ordered, regular, and determinate as the concept of the industrial life cycle suggests; despite certain regularities, the process is always open to a certain extent (Haid and Münter, 1999).

The evolution of an industry is shaped by, on the one hand, a variety of product life cycles and product generations of different companies, whereas on the other hand it is shaped by the **market life cycle.** This is defined as the ideal typical course of a market, in which a significant segment of the buying public is interested in purchasing a given product or service. The market life cycle is divided into the same phases as the industry life cycle (development phase, growth phase, maturity phase, and age). Each phase offers opportunities to enter the market, resulting in adjustments in the marketing situation, and thus effecting the marketing strategy and mix of companies (Koplyay, Liand Rochfort, 2010).

Since **startups** are designed by definition to grow rapidly in a short time, their product development has a significant influence on the industry lifecycle as well as on the market lifecycle. Such rapid growth makes flexibility enormously important and is reflected in all the different ways of working between agile and fast-acting startup teams, as opposed to strict hierarchical orders that paralyse and slow processes that are found in established companies. Through producing products and services that are urgently required, startups increasingly turn out to be the R&D department of our economy. With few financial resources at their disposal, startups are in need of finding pragmatic, new solutions quickly to establish themselves in a market, according to whose rules they should not actually exist (Hack, 2005; Arvanitis and

Stucki 2014).Young companies in the startup scene show how it is possible to act faster by building a company around a product or family of products with a single business model. Startups are more customer-friendly than ever before, which is the result of operating profitably on the market (Carbonell, Rodriguez-Escudero and Pujari, 2012).That is why many established companies are looking for access to the founder community to innovate. Established companies must decide between competition, cooperation, or integration strategies. Using cooperation and integration when the immediate interface and cooperation is intense, the biggest problem is the will to bring the pioneering spirit of startups into the company without being able to discard the old organisation and business models. Therefore, the following question continually arises: how high is the actual connectivity and transfer performance within startup cooperation? (Baum and Silverman, 2004; Benson and Ziedonis, 2009; Buenstorf, 2015).

However, with the markets becoming increasingly volatile, the **complexity of the life cycles** (fig.x) increases. Volatility as a known factor in risk models of the financial sector is used as an estimate of future fluctuation margins. Volatility is noticeable in two directions—risk of loss and chance of profit. For example, a stock with high volatility—high price swings both up and down—runs the risk of entering a period of sharply falling prices after that stock is bought. Simultaneously, however, the volatility of the investment also increases the chance of a correspondingly larger profit (Koplyay and Mitchell, 2014a). The challenge is to deal with the continuing volatility and the resulting increase in uncertainty. In particular, in the transition and initial phases of the industry lifecycle, the cycles cannot actually be predicted and the patterns of the past at best provide a first starting point. The interactions between the different levels of consideration and the complexity in economic systems must not be neglected and demonstrates the complexity in industry life cycles. For example, economic actors always make their decisions in an overarching context that has a certain influence on them. Dynamics within an industry or even in an economy as a whole can therefore not be explained only by the sole consideration of entrepreneurial development paths on the micro level (Dopfer and Potts 2008, Dopfer 2005; Brette and Mehier 2008; Schröder 2010).

In sum, because of startups, dynamics within the industry that increase uncertainty and complexity, as well as the context in which economic actors make their decision, the influence on the industry lifecycle and the increasing volatility in the markets make it necessary to reshape the common understanding of industry lifecycles.

2.2.2. The Product Life Cycle

The **product life cycle** plots revenues or sales volume against time, but follows the same logic. It consists of four stages, beginning with the introduction of a new product. When it is launched first onto the market, sales volumes are at a low level; this is followed by growth, as when an acceptance is built up by consumers, sales volumes increase, followed by maturity when sales volumes stabilise, and ending with decline when sales volumes decrease (e.g., Urban and Hauser, 1993).With a few exceptions, all products go through this lifecycle from development through market launch to disinvestment, the exit from the market. In the different phases of this cycle, the products generate different contribution margins for the company. It is thus an analysis concept that serves to describe the development of individual generations of a product. (Taylor & Taylor, 2012).However, the exact course of product lifecycles depends on the company, demand, and technological determinants, and the interplay between product development speed, the company's product policy, competitive behaviour, and consumer behaviour (Lambkin and Day 1989). It is a reflection of different industry- and company-specific factors, which themselves are subject to temporal change. Although product lifecycle analysis does not provide a holistic view of future earnings growth, it is very helpful in classifying and estimating future earnings growth. Because auto products are defined by software, the integration of hardware and software life cycles requires integrated lifecycle management. Product lifecycle management and application lifecycle management must be merged into a single system approach (Stark, 2005; Stark, 2015).

Over the past decades, the complexity in the product life cycle has increased. At the beginnings of the automotive industry, to use the words of Henry Ford (1923), 'Any customer can have a car painted any colour he wants so long as it's black' (Grafstein, 2012, p. 203). At the turn of the millennium, the products of the automotive industry largely consisted of mechanics, electronics, and some mechatronics. Software was there, but it lived in the mechatronic components and was inseparable from them (for more details see subsection2.4.1).Everything that is now common under the slogan 'digital' was out of sight for many years. Today, digital services, software as a product, or automated driving with all the new related tasks such as functional safety and the assumption of responsibility for driving activities, are becoming increasingly relevant. Therefore, product lifecycles must be adapted and seen differentially.

2.2.3. The Technology Life Cycle

Within the early phase of the **technology life cycle,** product and radical innovation play the most critical roles; because it is the emergence of a new technology paradigm, technological uncertainty is high, but market potential is large in spite of market needs for a new technology being ill-defined. Within later phases, the expenditure of volumes results in process and incremental innovation activities, and price becomes the new critical factor of success (Pyka, 2000; Abernathy and Utterback 1982).Two models of the technology life cycle have prevailed in science: the model of Fordand Ryan[8] and the model of the consulting firm Arthur D. Little[9] (Little o. J., cited from Höft 1992, p. 78f.). The two models differ in the number of phases that a technology goes through and in the reference quantity.

However, the proportion of companies with pure process innovations has continued to decline. Pure rationalisation measures without new products are barely successful (Haid and Münter, 1999).

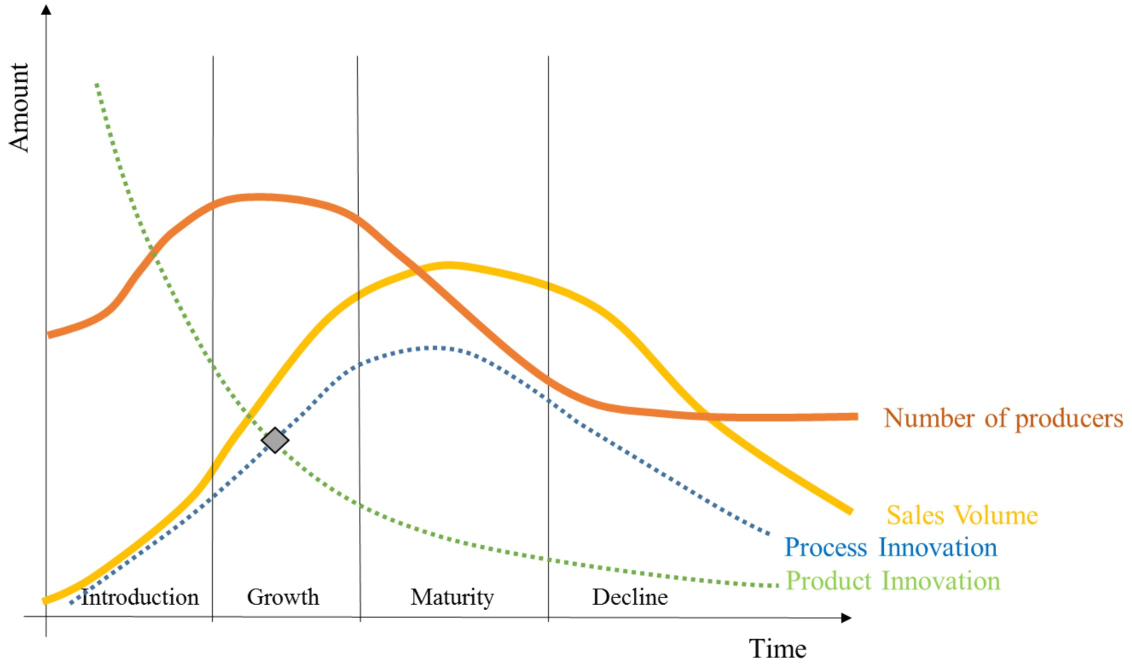

Figure 4: Life cycles seen in the old way (own representation based on Klepper and Gort [1982], Pyka [2000], and Taylor and Taylor [2012]).

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[8] Ford and Ryan consider the penetration of technology ("penetration of technology") and divide the time axis into a total of six phases (see figure 2.7): 1. Technology emergence, 2. Application development, 3. Technology first, 4. Growing technology application 5. Technology maturity and 6. Technological decline.

[9] Arthur D. Little chooses the degree of competitive potential as a benchmark and divides it into four phases based on the product life cycle: 1. Genesis, 2 Growth, 3rd maturity and 4th age.

Four phases of the evolution of technologies can be identified, namely introduction, growth, maturity, and decline. In the terminology of Malerba and Orsenigo (1993, 1997), the introduction phase (phase I) can also be called the innovation phase of the Schumpeter I type. In this phase, a radical innovation induces a series of product innovations; the competition is intense, market barriers are low, and the market is turbulent. In the further course, with a standardisation of the technology taking place, phase 2 (growth) starts. Through shaping and limiting further technological development to some extent and pursuing process innovations more strongly, company size increases and competition intensity falls as market entry barriers increase(phase 3: maturity). In the final phase (decline), the innovation momentum declines, only a few incremental process innovations are observed, market concentration is high, and the number of possible business combinations is increasing. These last two phases are more likely to be associated with innovative behaviour that corresponds to the Schumpeter II type. As early as 1980, Dasgupta and Stiglitz (1980) made a reference to the interdependence of market structure and innovation activity (Cantner und Hanusch, 1998).

The increasing economic and technological dominance of a leading technological company is achieved through the selection of competition as well as the scale or size-dependent innovation success, with the consequence being monopolisation (Schumpeter II, of success-breeds success hypothesis) (Flaig, and Stadler, 1994).

2.2.4. Redesign of the Life Cycles

With customer demands becoming more individualised, resulting in changing demand needs on the market, product life cycles are becoming shorter. Thus, as previously mentioned, product and process optimisation must occur simultaneously, which makes companies rethink their production system. Furthermore, the rising volatility as well as the influence of startups on industry lifecycles sharpen the course described in figure 4 in a different way (figure 5). To improve their chances of success startups need to create new and disruptive products (simpler, cheaper, and more convenient) as fast as possible, in addition to locating strategic alliances (Buenstorf, 2015). That is why a fast growth curve can be observed for startups. Startups then evolve in three different possible ways. First, they can be taken over by an established company; second, they cannot cope with the breakthrough and disappear from the market; or third, they can establish themselves as a stable company and follow the line of numbers of producers. The influence of startup and volatility then result in shifting product and process innovation cycles as well as the sooner or later defining dominant design.

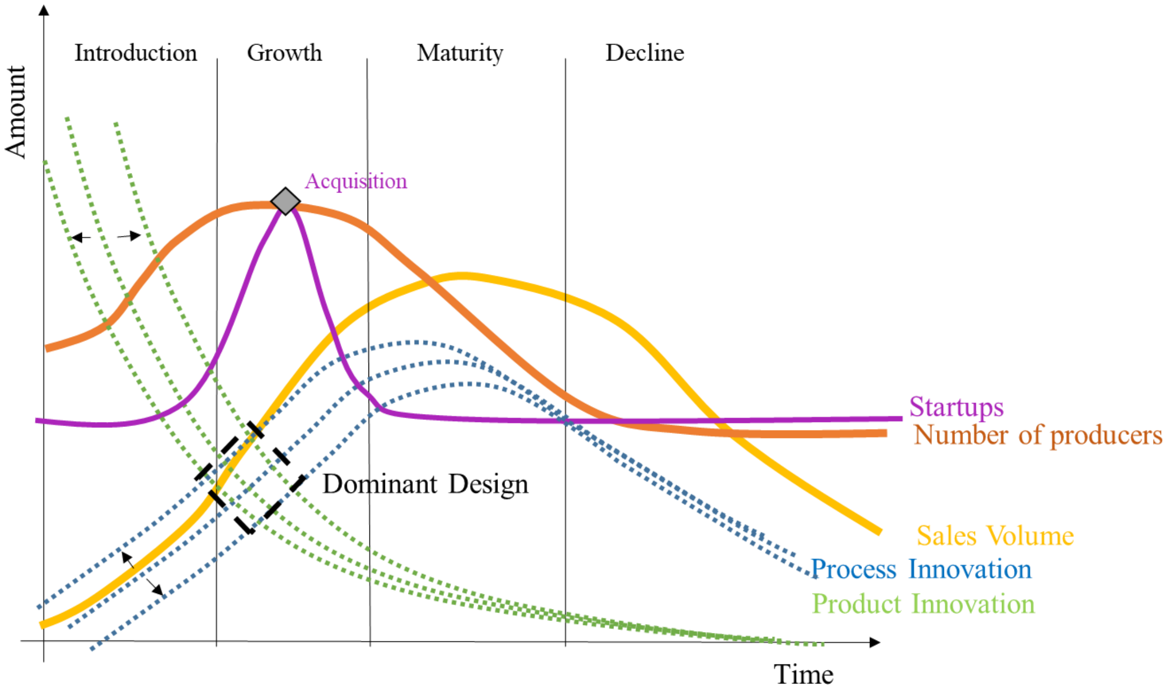

Figure 5: Life cycles seen in the new way, Generelles Beispiel (own representation based on startup, volatility. and technology shifts).

All of these lifecycles can be seen in the following example of the automotive industry.

The consequences of the financial economic crises offer companies new opportunities, but also challenges. One of the weakest capacity utilisations in the automotive industry in the past 20 years can be seen in the slump in demand in industrialised countries worldwide. Because of legally binding CO_2 targets, the necessary technological change from combustion engines to other forms of mobility and drive strain technologies, companies in other sectors as well as start-ups with innovative technology will enter the automotive industry. Instantaneous innovation is essential and required for startups in fast moving business environments with intensive competition to survive in the market.

All these aspects are having a massive impact on the complexity of the product and production processes. All products basically have a limited lifespan (Homburg and Kromer 2003 p.366). Each product goes through its product-specific cycle, which is divided into individual phases. The phases are characterised by different profit and sales potential, changes in the macro structure, as well as strategic marketing decisions. The history pattern is different for each product, and not all phases need to be passed over the time period. Since complex products consist of numerous parts, each part can boast an individual product life cycle. Thus, each product/subcomponent goes through its individual life cycle. In addition, the life of the product component is shorter than that of the system architecture. Each component can thus be located in a different phase section, which in turn makes it difficult to assess the product life cycle of complex products. Moreover, product lifecycles may be overlaid by multiple technology life cycles, resulting in the development of new products or subcomponents[10]. Without endangering functionality and compatibility, it is not possible to integrate new components into a complex product without hesitation at any time (Schmidt, 2009). The different types of complexity as well as their appearance in the automotive industry are discussed in detail in Section 2.4. However, to understand the behaviour of companies within the different life cycles and how they deal with the tension resulting from their complex goods/products, it is crucial to understand the production structures (i.e., the production system) before complexity types are integrated into the discussion.

2.3. Knowledge and innovation networks and ambidexterity—Influence on the Production System

To develop products rapidly, fulfil individualised customer demands, and respond to volatile markets, the production system of manufacturing companies must be flexible and reactive. Furthermore, due to the increase of international supply chains, the environment has become increasingly complex, entailing the establishment of intelligent products and production systems (Vyatkin et al., 2007). To rise to these challenges, products require internalised consumer information and manufacturing specifications to lead their way through the supply chain independently (Spath et al., 2013). With the rise of big data and the development of cloud-based data collection and storage, the role of human decision making will change fundamentally, because production systems will become knowledgeable and self-optimising (Yan et al., 2007).

To keep the competitive advantage gained through innovation and spawn new innovations, innovation networks, in which knowledge is shared, codeveloped, and recombined, play an critical role (Pyka 2002) and enable learning in a way that can hardly be provided by other means (Summerton 1999).

In knowledge-intensive markets and fields of production, such as the automotive industry, network structures already exist that are a result of global manufacturing chains, supply chains, and production systems. Moreover communities that are pursuing a specific purpose and come together based on tasks can be seen in this industry as well. A community is defined as a group

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[10] Technologic Substitution vs. Economic Substitution (Geels 2005; Dietz 1990)

of like-minded actors, often from several companies and different institutions, who come together on a task-related basis and promote a specific innovation project (Gerybadze, 2003). Following Gerybadze (2003) it is essential to differentiate between several forms of communities:

- Communities of practice (e.g. Verband der Automobilindustrie (VDA)) are formed in very specific areas of work and for the pursuit of professional interests.
- Innovation communities (e.g. Nationale Plattform Elektromobilität (NPE)) are aiming to help an innovation in the technical, economic or social field to make a breakthrough.
- R&D communities (e.g. Innovationscampus „Mobilität der Zukunft“ of the University of Stuttgart) are scientific communities that pursue certain research topics.

Communities and the resulting network structures influence the knowledge creation and sharing impressively. With the rise of the Industrial Internet of Things (IIoT), a new kind of information (big data) and way of information sharing (cloud) that can be felt at every level of the manufacturing and scientific ecosystem has been created (Tien, 2013). The potential of big data is not only a purely technical extension of reporting but also the change of processes and development of the organisation towards a data- and analysis-driven company. With data sets of a size that does not allow access, analysis, or applications to be undertaken in a reasonable amount of time and that are beyond the ability of available tools, the created knowledge has an impact on the network structure, analytics, methods, information sharing, as well as information availability within companies and the above described communities. (Tien, 2013)

Using big data techniques, data can be processed in greater quantities, speed, and variety than is possible with conventional methods. Big data must be analysed or processed to yield critical information first; before this, big data is worthless from a decision-making point of view. Big data techniques allow for completely new data sources and a greater input as well as increased forecasting quality. Forecasts that are created within the framework of company controlling usually serve as decision support. Therefore, it can be expected that with big data analytics we are able to make informed decisions in science, business, defence, engineering, education, healthcare, and society at large. (Tien, 2013).In addition, **the system in which the knowledge is generated** and analysed to make decisions plays a vital role. In terms of the automotive industry, every company is acting within the supply chain and has a production system.

2.3.1. Productions System—Knowledge and Innovation Networks

Within the literature, the terms ‘supply chain’ and ‘production system’ are used interchangeably. However, in this study, a clear separation of both terms is necessary. Hereinafter, the supply chain is defined as a network in which stakeholders such as suppliers, manufacturers, and distributors transform raw materials into a final product, which is eventually delivered to the customer (Tavan et al. 2013). The production system is defined as a company’s production strategy aligned to the customer demands (queried by consumer research and direct customer feedback), in which he management of stakeholders of the supply chain is specified.

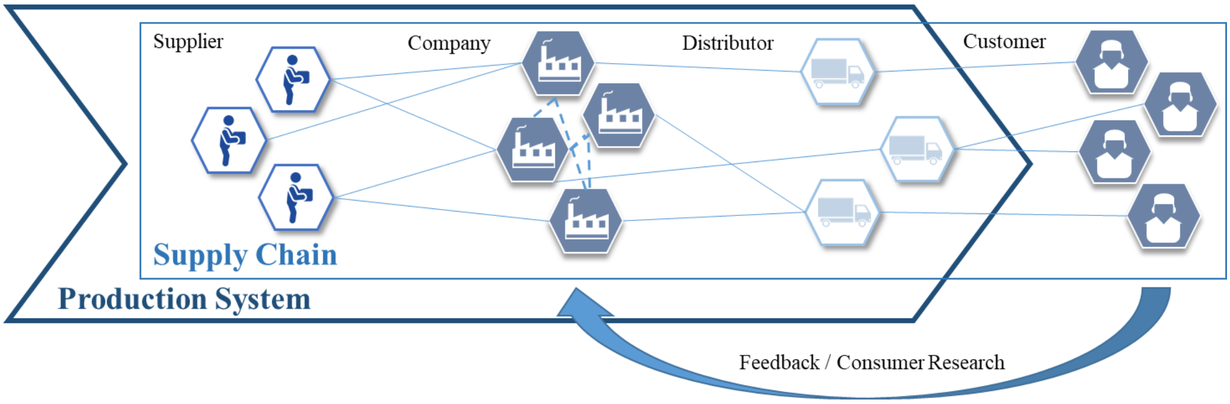

Figure 6 Supply chain as a part of the production system (own representation).

The supply chain as well as the production system resemble a network structure. As already described by Wasserman and Faust (1994), the specific structure of networks is the result of an evolutionary process in which the emergence and dissolution of ties between different actors plays a crucial role. The knowledge flow between the actors supports knowledge diffusion and mutual learning as well as creates new technological opportunities in the network (Buchmann and Pyka 2012). Within the supply chain, ties exist between suppliers (supplier relationship), distributors, customers (purchase relationship), and within the company itself (resource- and information flows, cooperation- and direction relationships) (M. Rürup et al. 2015). The role of suppliers is increasing in the automotive industry. With an expected drop of R&D shares of OEMs from 60% (2012) to 47% (2025), suppliers and engineering providers will benefit greatly from this evolution (Buchmann and Pyka 2015), and the ties of the network will also be influenced/affected. There has also been a shift in the supply chain, resulting from the synergy and economies of scale that suppliers can achieve by distributing development and production costs over a large volume of production and thus meet the cost pressure. Only large quantities, which can be achieved by system suppliers, make the profitability of complex innovations possible. Due to price advantages of competitors, many manufacturers have no choice but to hand over corresponding development and production scope to suppliers (Freitag and Student 2009; Mercer Management Consulting 2004).

This makes suppliers an essential resource for innovation. Moreover, according to innovation activities, the consideration of a productions system network must be expanded by several other stakeholders, institutions, and cooperation partners. Participants in an **innovation network** can be divided into market forces; the science system, such as universities and research institutes; the state and state bodies, such as patent offices; as well as transfer systems, such as technology centres and consultants (see Hauschildt 1997, p 73), as displayed in figure 7. Innovation networks are social systems that focus on invention, innovation, and market adoption. Based on mutual trust and resulting, if successful, in longer cooperation periods also forming innovation communities, R&D communities are communities of practice. These networks and communities are flexible rather than rigid hierarchical relationships. The innovation activities are thus no longer limited to the individual entrepreneur as in Schumpeter (see Schumpeter 1912) but networked with the innovation activities of other network participants. The interaction of permanent change, search, as well as learning processes are triggered in such networks and lead to competitive advantages over the lead competition. This resembles the significant advantage of such an open, partially informal network of relationships compared with the generation of innovations on a single company level (Hellmer, 2002).

Two-thirds of cooperation partners can be assigned to the economic system (see Zündorf 1994, p.249). In particular, these include suppliers and production equipment manufacturers (novel component and system technologies), customers (definition of new requirements, reference developments, and solutions to implementation problems), competitors (preliminary developments in basic questions, enforcement of standards and standards, and introduction of complementary know-how), or distributors (change and weighting of demand needs, information about developments of competitors). Depending on the subject matter of the innovation, the participating network companies may belong to one or more interlinked industries (Zündorf 1994).

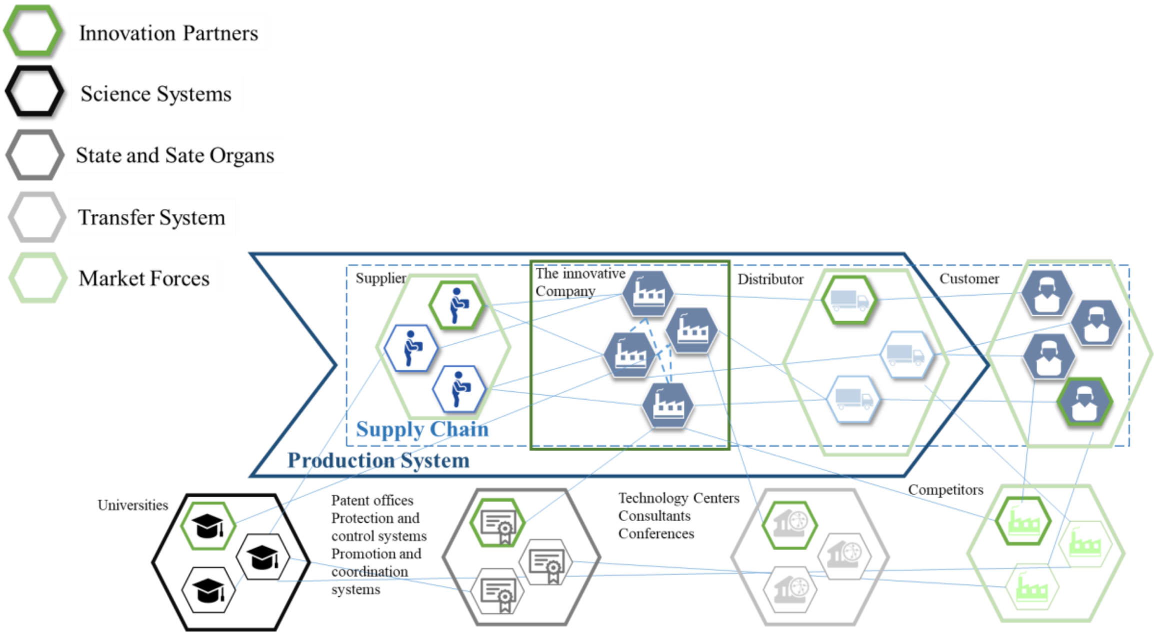

Figure 7: The production system as a part of the innovation network (own representation, based on Hauschildt [1997], p. 73).

For companies, increased market volatility (as described in Section 2.2) can result in severe shocks, and a higher frequency of market and economic cycles must be expected. Suppliers, raw materials, competitive intensity, and customers have a particularly high pace of change and are potential trouble spots. A significant increase in the impact of exogenous shocks, particularly as a result of the global scope of action and the high integration of value chains, must be expected (Güttner, Sommer-Dittrich, 2008). The following question needs to be answered: how can companies successfully assert themselves in volatile markets and reduce the crisis susceptibility of their value chains through the sensible combination of existing methods and instruments with new ideas/innovations? Because competition, especially in the automotive industry, is increasingly determined by the efficiency of the value creation structures and not only decided on the sales markets (Garcia Sanz, 2007), to deal with uncertainty and respond to these challenges, the concept of ambidexterity plays an even more critical role in this industry.

2.3.2. Production Systems—Ambidexterity and Innovation

As previously discussed, the defiance that companies have to face today not only includes the challenge of product and process optimisation/innovation having to take place simultaneously, but also the **exploitation of current capabilities**/innovations and the **exploration of new competences/innovations** simultaneously (Levinthal and March 1993). In organisation literature, the trade-off between exploitation and exploration strategies is called **ambidexterity,** and creating a healthy balance between these two strategies is a key factor in achieving long-term success (March 1991).Being able to develop a successful balance within the company between both strategies and using the generated knowledge effectively can be considered a critical resources that companies need to establish to stay competitive, and therefore follows the resource-oriented approach. A company's behaviour and success, primarily explained through the existence and use of its unique resources, are the basis of the approach. Due to the assumption of a resource heterogeneity in the markets, a company can gain a vulnerable market position based on specific resources, which translates into a lasting competitive advantage (Zentes, Swoboda and Morschett 2003). Dynamic characteristics (for example, balancing exploitation and exploration) within the resource-oriented approach deals with the internal development, protection, and further development of such resources (Duschek 2002). The innovations are interpreted as being path-dependent, which means that the tangible and intangible resources of the company enable or limit the possible innovation processes.

While **exploration strategies** imply searching, experimenting, risk taking, and discovering behaviour that is associated with improvised, autonomous, and chaotic system structures, **exploitation strategies** focus on refinement, selection, efficiency, and implementation behaviour that is associated with routine, controlled, and bureaucratic system structures (Ancona et al.2001, Cheng and Van de Ven 1996,).Furthermore, these two strategies have an impact on the returns of the company. While returns caused by exploration are more distant in time and have a more variable character, those caused by exploration result out of a more stable performance with lower variability and are less distant in time. **Organisational ambidexterity** is thus defined as the ability of organisations to be efficient and flexible at the same time (He Wong, 2004). Each company faces the innovator's dilemma, referring to the fact that companies that are successful on the market could disappear into insignificance from one day to another because they have missed out on a new technology (Christensen, 1997). Specifically, when a business is successful, they neglect the R&D of new technologies and instead put all resources into their supposed success story, because this seems to be more efficient and less expensive. However, even if they try to overcome this challenge by creating Innolabs or startups in the organisation, they tend to fail because they misunderstand the basic meaning of ambidexterity. At the heart of the model is the thought that everything stays in one organisational body. One cannot just hand over innovation to the other hand without keeping a connection to the rest of the organisation. Thus, organisational ambidexterity means the parallelism of exploitation of the existing and exploration of the new. In addition to the tasks that differ in the two spheres, a parallelism also exists in organisational methods. While the core business is optimisation (exploitation), which is best achieved through fixed structures, processes, time horizons, and regulatory compliance, innovation spaces are about creativity, the breaking of routines and patterns, leaving of comfort zones, and therefore the discovery of new solutions (exploration). The solution and moderation of these conflicts succeed only through contextual or harmonic ambidexterity, in contrast to structural or cyclic ambidexterity (Carmeli and Halevi, 2009).

- **Cyclical ambidexterity**: Long cycles of exploitation are interrupted by short periods of exploration (Gupta et al. 2006).
- **Position-based ambidexterity**: Exploration and exploitation are located on different hierarchical levels of the organisation (Volberda et al. 2001).
- **Structural ambidexterity**: Different teams and locations are used to separate the learning types, which include inter organisational realisation (Wollersheim 2010).
- **Contextual/harmonic ambidexterity**: The individual level (i.e., one person) is decisive (Gibson and Birkinshaw 2004).

Thus, the resulting question is whether exploration and exploitation, which are orthogonal competencies (Gupta et al. 2006), can be effectively exercised simultaneously or sequentially (Guffarth 2016).The seamless integration of efficiency today as well as innovation in the future describes the necessity of exhausting the existing, and simultaneously exploring the new. This resembles the true nature of ambidexterity.

In addition, the focus on either exploitation or exploration strategies can result in a self-reinforcing trap, namely the so-called **efficiency trap** (exploitative strategies) or **innovation trap** (explorative strategies). Whereas the innovation trap inhibits the unsuccessful commitment to an innovation project, through spending increasing amounts of money and time disregarding the disappointing experiences that have already appeared, in the efficiency trap companies tend to neglect investment in exploratory innovation activities because the short-term success of the incremental optimisations offers quick returns and a low risk of failing, similar to the innovator’s dilemma(Benner & Tushman, 2003; Gupta et al., 2006; March, 1991). Focusing on product innovation/new product development (NPD), companies concentrate on the same strategies without consideration of differentiating between exploitation and exploration. With regard to a company’s performance, a cross-functional structure for explorative (radical) innovations significantly enhances the breakthrough innovation performance, whereas a functional structure for exploitative innovation (incremental) significantly enhances the derivative innovation performance (Visser, Weerd-Nederhof, Faems, Song, van Looy and Visscher, 2010).

Furthermore, the system in which the innovation/knowledge is generated or needs to be adapted plays a crucial role. In the automotive industry, the production system as well as the product can be described as complex.

2.4.Complexity in the context of innovation—Complex products in complex systems

In this section, complexity is seen as the behaviour of a system or model whose many components can interact in different ways (Willke, 1987). The focus is on the role of complexity in the product (2.4.1), the production system (2.4.2.), the social system (2.4.3.), the network (2.4.4.), and political instabilities (2.4.5.). The transformation of the automotive industry and its products over the last centuries serve as an example to show the results of the interconnectedness of the world, due to the rapidly increasing complexity displayed at the macro, meso, and micro levels.

2.4.1. Complexity in the Product

Products themselves are becoming increasingly complex; moreover, innovation today often occurs in software. The reason for the increasing variety of offerings and variants is the race of manufacturers to meet consumers’ wishes through innovative vehicle concepts as well as new technologies (Stock 2007). The number of vehicle variants or vehicle models has increased significantly in recent decades (Becker 2007) (Figure 8).

However, the increasing customer requirements not only create complexity in the form of additional models but also increased complexity in the systems of a vehicle. To offer maximum functionality, an increased network of individual systems is necessary (Hessing 2008).With enhanced complexity, the strain of the achievement of goals increases and conflicting goals emerge. The rising security requirements demanded by customers and by law, with control units, additional sensors, actuators, and crash-optimised body structures, satisfy the desire for more safety in vehicles; by contrast, the additional weight in the vehicle has a counterproductive effect on other customer requirements. This example demonstrates the conflicting goals impressively (Lindemann et al., 2009).

Depending on the phase a technology is in, the different technology types can be distinguished into pacemaker technology, key technology, or basic technology (Little 1988). For companies this classification is crucial under the rise of complexity in two ways: first, the technology life cycle considerations serve as the basis for investment decisions for an existing technology portfolio, and second, comparison of the cycle phases of complementary or substituting technologies is used to specifically aim for a technological change. This causes a field of tension within the goals and decisions of a company, as well as the knowledge transfer within it. All technology types are necessary to compete on the market, but require an indiscriminate investment in manpower, knowledge, time, and cost. Finding the right trade-off reflects the challenging situation of companies. False investments in only one of the described types of technology, as the example of Nokia has shown in the field of display and control development on the mobile phone market, can result in a company losing its connection to competitors and being forced out of the market within a few years.

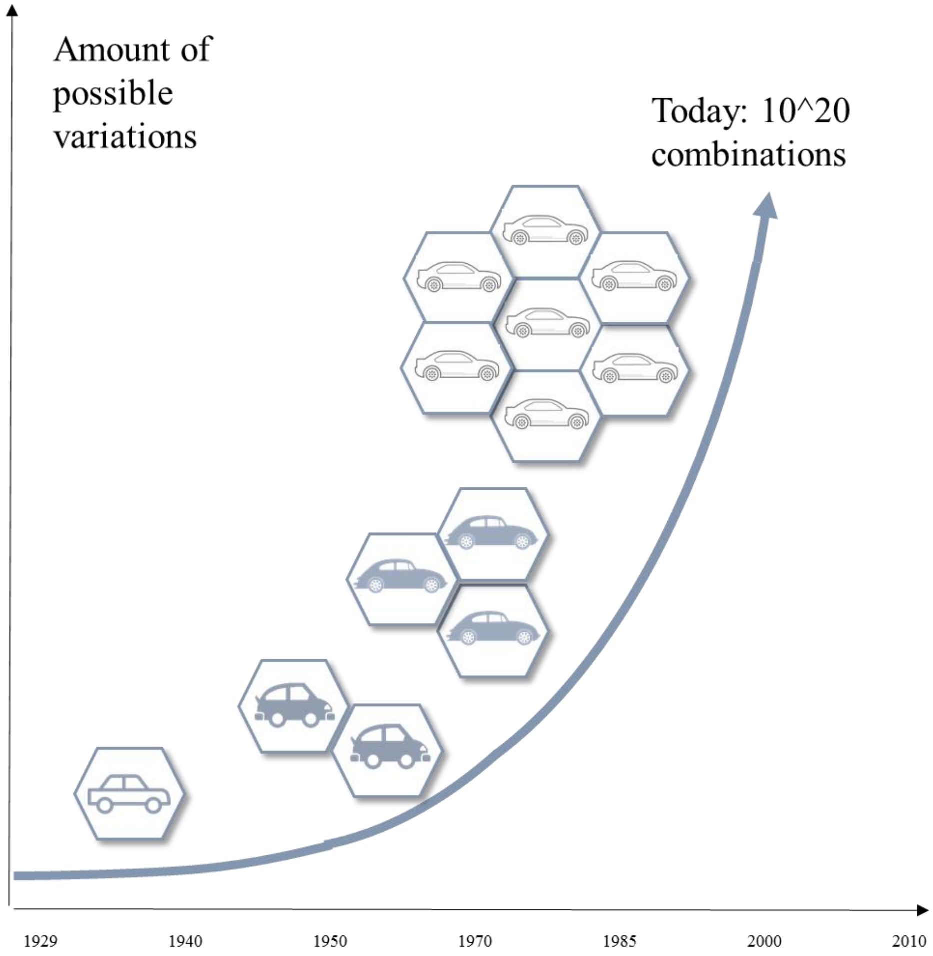

Figure 8: Increase in variation combinations over time (see Becker [2007], pp. 27 ff.).

2.4.2. Complexity in the Product Production Process

Complexity in the product production process is displayed in the **organisational dimension** of the production system of the company, and also in the **knowledge-skill dimension** of the company's staff. Looking at the **organisational dimension** first in the production of simple products, in contrast to the production of complex products, the creation of standardised products and services keeps customers' needs in check and lowers production costs. The production process consists of a high proportion of repetitive, standardisable activities. In this environment, employees function within a narrow framework of prescribed rules and can be easily trained for their tasks. The training requirements are low, as are wages (King, 2009). Thus, the knowledge-skill dimension is kept at a low level. To drawing a connection to the automotive industry, this situation can be observed in Figure 8 between the 1930s and 1960s resulting from few product variations in the automotive industry. The limitations of this mechanistic and repetitive production in a dynamic environment of increasing complexity, requiring ever more skilled labour, are obvious (King, 2009). With an increase in automation, almost all processes in modern working environments only run much faster than a few years ago. Especially in industrial contexts, the introduction of robots—which take a broad variety of tasks, work for employees, or remind them what to do next—is a big step towards partial and full automation. Therefore, work content is no longer defined by standardised tasks with the core modules of planning, decision, arrangement, and control. The focus is no longer on the production of goods or services with a high proportion of repetitive, standardisable activities, but rather on the flexible reaction of knowledge workers to the new daily challenges of the markets and the exploitation of market opportunities and new technologies (Koplyay and Mitchell, 2014a).

The **knowledge-skill dimension** increased rapidly in past years, resulting from the increase of product variations from the 1960s until today (Figure 9). Especially in the last 10 years, digitalisation has transformed classic jobs, resulting in activities becoming obsolete that a few years ago were an integral part of everyday work (Koplyay and Mitchell, 2014a). Likewise, driven by increasingly customised manufacturing and innovation cycles that are shorter than ever before, new tasks are added in product design, quality management, or in manufacturing processes themselves (Koplyay and Mitchell, 2014b). As the organisational dimension of the product production process shifts from non-automated, man-strong manual work to fully automated production with human–machine cooperation, the knowledge dimension develops into the flexible reaction of knowledge workers who must solve the new daily challenges of the markets and use the opportunities brought by new technologies and digitisation. This results in rising complexity in the social system.

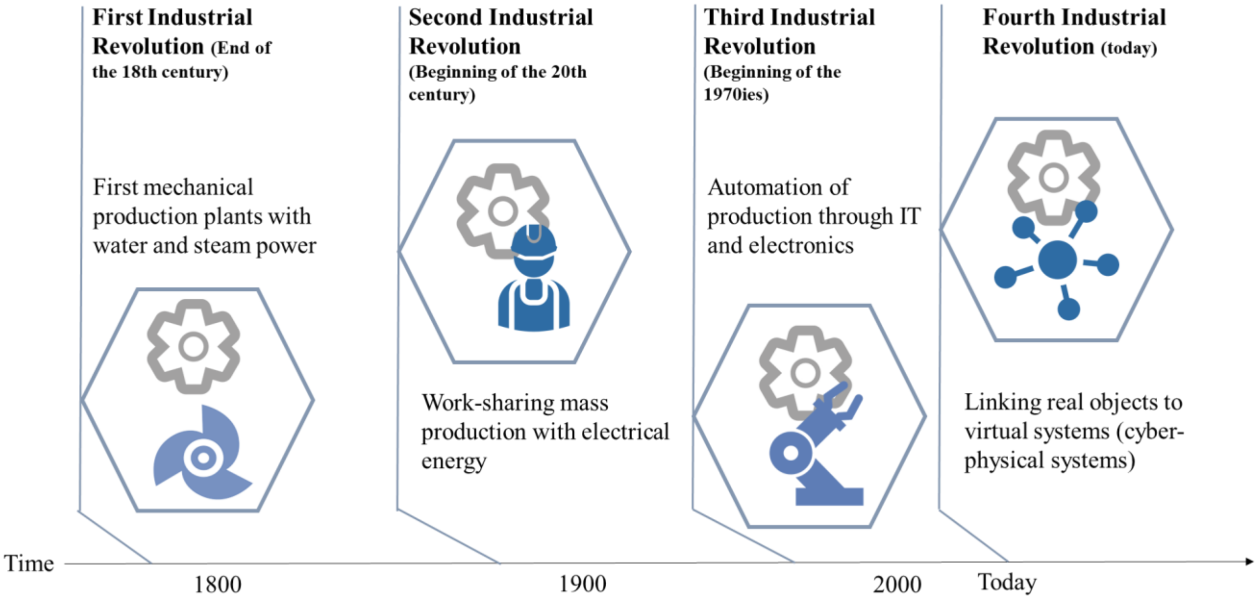

Figure 9: The four industrial revolutions (own representation based on Stearns [2018])

2.4.3. Complexity in the Social System

Parallel to the digitisation of products and processes, the ways in which people are learning, working, and living are changing as described above. The increase in the knowledge-skill dimension leads to significant implications for learning and skill development and is more crucial than ever. Today, the VUCA[11] principle is increasingly cited to describe modern working contexts and the **complexity in the social system** (Mack and Khare, 2016). This principle deals with the fact that there are no fixed rules, no certainties, and clearly recognisable relationships, meaning that everything is possible, even its opposite (Seifert et. Al. 2017). Each letter (V, U, C, A) resembles the first letter of a word describing influencing factors of a social system:

- **V**olatility: Characterising conditions that are unstable and thus unpredictable.
- **U**ncertainty: Referring to a state of a lack of knowledge, ambiguity, and unknown risk.

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[11] VUCA is an acronym of the words **V**olatility, **U**ncertainty, **C**omplexity and **A**mbiguity and was first stated by Bennis und Burt Nanus in 1987. VUCA - in its German variant VUKA - is increasingly used in economic contexts and when it comes to leadership issues in profit-oriented companies. (Seifert et. al. 2017)

- **C**omplexity: Referring to the behaviour of a system or model whose (many) components can interact with each other in a variety of ways, following only local rules and where higher-level instructions are unknown.
- **A**mbiguity: Referring to contradictions and alternative facts making decisions difficult, because simple explanations are not working anymore and there are no clear solutions to an existing problem (Bennett and Lemoine, 2014a; Horney, Pasmore and O'Shea, T. 2010).

Because each share of the principle cannot be seen individually or isolated, but they are seen as networked, dissolving becomes even less possible. It is exactly through this network that an unpredictable conflict arises (Bennett and Lemoine, 2014a).In contrast to young startups, established companies usually have an inheritance that does not allow them to reject all previous organisational mechanisms in the VUCA world and establish a radically new form of organisation. In many areas, the efficiency- and quality-oriented established structures and processes continue to offer indispensable value (Johansen and Euchner, 2013; Bennett and Lemoine, 2014b).

The need for digital transformation and the VUCA world requires overcoming of the inertia of traditional organisational forms and management principles (Rodriguez and Rodriguez, 2015; Sarkar, 2016). The concept of ambidexterity, therefore, provides for the establishment of a second parallel operating system. Whereas an efficiency-oriented organisation is concerned with continuously optimising what already exists, a parallel organisation is concerned with the future viability of radical innovation and new business models of the company. As mentioned earlier, the challenge of this ambidexterity is to master both simultaneously: to optimise the existing and create the new. A good balance of the different principles is important for success on both sides (Balthes and Freyth, 2017).

Paradoxes and contradictions inevitably arise in the organisation because of this parallelism of economically resilient investment in strategic innovations on the one hand, and the profitable, efficiency-oriented optimisation of the core business on the other (Balthes and Freyth 2017). The adaptability as well as the exploration potential of companies in a situation characterised by volatility, uncertainty, complexity, and ambiguity, while simultaneously not losing sight of the exploitation in environments characterised by stability, security, simplicity, and uniqueness, are elements of several decision models for complex social systems.

The Stacey Matrix, named after Ralph Stacey, correlates the degree of unity on the way and the degree of certainty (certainty). In simple situations, when all parties in the company agree on which path to take it is clear which way to go, and tried and tested standards with strict monitoring and continuous improvement can be used. By contrast, in situations with a disagreement about the solution path, because of high diversity among the stakeholders, insufficient information available, or the need to develop new technologies, the path to achieving the goals becomes increasingly insecure and the complexity increases. In this complex situation, standards only help a little; negotiating ways through open forms of cooperation and promoting creativity and innovation are more effective (Stacey, 2001).

Similarly, Dave Snowden (2007) differentiated four different areas of life of organisations in his **Cynefin framework**, namely simple, complicated, complex, and chaotic areas.

- **Simple** and **complicated** areas are clear enough to derive what to do from best or good practices. In simple and complicated areas, one perceives what happens, and then categorises or analyses the perceived reality and shape one’s reaction based on the results.
- **Complex** and **chaotic** areas lack clarity and therefore only emergent or novel practices help. In complex and chaotic areas, one starts testing or acting to be able to perceive what has happened, and then make my next step of the reaction (Snowden and Boone, 2007).

Today, both the Stacey matrix and the Cynefin framework are used to identify the current situation of a project landscape. In simple and complicated areas, it makes sense to exploit efficiency by exploiting standardisation, since the necessary stability, security, simplicity, and uniqueness are given. Efficiency programmes, such as from the Lean environment, make sense here. By contrast, in complex areas characterised by volatility, uncertainty, complexity, and ambiguity, exploring agile ways of working is most suitable. How to be lean and agile simultaneously, and what this means for the automotive industry and companies’ production systems, are discussed in Section3.1. With these paradoxes and contradictions inevitably arising in the organisation, the complexity in the network also increases.

2.4.4. Complexity in the Network

Networking itself is an initially value-free event of economic activity, which can be described in the course of the evaluation of and decision between alternatives under scarcity of resources in a first-course determination with complexity, unmanageability, and non-transparency (Willke, 1987). A classic example is the car and the automotive industry. In a car itself, up to

100ECUs are installed and form an electronic network. Each of these controllers can again contain millions of lines of code. Moreover, all parts that need to be assembled within the manufacturing process form a complex network of hardware and software. In addition, the manufacturing structures as well as suppliers and distributors form a complex network of services and goods. Therefore, as a contribution to this research, various sources of complexity in companies are addressed and applied to the automotive industry (Koplyay and Mitchell, 2014a).

In displaying production system networks (subsection2.3.1), the whole **automotive industry** can itself be described as a **complex network**. Following the definition of Scholz (2009), a real complex network is a complex system consisting of individual elements (people, computers, or molecules) and connections or relationships between them (friendships, networks, or interactions). Real complex networks are naturally grown or emerging networks (not centrally planned; Scholz, 2009).Through the formation of networks, the company hopes for improved mobilisation and pooling of resources, innovative concepts, structures, and processes as well as the reduction of transaction costs. In a rapidly changing environment, networks are always an attempt to condense mutual dependencies and turn them into social capital that can be used in turbulent conditions (Henning, Oertelt and Isenhardt, 2003).

Network researchers have analysed the most diverse relationship aspects of a system (see Salancik, 1995; Cook, 1992; Freeman 1979; Nohria and Eccles 1992):

- **Cooperation relations**: Who is researching together with whom? Who publishes with whom? Who cites whom?
- **Formal relationships**: Who is reporting to whom? Who is the shareholder of which research company? Who owns which patent rights?
- **Communication relations**: Who gets advice and tips from whom? Who talks to whom? Who is connected to whom via a virtual communication infrastructure?
- **Economic relations**: Who is sponsoring which scientific conference? Who is a customer of which research company? Who is the supplier of which research company?
- **Affiliation, memberships**: Who is a member of an advisory board, a jury? Who is the reviewer or publisher of which journal? Who lives, works, and researches where?

Due to this complex constellation of network partners (subsection 2.3.1), innovation processes are not completely controllable. This does not mean that they occur accidentally or are determined exogenously, but rather that they run between internal and external coordination

(Duschek 2002). A higher degree of novelty and complexity, the associated uncertainty, and a higher content of conflict make it difficult to control innovation processes; this is in contrast to routine operational processes, which are relatively easy to control through standards and constant repetition (Thom 1980).

Especially globally-dispersed innovation processes with distributed R&D activities are the reason for highly complex, uncontrollable and unmanageable organizational structures and architectures. To manage the innovation activities in a lean and effective way a spatial distribution between learning and coordination is necessary. Creating and enabling multiple centres of learning accommodated by one dominant centre of coordination and control is an effective strategy companies have already adapted to manage complexity in these networks. (Gerybadze and Reger, 1999)

At the same time, foreseeable developments such as climate change, demographic change, or the scarcity of resources pose challenges that create pressure to act as well as shape the future, and must therefore be addressed by politicians as well (Fischer and Wiegand; 2012).

2.4.5. Complexity Through Political Instabilities

Long-term and reliable **political conditions** are essential for the industry as well as its employees, and can be international drivers and encourage investment. A political environment that allows cooperation and demonstrates stable structures offers numerous advantages for international companies (Dyer and Chu, 2003). Therefore, managing interdependencies is not only a challenge for companies but also for politicians and countries. These interdependencies occur between private and public (usually collective) actors, between a complex political regulatory system and other functional systems of society (Benz 2004a).

Cost-oriented benefits of **cooperation** result from economies of scale, economies of scope, optimisation of the degree of integration, and risk sharing. The economies of scale or scope (Backhaus and Plinke, 1990) can be attributed to the sharing of production factors, which according to Porter (1985) leads to enhanced capacity utilisation and faster learning curve progression. Cost-related synergy effects through the optimisation of the degree of integration occur when the coordination mechanisms within cooperation for the coordination of interdependent business processes are more cost-effective than when coordination between external organisational units (i.e., via the market) must be conducted (Transaction Cost

Theory[12]) (Lyons B. R. 1995, Dyer, 1997; Coles and Hesterly, 1998). Risks arise particularly in the case of investments that are subject to high uncertainty (e.g. R&D investments). Through cooperation, the effort and thus the risk of the individual company can be reduced (Gahl 1990; Dyer, 1997).Market-oriented advantages arise when the market position of a company can be improved through cooperation. This can be done in relation to the suppliers, with regard to the customers or also with respect to the competitors (Backhaus and Plinke 1990). Reasons for cooperation are to gain access to international sales markets through a foreign cooperation partner or to aim for a diversification strategy, which leads to an expansion of the range of services (Eisele 1995). Cooperation is necessary when it is not possible to enter the foreign market unilaterally due to legal or cultural restrictions. Likewise, cooperation can aim for a diversification strategy (Eisele 1995). Aiming for diversification is essential when a company can gain more ground through cooperation and is less dependent on a single product, single service, or single customer segment. Market-oriented advantages can also arise if standards are established through cooperation and system leadership results from this (Plinke 1990).

The emergence of knowledge related to innovation within a production system, which can be described as a complex process with the output car (a complex product) and the difficulty people and the organisation face to deal with it, is a primary component of this work. The different approaches that have emerged in recent years in the automotive industry to meet the growing complexity, increasing demands, and volatility of markets as well as politics are the theoretical basis for the empirical validation of the legibility of lean and innovation in the following sections.

The natural response of people and organisations to complex challenges varies widely. A common and frequent reaction is to try to solve the complexity at the structural level, such as through lean management principles and methods. Furthermore, a change of channels or messages is another frequently used approach, such as agile principles and methods (see Chapter 3).The consequence, however, can also be that the complexity is not reduced, but even increased. Moreover, for employees and customers, this can lead to additional irritation if concepts and methods are not integrated into the company culture in the right way.

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[12] Transaction Cost Theory: Transactions cause costs (information, communication and coordination costs), so-called transaction costs (search costs, initiation costs, agreement costs, processing, adaptation and control costs) (Coase, 1960; Picot, 1982; Windsperger, 1983). A transaction is the transfer of a preliminary or intermediate product or a service from an upstream to a downstream production stage. (Ghoshal and Moran 1996)

2.4.6. Complexity at the Macro, Meso, and Micro Levels

The complexity of innovations at different levels results in immense uncertainty with regard to assumptions about possible developments. Developments in technology, the economy, and society cannot be predicted with certainty. Therefore, complexity leads to uncertainty at all levels (micro, meso, and macro) and is described in the following paragraphs (Fischer and Wiegand; 2012):

Complexity at the macro level: The complexity of the social system as well as through political instabilities shows the uncertainty at the macro level. In particular, the effects on the economy caused by the financial crisis of 2008 and 2009 in the automotive industry show the influence of VUCA principles as well as the political instabilities at the macro level. The uncertainty is reflected in the decline in registrations and production figures in the automotive industry in 2008 and 2009.In the fourth quarter of 2008, sales markets such as the USA lost in some cases over 40% compared with the previous year (Freitag and Student 2009). With manufacturers under extreme pressure to save costs as well as companies not pursuing competitive technologies in times of crisis, the inherent risk that competitors will gain technological advantages as markets recover was rising enormously. Some companies had to reduce their spending on R&D or exclude certain fields of action such as electrification from austerity measures in those years to not lose touch with competitors. Furthermore, the indecisiveness of German politics, since there was no solution, for example, to reorganise the motor vehicle tax, did the rest (Freitag & Student 2009). Facing uncertainty on the customer side as well as in the development of products and production processes leads to an increase of complexity at the macro level, but also influences the micro level of the automotive industry enormously.

Complexity at the micro level: Uncertainty in product development as well as the selection of the right sustainable technology for the future in general, but especially in times of crisis, displays the complexity at the micro level. In the automotive industry, the market change caused by customers increasingly wanting individualised products means that the number of variants increases significantly and implies a more complex production or service by producing different versions with the same production volume. This, in turn, brings out economies of scale and challenges in the traditional structures of a company (Wildemann, 1998).

The structural changes in the global economy become clear when one sees the economy as part of a dynamic network. The objects of this network (such as market players, assets, factors of production, available information, and skills and knowledge of employees) are in different relationships with each other (see Section 2.3).The decision made on an individual level affect the company (e.g., skills and knowledge of workers, project management, innovation processes, and innovation culture) and result in rising complexity at the micro level. In particular, the type and aspects of relationships, characterised by the type and number of elements as well as the type, strength, number, and density of interrelations, increase the complexity. This can positively result in shorter development and decision cycles, the use of new technology, and the gain and sharing of task relevant knowledge; however, it can also have negative results when failing to anticipate or neglecting the cost effects of complexity (Hundertmark, 2013).

Therefore, innovative change can be seen through new rules (innovation) at the micro level, which, if successful, lead to a structural change at the meso level. This shows that the complexity to be found at the respective level makes it necessary to put a meso level in between .Only the meso level makes it possible to unite the minimum unit (micro) and a maximum unit (macro) and be able to find the causes of the change described at the macro level and explained at the micro level (Carlsson and Eliasson 2003; Savotti and Pyka, 2004)

Complexity at the meso level: The causes of change can often be found in the interplay of decisions of individual units on an organisational and institutional level under the given framework and influencing factors. Decisions are not made at an individual (micro) level anymore, but rather on an organisational level (between different micro units). Organisational decisions are characterised by the fact that they are not only anchored in the brain structures of those involved but also in the surrounding social systems, such as organisations or cultures. Therefore, a rule system and structures are required because the underlying evolutionary process is much faster than the biological one and can result in increasing complexity at the meso level (Arthur, 2013).

The digital transformation for innovation systems opens up ground breaking new perspectives in understanding why market players trade with each other, certain production factors are required to produce a good, and a market or players have certain information and therefore help in developing the right rules and structures in the company to reduce uncertainty and complexity. Intelligent digital networking, new digital technologies that complement an array of technologies, digital platforms, and the arising intelligent networking of people and objects are advantages (Bauer et al. 2015; acatech and BDI 2017); however, when understood incorrectly, they can also be disadvantages and a reason for the increase of complexity in innovation systems at the meso level. This is especially true if nationally or regionally varying shaped values as well as thinking and cultural patterns need to be incorporated into overarching innovation processes and further refined in a globally competitive way (Tushman and O’Reilly, 2002).

It is of course an essential element that all levels (macro, meso, and micro) feed back to the levels below, which is a major cause of the complexity observed.

2.5. Link between innovation and lean management/production and the link to evolutionary economics

There is no doubt that without technological innovations our lives would look very different today, because they have created new opportunities for communicating, interacting with each other, seeing, thinking, and living. Simplification, organisation, and coordination of tasks are what management has been based on since the beginning of the 20th century. Developing corporate policies, creating hierarchies to ensure worker compliance, and reducing the surrounding complexity levels were the main goals. This is why lean management and methods play a critical role in companies handling complexity. Core principles in the lean philosophy are based on problem solving and continuous improvement. Connecting these principles to innovation theories, in practice, the challenge is often to find a problem for which an idea provides the solution. Good ideas often start with the question of the right problem: what exactly is the problem we are looking for solutions to? (Chen and Taylor, 2009).In 1975, Kodak launched the first digital camera that could only save a few pictures, but obviously had great potential. However, it was a good idea at the wrong time, with nobody buying it. Once people realise which of their problems is solved by an idea, the idea has a great chance of survival (Lucas and Goh, 2009).

This leads to the dilemma Porter (1980) stated—it is impossible for companies to pursue a low cost strategy as well as a differentiation strategy and not get stuck in the middle. This section clearly shows that Lean and innovation can co-exist and are not mutually exclusive, and in fact are vital components to the bottom line equation of cost, quality, and value. Coupling the two concepts might seem challenging first, but a commitment made by those in management to merge the changes they engender into the operational strategy and assure that the implementers understand and accept the main determination and goal, the difficulties will be dissolved and a cutback in complexity at all levels will be ensured.

2.5.1. Lean: The Upcoming of Lean and its Link to Innovation in the Automotive Industry

Lean management combines a multitude of methods. The supporting pillars are just-in-time (JIT) production and Jidoka (Monden, 1983; Sakakibara et al., 1993; McKone and Weiss, 1999), described as the autonomous shutdown of a plant in the event of production problems. To do this, production and processes must be levelled, standardised, and visualised. The core principles aim to optimise the production factors and product quality as well as to make the production apparatus more flexible (Li et al., 2005; Shah and Ward, 2003; Sugimori et al., 1977).

The most valuable features of lean are the continuous improvement (kaizen) of the processes and the concentration on customers, suppliers, and employees (Kranz, 2007). This is illustrated in the TPS house. In Japan, after the Second World War, a different strategy was chosen to that chosen by automakers in the USA and Europe. Instead of pure mass production, the focus was on rapid product innovation. This rapid change required a different production strategy. Taiichi Ohno and Shigeo Shingo are considered the founders of this new philosophy of production, and in the 1950s they shifted process planning from the top of the hierarchy to the place of actual work. Newly created principles enabled companies to react faster to change and thus be more agile in the market. Positive effects within production are reductions in unused production areas, employees, development times, inventories, lead times, and sources of error. This increases product diversity, product quality, and overall customer satisfaction, and therefore has a positive impact on competitiveness (Womack and Jones, 1996; Spear and Bowen, 1999). Furthermore, employees were included in the planning to not only create rapid product changes but also adapt the production strategy to these changes. Thus, the idea of the continuous improvement process (CIP) was born (De Treville and Antonakis, 2006; Hopp and Spearman, 2004; Narasimhan et al., 2006; Womack and Jones, 1996).

Lean production should ideally be combined with a lean administration, which then results in a doubling of production and halving of costs in all areas of the company. It boils down to allowing people to collaborate better in lean production: cross-disciplinary, silo-disruptive, thereby shortening the communication channels between the individual members of a project, department, or organisation (Hall, 1987; McLachlin, 1997).

At the beginning, many companies failed because they only used lean methods and management to solve individual problems or improve single processes. The mindset behind the methods was ignored. Crucially, the management work must create a tight mindset on the basis of the company's vision and goals. Important components of this mindset are manufacturing, leadership, and organisational principles that together form a system in which the mindset, methods, and approach concept belong together. This system represents the guiding principles for executives and employees in their day-to-day work. Employees are trained in lean tools and methods to optimise processes in the prescribed guidelines to enforce the principles. This forms the basis for the change process (Womack and Jones, 1996).

The link between lean and innovation provides insights through the components of emerging knowledge. On the one hand, early routinisation and reduction of uncertainty through being rigid, standardised, and constrained to productivity leaves less room for radical creative thinking and disruptive innovation (Ven de Ven, 1986). However, as lean's focus is on optimisation strategies and process improvements, it has a decisive impact on the emergence of incremental knowledge in innovation processes. Tried-and-tested models that promote the idea of optimisation within innovations and reflect incrementally generated knowledge include the **theory of inventive problem solving** (TIPS) and **lean innovation**.

TIPS and lean innovation both have the intention of eradicating items that do not add value in the innovation process by encompassing the optimisation of the operations of the system (Chen and Taylor, 2009; Yamashina, Ito and Kawada, 2002; Schuh et al. 2015). Thus, implementing a lean culture in which slack, risk, and variability are reduced has a positive impact on the innovation process of companies (Chen and Taylor, 2009).

TIPS is a Russian concept of inventive problem-solving and is based on two basic ideas: solving a contradiction leads to high-quality inventions and inventing is a repeatable and reproducible process. Recurring patterns, meaning that thousands of inventors have repeatedly overcome similar contradictions with comparable solutions, were described as generic solutions by Altschuller and Shapiro (1998). These solutions are the '40 inventive principles' known today (Gundlach and Nähler 2006, p. 14). Each and every invention and innovation can be traced back to one or more of these inventive principles. In the Altschuller matrix, contradictions and the inventive principles applied to the solution are clearly depicted and ordered by the frequency with which they were used to solve the problem situation (Altschuller 1998).

Compared with the other problem-solving methods, TIPS can solve a wide variety of tasks of different complexity. Most of the other problem-solving methods such as trial and error are unsystematic because they attempt to achieve the desired solution by experimenting several times or reaching its limits with increasing complexity, such as the morphological box (Livotov and Petrov 2010).

By demanding the exact description of the problem and not concentrating on generating as many solution variants as possible, TIPS clearly delimits the search field for new ideas or solutions, and therefore combines all techniques into a complex problem-solving methodology (Herb et al 2000). This allows a targeted search for solutions and the finding of high-quality results that approach the ideal end result (Koltze and Souchkov 2011).

Lean innovation, defined as the waste-free and value-oriented implementation of product innovation, shares many similarities with lean management. The larger the organisation, the more the market-centred thinking seems to move away and being innovative becomes more difficult. Through moving back to the base of the company, lean management resembles a countermovement with core principles coming into play. Building on these core principles, the lean innovation system of the WZL at RWTH Aachen University is based on four phases/categories, containing 12 principles in total (Schuh, 2007):

Clear prioritisation: Strategic success positioning – Clear hierarchies – Road mapping

Unequivocal prioritisation is the incarnation of value orientation in innovation management. If you do not strategically prioritise your innovation resources, you will at best come to market success at random—regardless of how efficient your processes are (Schuh, 2007).

Early structuring: Product architecture design –Assortment optimisation –Solution space control

Early structuring translates into effective frontloading through defining the guard rails for value-based product design. It is crucial to exclude the cause of waste in the project, above all in downstream stages of the value chain, even at an early stage (Schuh, 2007).

Simply synchronisation: Value stream optimisation – Data consistency – Timing

The interplay of the disciplines involved in an innovation project is like a symphony orchestra: numerous experts and artists work together simultaneously, but only the perfect synchronisation creates a work of art –it counts the ability to easily synchronise all involved in the project (Schuh, 2007).

Safe adaptation: Innovation controlling – Release engineering – Continuous improvement

Lean innovation requires the versatility of innovation management: secure adaptation describes the goal-oriented further development of products and processes with regard to identified potential for improvement (Schuh, 2007).

Moreover, lean innovation can only be methodically implemented if the right framework conditions for employee motivation and development are in place. The focus is on product identification, defined as the measure of emotional attachment and enthusiasm for the product in whose immediate environment one works (Schuh, Lenders and Schöning 2007).This goes hand in hand with the principle of lean management, that all activities are geared to the **customer's benefit** and therefore the resulting knowledge is tailored to the customer's satisfaction and benefit (Bergman and Klefsjö, 2010).

Only if the customer of a product or service promises a **benefit** will he or she be willing to pay for it. In simple terms, the higher the benefit, the higher the price that can be charged. Criteria such as product quality, process service (e.g., smooth ordering and short delivery times), and customer service (e.g., customer friendliness, good advice, warranty services, and payment methods) are still key elements for which the customer is willing to pay. However, customisation of the product is becoming increasingly important. Thus, taking this aspect into consideration, customer benefit is the advantage that the customer gains through the performance of the product. However, it is not the objective benefit that is relevant but rather the benefit subjectively felt by the customer, and therefore it may vary from consumer to consumer. The better the **customer needs** are met, the higher the customer benefit (Bergman and Klefsjö, 2010).

Customer satisfaction or dissatisfaction arises when the customer compares his or her expectations regarding the company with the perceived performance. If the expectations are met or even exceeded, he or she is satisfied, but if the performance does not live up to its claim, the customer is dissatisfied (Zairi, 2000). Lean is known to have several negative effects as well. First, lean value analysis has a negative effect on a company's competence to profitably deal with radical innovations and disruptive innovations. Second, lean supply chain management has an unfavourable effect on a company's receptivity to radical innovations and revolutionary innovations. Third, lean human resource management has a negative effect on employee creativity (Bhasin, 2008). Thus, only being lean cannot be the solution and being flexible and agile comes into play.

2.5.2. Agile: The Upcoming of Agility and the Link to Innovation in the Automotive Industry

The concept of agility has existed in the system theory of organisations since the 1950s (Jensen, 1980, Atkinson Reay and Moffat, 2005). The American sociologist Talcott Parsons identified the following four functions that each system must meet to maintain its existence (Sciulli and Gerstein, 1985):

- Adaptation: Core elements are the ability of a system to respond to external changes
- Goal attainment: To define and pursue goals
- Inclusion and integration: To establish and assure cohesion and inclusion
- Latency: To maintain basic structures and processes of value patterns (Jensen, 1980)

The initial letters of these four functions result in the well-known AGIL scheme (Jensen, 1980).

The upcoming of agility can be seen in three different areas:

Agile Software Development: Reinforced by methods such as ‘Scrum’ and ‘Kanban’, since the beginning of the 21st century, agility has become apparent under the heading of agile software development. With the formulation of the so-called ‘agile manifesto in software development’ (Agile Manifesto, 2001), a kind of action orientation exists, according to which principles the development of software should be designed so that it can be described as agile and the benefits postulated actually come to fruition (Dybå and Dingsøyr, 2008).

Agile Manufacturing: Agile manufacturing, created in response to lean production, is a production philosophy that focuses on meeting customer demand through flexible production practices, by focusing on fast product development (simultaneous engineering), multi-functional teams, and continuous optimisation of production processes (Sharifi et al., 2001; Zhang, 2011).

Agile manufacturing alters from lean production in its focus on complying customer needs without losing quality or creating additional costs. The suggestion is based on the approach of the virtual enterprise and seeks to establish flexible, often short-term relationships with suppliers when market opportunities arise (Gabler Wirtschaftslexikon, 2016).

To give the fulfilment of customer requirements and thus customer satisfaction more importance than the pure production volume, a self-sufficient and intelligent workforce is needed in agile manufacturing. This structure can then also be described as an agile organisation (Kaufmann, 2015).

The Agile Organisation: The decades-old concept of agility is experiencing a renaissance and practical benefit due to the challenges that current megatrends in the workplace bring with them. By not focusing on agility in one part of the organisation, production, or (software) development, but rather on issues such as the transformation of business units or even entire companies, the organisation itself achieves the necessary flexibility to meet and react to customer benefit and demands (Atkinson and James 2005).

Ultimately, it is about agile teams solving customer-related issues because market dynamics require rapid reaction. A maximum of dynamic and target orientation makes it possible to respond promptly to continually changing customer requirements, with the goal of creating a potentially usable product for the customer. This product may not be fully developed yet, but offers added value to the recipient (Power, Sohal and Rahman, 2001).Agility is primarily a matter of mindset (value and principles), which unfolds the effectiveness of the mindset change taking place. Concrete practices such as Scrum[13] and Kanban[14]can only help you learn this mindset and anchor (Ahmed et al. 2010; Sharma, Sarkar and Gupta 2012; Dickmann, 2015).

The cycles of vehicle manufacturing are growing ever shorter. Althought here are still model development cycles of more than 36 months in Germany, manufacturers such as Toyota, Peugeot, and Tesla drive the market ahead of them (Womack, Jones and Roos 1991, p. 125 ff., Clark and Fujimoto 1992, p. 95; Schulze, MacDuffie and Täube; 2015, p. 604).

A critical factor affecting the production system is the constantly changing economy, due to digitisation and other megatrends and a resulting pressure on abilities such as flexibility and adaptation. A flexible integration of new technologies is the only way to not offer outdated innovations to customers, as the example of navigation systems shows. To avoid old components or outdated navigation systems being put on the market in a new car after a three-year development phase with a subsequent 18-month production integration phase, software updates are made available for customers continually (Atkinson and Moffat, 2005).To make this possible, the production itself must be opened back and forth by reducing the boundaries between supplier and manufacturer as well as between manufacturer and customer(Güttner, Sommer-Dittrich, 2008).Replacing software components and making the customer part of an iterative circle by creating new functionalities on demand (even after a purchase) is the only

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[13] Scrum is a method of agile development based on the incremental software development process aiming to increase productivity In the method the entire development cycle is divided into a series of iteration where each iteration (=sprint) has a maximum of 30 days. (Sharma, Sarkar and Gupta 2012)

[14] Kanban is a work management method that originated from the Toyota Production System (TPS). but also in the software development to Appearance comes. In the late 1940s, Toyota introduced just-in-time production. The approach is based on a pull system. Production is geared to customer demand and is not fixed to specific quantities as is the case with push systems, which then come onto the market. In software development, the method serves to limit the number of parallel tasks, thus achieving shorter throughput times and making problems - especially bottlenecks - quickly visible.(Dickmann, 2015)

way to stay successful in the market and meet the current challenges. Agility gives companies the flexibility and dynamism they need to cope with the increased complexity.

Agile optimisation, for example, accompanies the entire process such that bottlenecks can be identified early on and operations prioritised and rescheduled. When changes occur, the algorithms used in agile optimisation help to quickly take them into account and, above all, to understand their impact on the whole (Savelsberg, Dorndorf and Weiler, 2018).

The different aspects of agility show that both the digitisation of the value chain as well as fostering of agile thinking by internalising and acting on the agile value system are core competencies a company needs to build to stay competitive and produce more effectively, sustainably, and faster. Therefore, what does it mean when these two concepts, lean and agile, collide in an industry and the companies reacting, pricing, and selling products in the market? Are there similarities and differences that can support the compatibility?

2.5.3. Lean vs. Agile: Similarities and Differences

In comparison and similar to the upcoming of lean, similarities and differences can be observed upon a detailed examination of the definition of both concepts and their core principles.

Definition of Agility:

> ‘Corporate agility, the capacity to react quickly to rapidly changing circumstances, requires a focus on clear system output goals and the capability to match human resources to the demands on changing circumstances’ (Brown and Agnew, 1982, S. 29).
>
> ‘… an effective integration of response ability and knowledge management in order to rapidly, efficiently and accurately adapt to any unexpected (or unpredictable) change in both proactive

Definition of Lean:

> ‘Lean production (...) is lean because it uses less of everything than mass production - half of the factory staff, half of the production floor, half of the investment in tools, half of the time to develop a new product. It also requires far less than half of the necessary inventory, leads to much fewer errors, and produces a larger and ever-growing variety of products’ (Womack et al., 1992, p. 19).

> and reactive business/ customer needs
> and opportunities without compromising
> with the cost or the quality of the
> product/ process' (Ganguly et al., 2009,
> S. 411).

Elements found in both approaches (**similarities**) are the importance of tight (and lean) vendor and customer relationships as well as the abolition of hierarchies in organisations, which involve shifting decision-making to the lower levels of the hierarchy. Highly motivated, well trained, and informed employees are also an integral part of both concepts (Förster and Wendler, 2011). The **core principles** of lean are also significant features of agility (Schmitz, 1995)**:**

- Just-in-time production
- Error control system / Total Quality management (TQM)
- Reasonable technical equipment, robust uncomplicated automation technology instead of complex technical equipment, control and monitoring of the mechanical manufacturing process, short set-up times
- Work organisation in flat hierarchies (semi-autonomous group work, flexible workforce division, and job rotation)
- Qualification / motivation of employees (multifunctional employees)
- Continuous improvement process (Kaizen)
- Value creation and process orientation

The selection is more prevalent in agility; for example, not all elements of lean production are reflected in the concept of agility (**differences**). The idea of well-being and employee satisfaction is, for example, not as important in lean production as it is in agility. Furthermore, the agile concept, like the lean organisation, is focused on reducing resources, time, and costs, albeit not with the same focus on the cost aspect that has become a barrier to technological development within lean production (Conboy, 2009, S. 338).

It can be seen that agility is based to a large extent on the concepts of flexibility and leanness, although, especially with regard to leanness, the selection of aspects to be adopted has been made. In addition, the concept of agility contains a multitude of other approaches that are more or less widespread in business practice (Förster and Wendler, 2011).

It is not only the different types of complexity that play a role in the emergence of innovations; the interaction of the different networks within the company are also important.

Within a production system, different networks can be found, such as the production network, value-added partnerships, supply chains, strategic corporate networks, and innovation networks (see Section2.3).

As described earlier, innovation networks are defined as the complex network of a large number of cooperation partners who agree on and practice conscious, sustainable, collaborative, and interactive cooperation in innovation (Hausschildt, 1997).Innovations in the highest quality and most complex technologies are increasingly being provided by self-organising networks. With this networks being interconnected organisations—companies, universities, government agencies—that establish, promote, and unite specific knowledge and skills to invent complex technologies, the concepts of being lean and being agile play an even more important role. In other words, innovation networks are organised around permanent learning and the knowledge creation process is a main part of both concepts. In business and society in general, networks are becoming an increasingly relevant factor for success or competition, and therefore, the right balance of ambidextrous strategies needs to be found to not disturb or hinder learning in the network. This can be the answer to master structural change towards an information society, which is accompanied by the global economy and that places particular demands on companies in competition. Due to the complex constellation of network partners, innovation processes will never be completely controllable, but this does not mean that they occur accidentally or are determined exogenously (Duschek, 2002). Moreover, innovations are considered the growth engine of economic development and promote constant renewal, regardless of whether they are generated by lean or agile methods. How innovations are used as a necessary tool to increase and maintain competitiveness in the automotive industry is discussed in the following chapters.

3. Compatibility of Lean and Innovation in an Industry at a Macro-Level Perspective—Ambidexterity and Innovation Patterns in the Automotive Industry

With the macro level describing the change, the meso level finding the cause for the change, and the micro level explaining the change, the analysis of the compatibility of lean and innovation in the automotive industry starts with the macro level perspective. It is of course an essential element that all levels (macro, meso, and micro) feed back to the levels below and are a major cause of the complexity observed (see subsection 2.4.6).

In this chapter, the macro perspective provides descriptions to the following questions:

- How does industry evolve to cope with the volatility, complexity, and resulting uncertainty? (Demonstrated using the example of the automotive industry)
- Which existing concepts and models must be used and how must innovative ideas be implemented / generated to survive on the market?

The main goal is to discuss the connections between lean and agile (leagility) as well as ambidexterity to widen the theoretical fundament. It is necessary to know how it can be combined in one framework (3.1) and is empirically validated through a comparison of explorative and exploitative patent structure of OEMs(3.1.1),resulting in the description of the impact of this framework on a lean production system and vice versa (3.3.2). Based on these insights in the theoretical fundament and its empirical validation, the compatibility of lean and innovation from a macro level perspective are reviewed as well as concrete recommendations for action for industry and economy derived (3.2).

3.1.Leagility and ambidexterity—Two standalone concepts?

Leagility: Naylor, Naim, and Berry (1999) defined the concept of leagility for the first time. Whereas agility in manufacturing processes is the ability to respond to uncertain market situations, complexity, and change by exploring profitable opportunities, lean in manufacturing processes is the ability to handle competitive pressure with less resources by developing a value stream (Dubey and Gunsekaran 2014). Because it is not possible to employ both concepts successfully at the same point within the supply chain, current research suggests a decoupling point which divides leanness for upstream processes and agility for downstream processes (Cox and Chicksan 2005, Purvis, Gosling and Naim 2014).

In the last 17 years much research has been conducted in different industries with various foci on the leagility topic. Crocitto and Youssef (2004) concentrated on the human aspects of leagility including reward systems and organisational culture. Bruce et al. (2004) tried to classify companies in fibre production, the fashion goods industry, and premium manufacturers/retailers as agile, lean, or leagile. Within the automotive industry, the main interest in former research lies on the supply chain and how to design it with a higher degree of robustness (Tuner 2005). Naim and Gossling (2011) stated in a final summary that it is not possible to be leagile in every industry, but market as well as product characteristics can help to determine applicability. If significant organisational changes are undertaken by the company, then it is possible to achieve enhanced performance improvements resulting in increased market share and financial performance (Naim and Gossling 2011).

Ambidexterity: In comparison, but also somehow in connection to the concept of leagility with a decoupling point and a separation of being lean and agile, stands the concept of ambidexterity, which was explained in subsection 2.3.2.

3.2.Combining leagility and ambidexterity in one framework

In contrast to former research focusing on the concept of leagility mainly in the supply chain, this study attempts to combine leagility with the concept of ambidexterity to obtain a holistic view of different companies in the automotive industry.

The aim is to combine the above mentioned concepts—leagility and ambidexterity—in one framework (Figure 10). **Agility** is based on **exploration strategies**, including flexible reactions on market demands in yielding **radical innovations**. **Lean** is based on **exploitative strategies**, including efficient value streams in yielding **incremental innovations**. Lean thinking includes behaviour strategies such as continuous improvement, standardisation, routinisation, and formalisation (Jansen, Van der Bosch, & Volberda, 2006) and is therefore linked to exploitative innovation, which entails firm behaviour characterised by refinement, implementation, efficiency, production, and selection (March 1991). Companies must be careful not to fall into the efficiency trap. Agility encompassed behaviour strategies such as the capability to adapt or respond in an accelerated manner to a changing marketplace environment and undertake risk and change management, and is therefore related to explorative innovations, which imply firm behaviour characterised by search, discovery, experimentation, risk taking, and innovation

(Cheng and Van de Ven 1996). Thus, companies have to be careful to not fall into the innovation trap.

Whereas agile and lean methods focus on supply chains (e.g., Naim and Gosling 2011), ambidexterity focuses more on the research and development sectors of companies. Merging these two concepts provides the chance to estimate how good an organisation is in being lean and being agile based on their innovation capability. As a matter of fact, with both concepts (leagality and ambidexterity) containing the same factors, namely exploration and exploitation, it is obvious that these cannot be two standalone concepts and are thus analysed in detail in the following section.

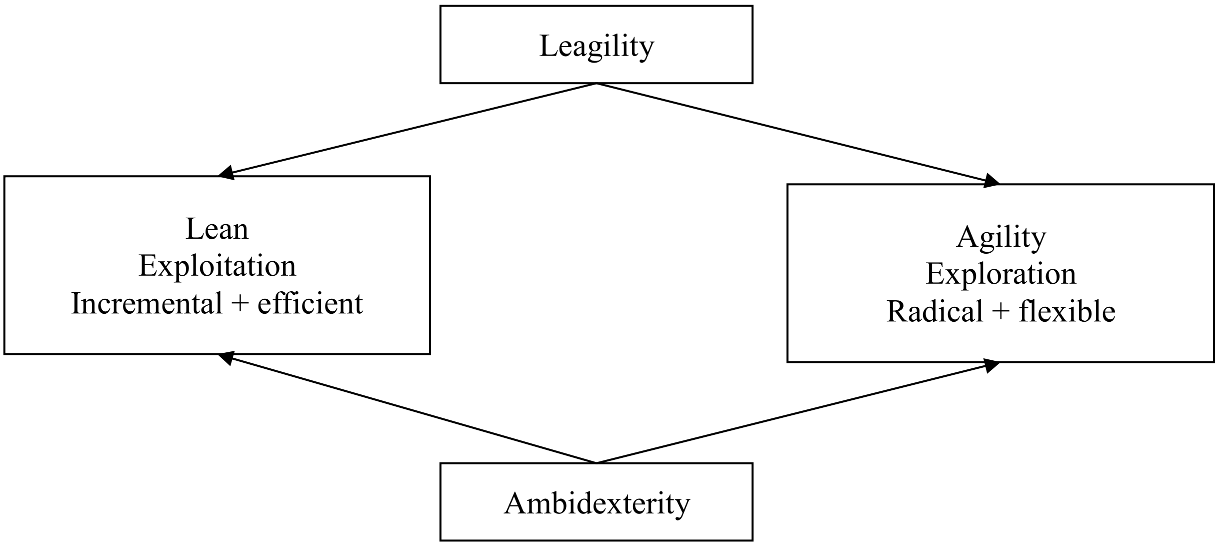

Figure 10: Leagility and ambidexterity framework (self-created representation).

3.3. Comparison of explorative and exploitative patent structure of OEMs and the influence on and of a lean production system

Technological aspects play a crucial role in the innovation management of companies with regard to the chances of success and to justify the unique position on the market. Patents are particularly suitable to obtain a great deal of technological information on the state of the art as quickly and easily as possible. Patents meet virtually all requirements in a standardised form, allow for international comparison, and are the empirical fundament of the following analysis (Ernst, 1996; Song, 2016).

3.3.1. Explorative and Exploitative Patent Structure of OEMs

To be able to understand the exploitative and explorative patent structure of companies, it is essential to differentiate between improvements, extensions, generational change, and market novelties (Figure 11).

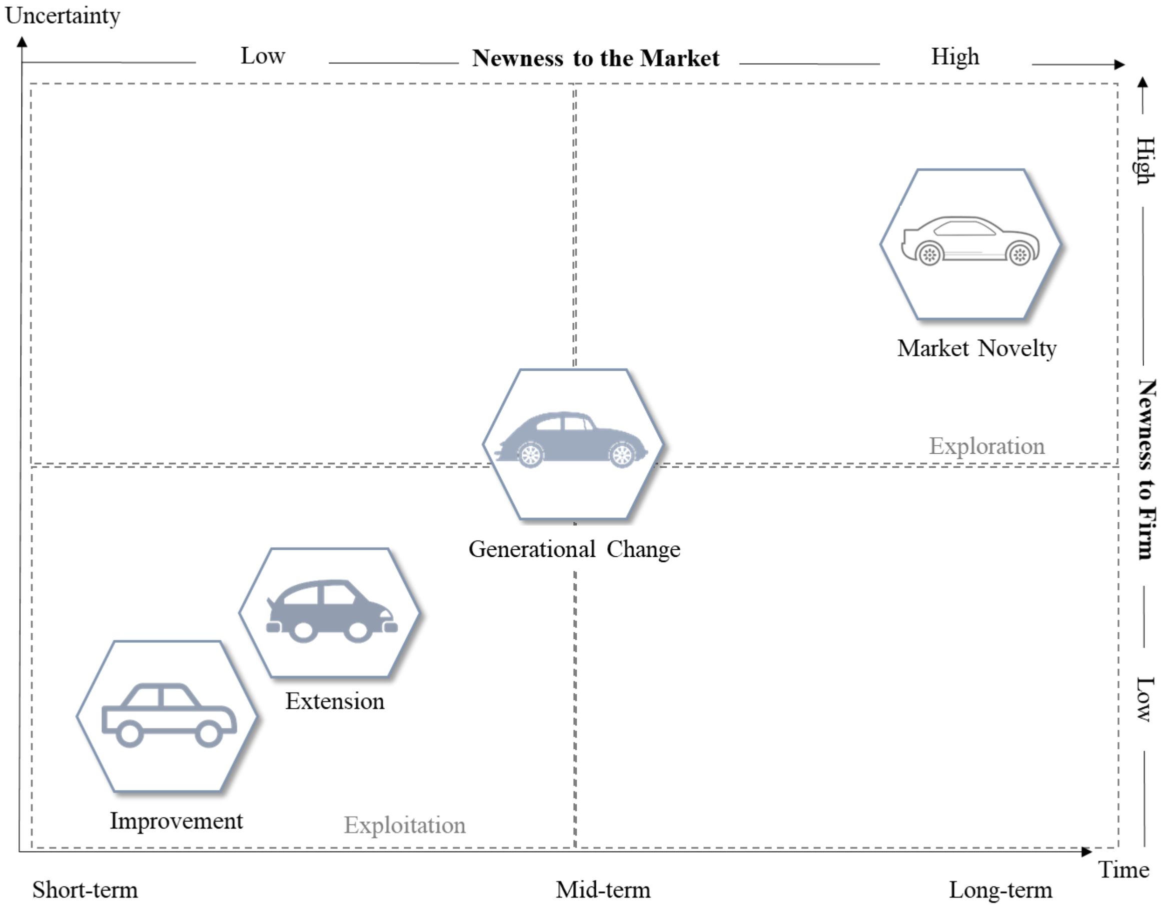

Figure 11: Improvements, extensions, generational change, and market novelties (own representation based on Booz-Allen and Hamilton [1982] and Ringen, Holtskog, and Martinsen [2012]).

Improvements are exploitative innovations that make small changes to existing products, with the goals of extending the life of the product and defending its market share, thereby increasing the return on development and start-up investment as well as earning money for other projects (Nelson and Winter 1982; Dewar and Duttton 1986; Ringen Holtskog and Martinsen 2012). These improvements serve to increase the functionality or quality of the product or reduce its production costs, and are therefore based on incremental innovations (Dewar and Duttton 1986).

In the automotive industry, improvements to the end user are often invisible and serve to eliminate problems or reduce production costs (Dewar and Duttton 1986). The most prominent visible example of an improvement is the facelift that automakers are introducing after a few years to extend the appeal of models. Furthermore, in the automotive industry, new variants with special features are often introduced sometime after introducing a new model, so-called extensions (Ringen Holtskog and Martinsen 2012).

Extensions are also exploitative innovations that introduce new variants and additions based on already existing products, with the goal to increase sales with an existing product line without a high development effort or risk (Ringen Holtskog and Martinsen, 2012). The basis for extension are also incremental innovations (Dewar and Duttton 1986). These include line extensions (product line extensions) and special variants for applications or target groups with special requirements.

By contrast, a product being replaced by a fundamentally new one is called **generational change**, which aims to maintain the medium-term competitiveness of the product line and provide a basis for expansions (Dewar and Duttton 1986). Radical innovation as well as incremental innovation play important roles, because they are often accompanied by the introduction of a new technology (Ringen Holtskog and Martinsen, 2012).By continuing an existing product on the one hand, but also including new technologies on the other, generational change lies between exploitation and exploration.

A completely new product that is not significantly derived from existing products, and therefore an explorative innovation, is called **a market novelty** (Dewar and Duttton, 1986), the goal of which is to occupy new markets or technologies to secure long-term competitiveness and growth opportunities (Ringen Holtskog and Martinsen, 2012). By attempting to gain a foothold in a new market for the offering company, it can be considered purely exploratory. The market novelty is a new solution for which the company has to rebuild technological competencies and market presence by introducing radical innovations (Varis and Littunen, 2010). Because of this, uncertainty is highest in this type of innovation.

All four aspects influence the patent structure of companies and the whole industry, by dividing innovations into incremental and radical or explorative and exploitative patents.

3.3.1.1.Method: Patent Analysis

The knowledge stored in patents can be used by anyone, directly or indirectly, depending on the respective legal status. Patents are readily available through many databases, as well as defined, classified, and largely tagged. Patents are one of the most cost-effective information sources for innovation management (Ernst, 1996). Patent analysis is the study of technology output using patent documents (Song, 2016).The objective of the patent system is to promote technical innovation, disseminate information and increase technology transfer. The legal framework of the patent system is the Patent Law (PatG; Patentgesetz, 1936). A patent holder is given a state-guaranteed right to dispose of the invention exclusively for a certain period of time and exclude others from commercial use, because a patent makes it possible to protect technical inventions that are new to the world, that are based on inventive step, and are industrially applicable. Patents may in principle be granted for inventions from all areas of technology, but they are limited in their effect, in space, by the territory for which it is granted, and in force in terms of its duration (normally 20 years with the extension possibility of 5 years) (Kastner 2011).

The aim of the following patent analysis is to present the macroscopic (i.e., the general trend) in the automotive industry concerning the compatibility of lean and innovation, and specifically combustion drive strain versus electric drive strain in the technology sector.

As in prior literature, the same logic is used in the patent data to differentiate between exploitative and explorative innovation (He and Wong 2004; Phelps, 2010). If patents cite no other patents in their patent application, the patent can be defined as an explorative innovation because the company is not building on prior existing technology and thus exploring new methods/products/technologies (He and Wong 2004).

Explorative Patents: Citing no other patent

$$\frac{\text{total new citations}}{\text{total all citations}}$$

If patents cite other patents in their patent application, the patent can be defined as an exploitative innovation because the company is building on prior existing technology and thus exploiting old methods/products/technologies (Phelps, 2010). Moreover, the number of citations is a valuable quality measure. If a patent specification (or publications of the author) is cited more frequently, the patent is likely to be of higher importance than a patent specification that is not or hardly cited (Kastner, 2011).

Exploitative Patents: Citing one or more other patent

$$\frac{\text{count of repeated citations}}{\text{total all citations}}$$

It should be noted that the following quantitative patent analysis aims only to give an overview and is not a detailed analysis of the whole automotive industry or the individual companies, since this can just be done by an additional qualitative analysis for certain patents. This overview serves to frame the necessary background information regarding explorative and exploitative strategies in the automotive industry and to provide an answer, if the described framework is a possible model.

3.3.1.2.Dataset Patent Analysis

For generation of the data, the OECD, REGPAT database, February 2016 (no update available) as well as the OECD Citations database, September 2016, was used. The International Patent Classification (IPC) categorises patents into different classes. Each patent is classified in one of 70,000 technical breakdowns (Slaby, 2005).

There are the following eight sections according to (Slaby, 2005):

- Section A - Daily necessities of life
- Section B - Working procedure, Transporting
- Section C - Chemistry, Metallurgy
- Section D - Textiles, Paper
- Section E - Construction, Mining
- Section F - Mechanical Engineering
- Section G - Physics
- Section H - Electrical Engineering

Especially for the drive strain patent analysis, Sections F and H are important in the following analysis (for detailed information on the classification see appendix data categorization patent application combustion and electric drive strain p.164)

The companies were identified on the basis of market and technology studies, association publications, specialist congress and meeting information, and company publications. The classification of companies into their parent companies was made according to participation shares, with 50% subordinated (aggregation) and, in the case of joint ventures with a 50% share, each partner being assigned twice. (See Cainarca et al., 1992, p 48; Knappe, 2014, p.236)

The dataset consisted of 15 companies (see Figure 12). The following is an example based on Knappe (2014):

Company	Consisting if named companies in the data base
Bayerische Motoren Werke AG	bayerische motor, bmw, rolls royce motors car, rolls-royce motor car, designworks, mitech mikroelektronik, apd industries, swindon pressings, riley motors, triumph motor, husqvarna motor, au-tomag, bpf midrand property, multisource properties, alphabet

Table 1: Example BMW AG (based on Knappe [2014]).

The main focus of patent application of all 15 companies laid in the following areas:

Category	Patents	%
Transport	61446	31,0
Engines, pumps, turbines	40540	20,4
Mechanical elements	21059	10,6
Electrical machinery, apparatus, energy	17152	8,6
Environmental technology	12619	6,4
Measurement instruments	6619	3,3

Table 2: Amount of patents per category.

The category **engines, pumps, and turbines** was chosen for the data analysis, because this area is undergoing one of the most vital transformation processes in the automotive industry. On the one hand, the combustion engine still has potential in terms of emissions and efficiency that must be improved, possibly also in combination with innovative renewable fuels (e.g., synthetically produced gas, Power to Liquid). Recent research into the reduction of nitrogen oxides in the operation of combustion engines has shown values in laboratory conditions that have the potential to compete with alternative drive technologies even in the longer term. However, this needs to be rapidly developed to market readiness first (vbw, 2017).

On the other hand, electro mobility (in the sense of battery electric vehicles) is certainly the technology of the future for motorised individual transport, despite the challenges that still exist today, such as costs, range, and fast-charging capability. It is logical to focus on electro mobility for the most suitable modes of transport (e.g., urban transport, fleet applications, industrial trucks), as the vast majority of German and international manufacturers already do (vbm, 2017). Thus, the automotive industry is confronted with major developments that have considerable disruptive potential, make great demands on their ability to innovate and display all categories from improvement to extension over generational change to market novelty. As shown in figure 12, especially in the area of the drive strain (electric and combustion), the application of patents is wave-shaped. The shape almost resembles a tadpole. The graph shows the development of drive strain applications from 1978 until today. The figures in the graph refer to the different companies that were chosen for the analysis. Patent application per company is presented in the form of columns.

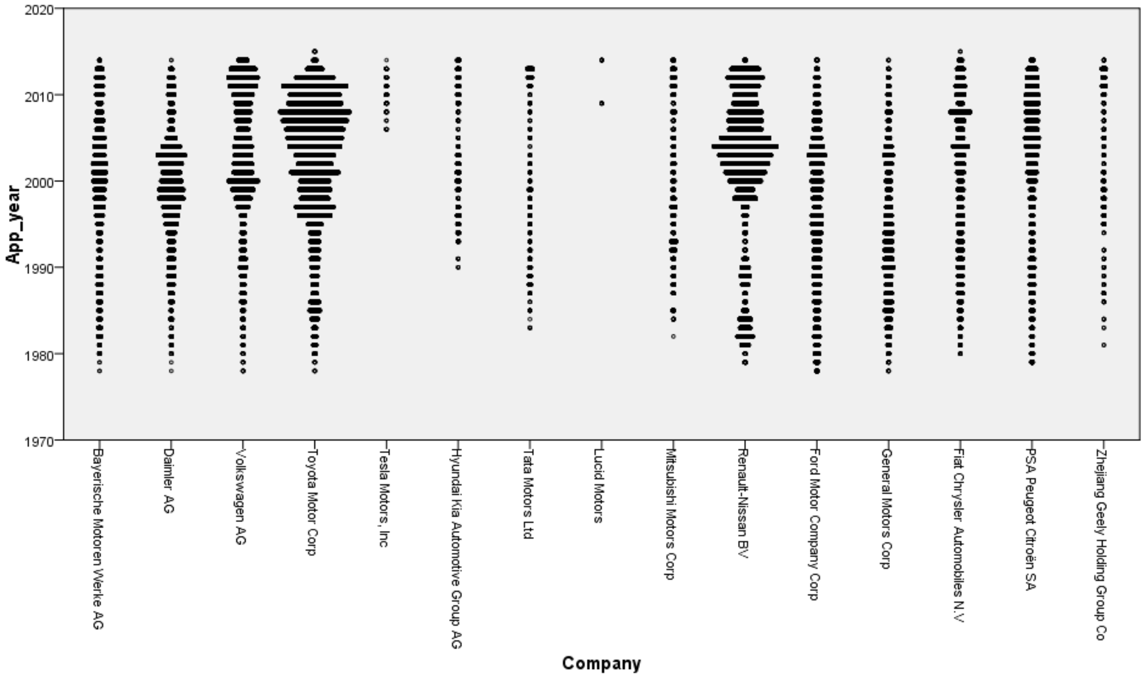

Figure 12: Patents drive strain (Electric H01/H02 + Combustion F01/F02).

The narrowing from the beginning of 2012 onwards can be attributed to the duration a patent application needs, whereas the sharp break of the German OEMs between 2006 and 2010 reflects the impacts of the financial crisis in the automotive industry. Patent applications increased from 1979 until 2007/2008, decreased during the financial crises, and have increased again since 2010. It can be assumed that strong jumps in the registration statistics often indicate radical changes in the general conditions or the environment (Glazier, 1995).The automotive industry was in its greatest crisis for years in 2007/2008. Car manufacturers worldwide were caught in the turmoil of the financial crisis, with a decrease of sales of new cars by more than between 20–49%[15]. The weak demand for new cars, the

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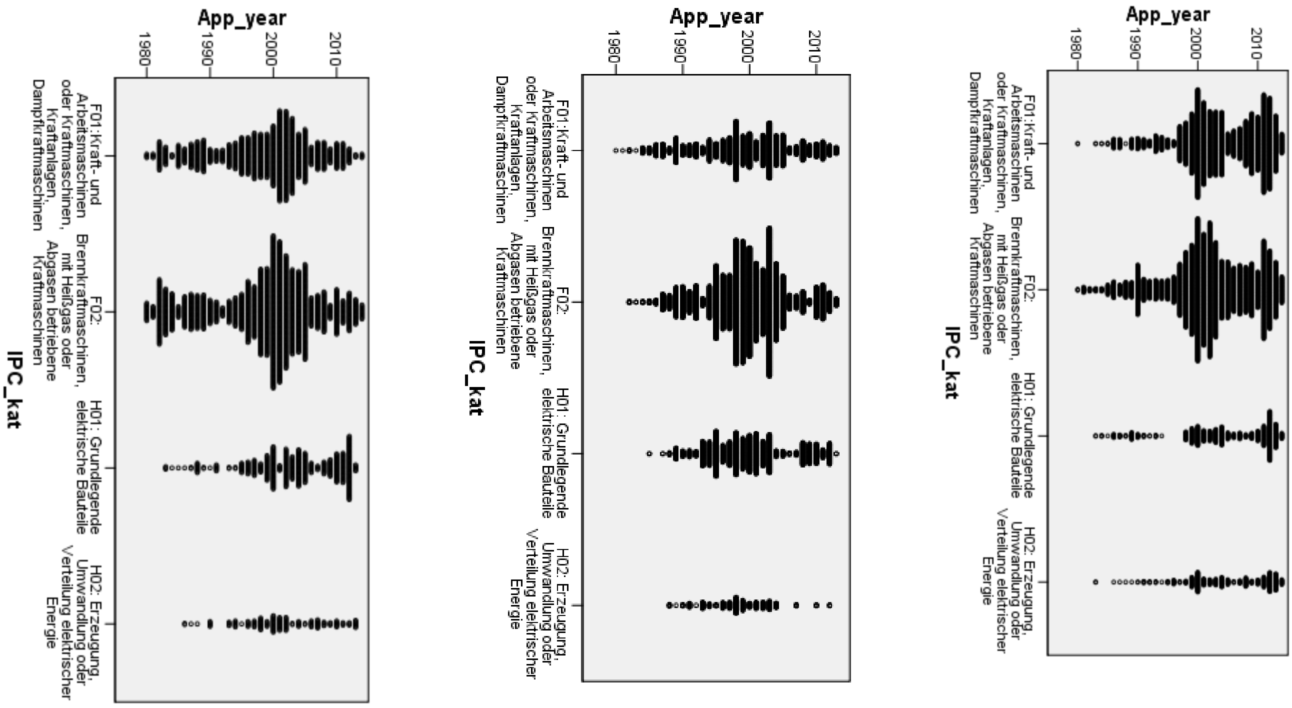
[15] BMW: 24% less than in 2007
Vokswagen: 20% less than in 2007
Volvo: 33% less than in 2007 (http://www.fr.de/wirtschaft/automobilindustrie-krise-von-audi-bis-vw-a-1133410)

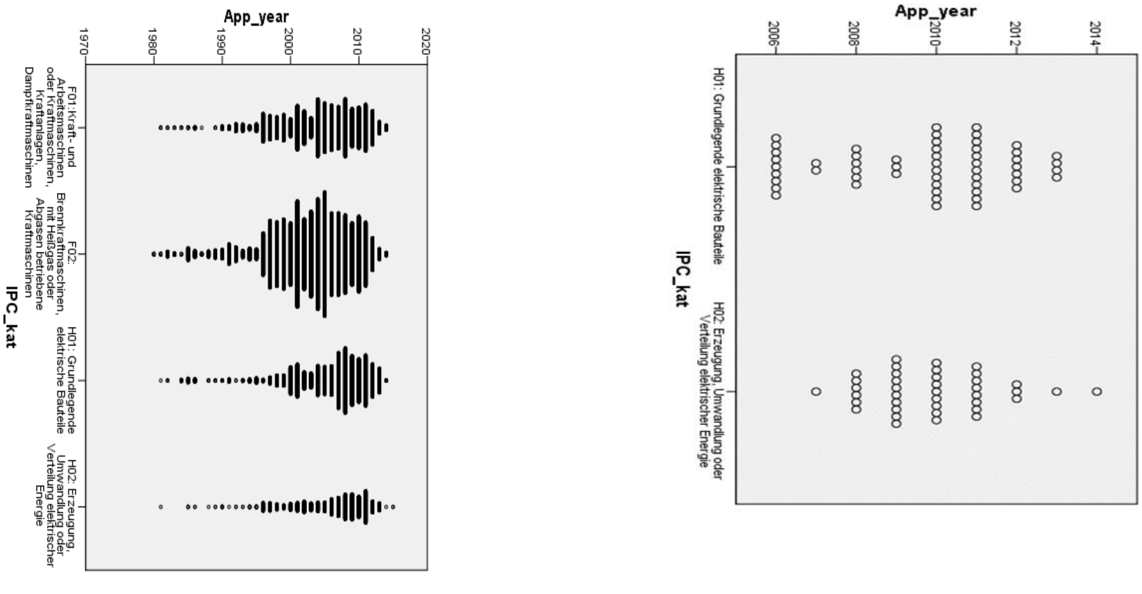
internationally increasing wage competition, as well as the growing interest in cheap vehicle segments, indicated these radical changes in the environment of car manufacturers (Jullien, 2010). Despite interventions such as strategic funds for endangered companies, loans and the car scrap bonus, as well as partial unemployment strategies, several problems remained and the crisis of the industry as a whole could not be solved (Jullien, 2010).However, in contrast to other industries and nations, the successful survival of the German automotive industry in these difficult times was home-made. It was the result of a long and rather tedious learning process initiated more than 20 years ago in the ‘Japanese challenge’ (Ouchi, 1981). It has been provoking a series of lessons since the 1980s that have benefited the country to this day. The key principles of lean management to produce faster, cheaper, and more flexibly than ever before, based on the analysis of the entire added process chain, was one of the biggest reasons for the successful mastering of the crises. Taking a more detailed look at the patent applications of BMW AG, Daimler AG, VW AG, and Toyota Motor Corp, the findings of the increasing number of applications from 1979 until 2007/2008, the decreasing number of applications during the financial crises, and then the increase again since 2010 were consistent. Interestingly, it can be seen that they are not only consistent for the combustion engine but also for electric engine applications. The tadpole shape appears in both categories. Figure 13 presents the development of the combustion end electric drive strain. Following the IPC classification, the categories F01 (=MACHINES OR ENGINES IN GENERAL; ENGINE PLANTS IN GENERAL; STEAM ENGINES) and F02 (=COMBUSTION ENGINES; HOT-GAS OR COMBUSTION-PRODUCT ENGINE PLANTS) display combustion engine applications and H01 (=BASIC ELECTRIC ELEMENTS) and H02 (=GENERATION, CONVERSION, OR DISTRIBUTION OF ELECTRIC POWER) represent electric engine applications.



BMW AG

Daimler AG

VW AG



Toyota Motor Corp

Tesla

Figure 13: Patents drive strain (Electric H01/H02 + Combustion F01/F02) for five OEMs.

As already discussed, strong jumps in the registration statistics often indicate radical changes in the general conditions or the environment (Glazier, 1995). However, keeping the evolutionary aspects of product and technology lifecycles in mind, one explanation is that the wave-like behaviour of the application resembles the shift from product innovation to process innovation. Looking closer at the industry life cycle, an additional explanation is that the technological regime is changing probably to the detriment of new companies. Skills acquired in the marketplace are becoming more important in exploiting technological opportunities and appropriating profits from innovation efforts. However, this does not mean that the technological possibilities or conditions of appropriation deteriorate in absolute terms, rather established companies with accumulated technological knowledge are favoured over new companies.

To obtain a deeper understanding of the innovation behaviour over time and the influence of lifecycles on this evolution/development, explorative and exploitative patents citations were used as a bibliographic element for the analysis. A citation can be differentiated into backward and forward citation and is defined as a reference to a previous work (prior art) that is considered relevant to a current patent application. Backward citations are patents that are cited by a specific patent and forward citations are patents that cite a specific patent (Karki, 1997).

The citation analysis proved to be relatively simple in terms of processing because of the unified structure and the distribution in backward and forward citations. Citation analysis enables capturing of the bibliographic coupling of patent documents and provides a basis for technology convergence. Thus, the analysis of backward and forward citations can analyse how different technologies are cited more frequently over time (Choi and Park, 2009; Karvonen und Kässi, 2013; Sung et al. 2013).A reason why Coca Cola has never patented its formula is that a patent application implies that the invention will be published. If the invention is a process that is difficult to reconstruct, it is more reasonable to keep it secret. Therefore, especially when looking at process innovation, it must be kept in mind that many successful inventions have not been patented (Moser 2012).

3.3.1.3.Results: Patent Analysis

An average of only 10% of all patents are explorative innovations (citing no other patents).It can be seen that the absolute number of zero citations differs greatly (0-3111). This is due to the size of the company as well as the number of total registered patents per company.

	Bayerische Motoren Werke AG	Daimler AG	Volkswagen AG	Toyota Motor Corp	Tesla Motors, Inc	Hyundai Kia Automotive Group	Tata Motors Ltd	Lucid Motors	Mitsubishi Motors Corp	Renault-Nissan BV	Ford Motor Company Corp	General Motors Corp	Fiat Chrysler Automobiles N.V	PSA Peugeot Citroën SA	Zhejiang Geely Holding Group	Total
Zero Citations	514	1264	1209	3111	4	22	53	0	28	1763	280	105	165	628	58	9204

Table 3: Zero citations: Overall patent citations (Dataset: citing/forward) (all 15 companies).

As shown in figure 14, the total patent stock for citing of patents is wave-shaped as well. The shape almost resembles a tadpole. The graph shows the overall patent citations from zero to 30. The figures in the graph refer to the different companies that were chosen for the analysis. Patent citations per company are presented in the form of columns. Interestingly, however, the structures of the individual companies do not differ from each other here, but in all graphs the tadpole structure is found. This suggests that although the absolute number differs, the innovation strategies as well as the balance between exploration and exploitation are similar.

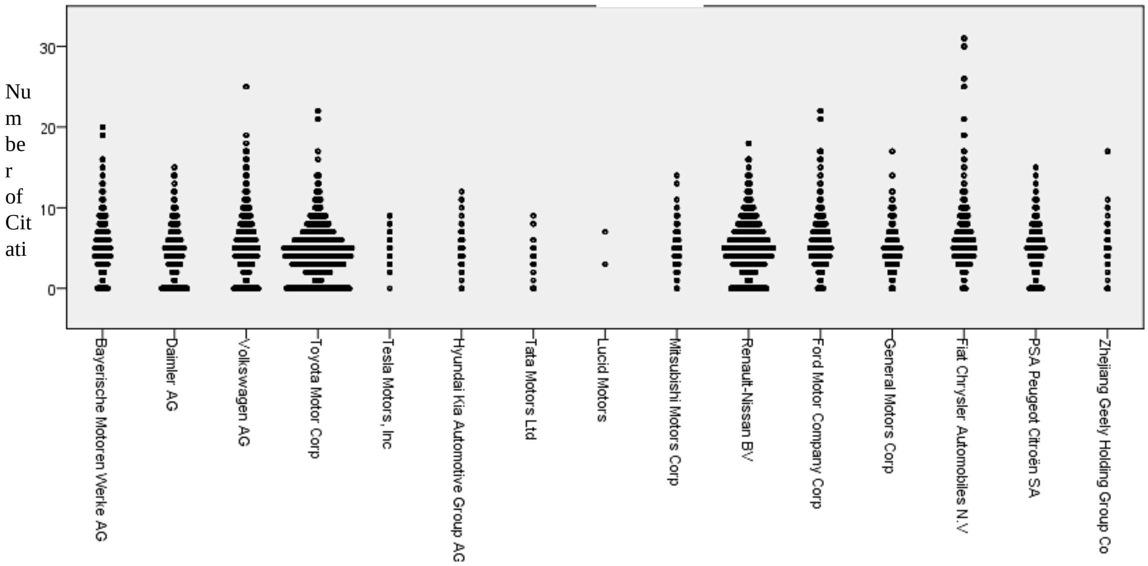


Figure 14: Overall patent citations (Dataset: citing/forward) (all 15 companies).

Picking five companies for a more detailed analysis shows that the percentage range of explorative innovations lies between 5–25% for BMW AG, Daimler AG, VW AG, Toyota Motor Corp. and Tesla (Figure 15).

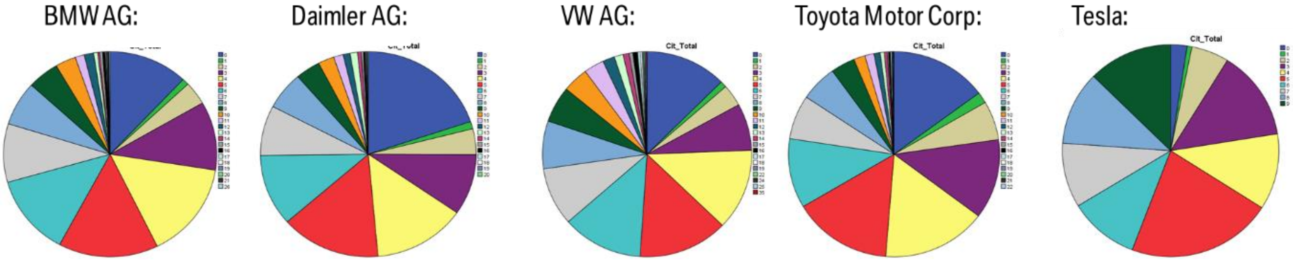


Figure 15: Patent citations (five companies).

Due to the size and colour of the representation of the sectors, the pie chart shows very clearly the percentage of zero patent citations in the total patent stock of the companies. The large proportion of patents cites three to six other patents. This resembles over 50% of the patent stock of all five manufacturers.

As shown in figures 16 and 17, the findings for drive strain patents are consistent with the overall picture. An average of 10% are explorative innovations looking at the patents registered in the combustion technology area, whereas an average of 15% are explorative innovations looking at the patents registered in the electric technology area.

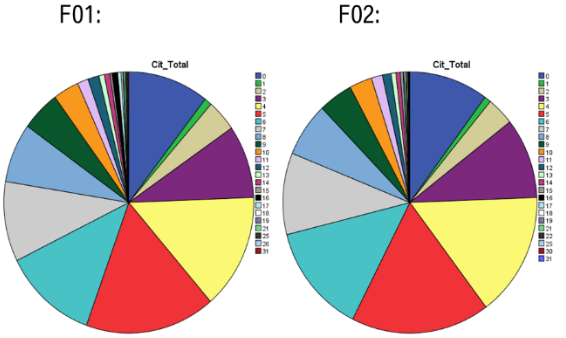


Figure 16: Patents combustion (all 15 companies).

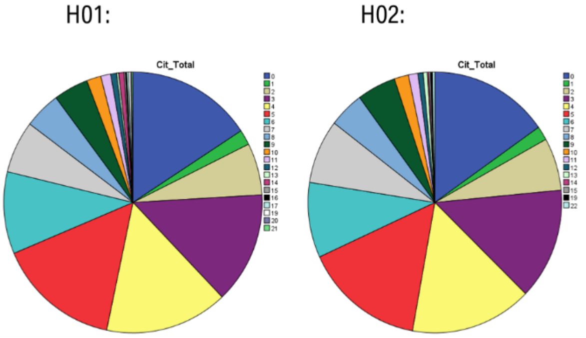


Figure 17: Patents electric (all 15 companies).

Moreover, when examining the five companies in detail, the findings for drive strain patents differentiated between combustion and electric are consistent with the overall picture. It can be seen that even more innovative competencies and exploration strategies are necessary in the research field of electric engines, whereas exhausting the existing technology seems to be the order of the day in the research fields of the combustion engine (Figure 18).

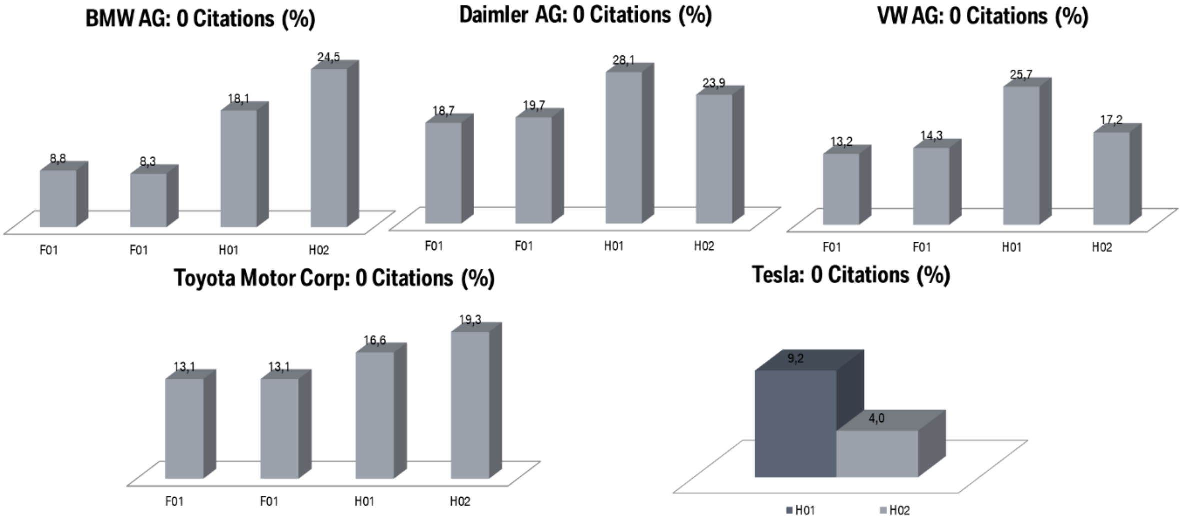


Figure 18: Patents combustion and electric (five chosen companies).

A reason could be that the technology of an electric car and its construction is less complex and does not require as many parts as a combustion engine. There is no need for exhausting the existing technology but a greater need for creating new technology. Furthermore, the production of electric motors will be easier for car manufacturers in the future, and thus less personnel-intensive. Production process innovation at an incremental level is exhausted faster for the electric engine than for the combustion engine due to lower complexity. The added value of an electric motor does not even reach 50% of a combustion engine. Therefore, complexity at the product and production process levels (described in Section 2.4) decreases, which is also positively influenced by the smaller size of electric engines as well as them requiring fewer materials and less maintenance. Furthermore, with reducing complexity, the technology and product lifecycle are influenced positively by OEMs. Moreover, the consumption of tyres should be lower as well because the aftersales processes are becoming less personnel-intensive and complex (Tolefson, 2008; Larminie and Lowry, 2003).

Certainly until today, the most serious disadvantage and the biggest potential for innovation is the low energy density of the batteries. It is only 1/50 to 1/100 of a gasoline filled tank. This displays two great potentials for innovation: the first is the weight of batteries and the second is the infrastructure required for long distance travel. Electric vehicles are not lighter than corresponding vehicles with an internal combustion engine because the weight of the batteries remains high. Battery capacity is a defining factor in vehicle weight and price (Larminie and Lowry, 2003).A short charging time to fill the energy storage—for example, an 80% charge of the batteries within 30 minutes—can only be achieved with high-performance DC charging stations. The previously insufficient and inconsistent expansion of the charging infrastructure prevents large numbers (Amirault et al. 2009). Thus, the question arises of whether there are differences or time-specific correlations when looking at the patent structure of the combustion engine and the electric engine according to their development.

Figure 19–Figure 23 show the number of patent citations over time (forward and backward). The tadpole structure becomes apparent here, but mainly between 1990 and 2010 for citing publication dates and from 2000 to 2015 for cited publication dates. Moreover, the results reach the limits of citation analysis (Tijssen and van Raan 1994).

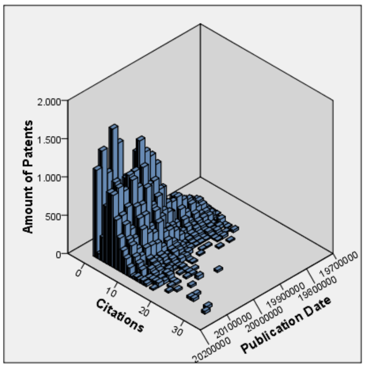


Figure 19: Drive strain citing publication date.

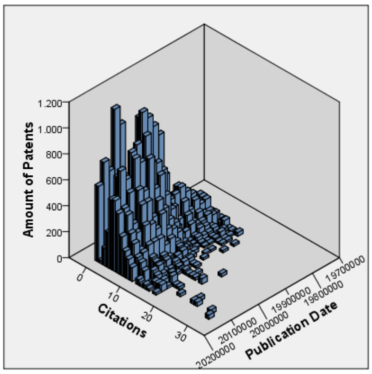


Figure 20: Combustion citing publication date.

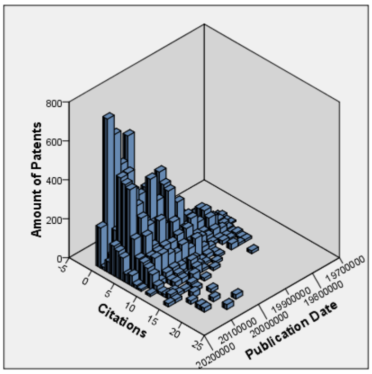


Figure 21: Electro citing publication date.

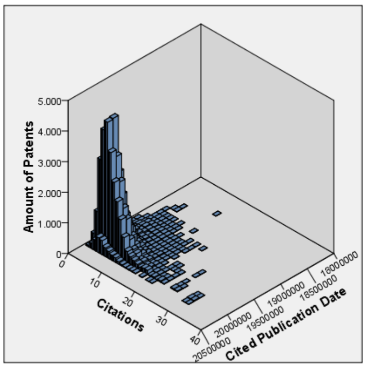


Figure 22: Drive train cited publication date.

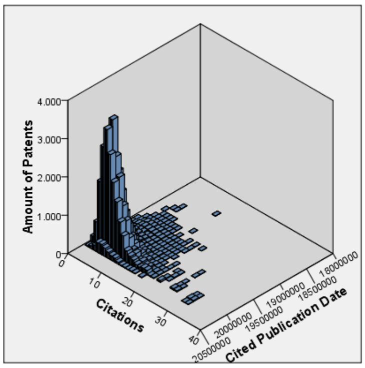


Figure 23: Combustion cited publication date.

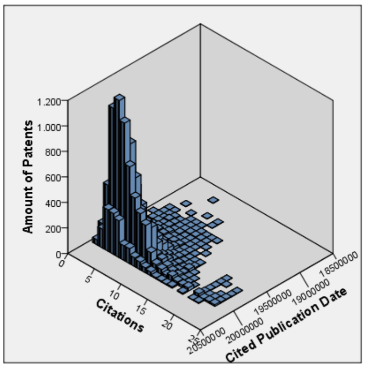


Figure 24: Electro cited publication date.

While forward citations usually occur with a time lag (older patents have more citations than younger ones; Lee et al., 2011), in backward citations different patent examiners can often cite different patents against the same invention (Wertburg et al., 2005; Gerken et al. 2010, Gerken and Möhrle, 2012). Furthermore, a correlation can be observed between the total amount of citing and the citing publication date and no correlation between the total citing and the cited publication date (Table 4). This means the newer the citing publication date, the higher the amount of total citations. However, the time lag of forward citations results in a bias in technologies with short lifecycles (Dahlin and Behrens, 2005).

		Cit_Total	Citing_pub_date	Cited_pub_date
Cit_Total	CorrelationPearson	1	-,059**	-,003
	Significance (2-seitig)		,000	,386
	N	78304	78304	69059
Citing_pub_date	Correlation Pearson	-,059**	1	,622**
	Significance (2-seitig)	,000		,000
	N	78304	78304	69059
Cited_pub_date	CorrelationPearson	-,003	,622**	1
	Significance (2-seitig)	,386	,000	
	N	69059	69059	69059

**Significance p=0,01

Table 4: Correlation between citing publication date, cited publication date, and citing total.

To summarise a holistic picture, patent applications increased from 1979 until 2007/2008, decreased during the financial crises, and have been increasing again since 2010. Companies have applied for more patents in the field of H01/H02 (electrical drive strain) from 2010 onwards because of the innovation potential in battery technology and charging infrastructure. An average of only 10% of all patents are explorative innovations. The percentage of explorative innovations of the electrical drive strain (15%) is 5% higher than the percentage of explorative innovations of the combustion drive strain (10%).It is crucial to establish a form of innovation that suits the respective area and topic, but also to the own organisational culture. It seems that the automakers with the 90–10 / 85–15 approach have found a balance between radical and incremental innovation, and thus are lean and agile, which also seems to blend in with their corporate culture, leadership, and other industry-specific challenges.

However, the most significant disadvantages of patent information are certainly the priority period, which is 12 months in Germany, and thus predates the ‘state-of-the-art’ that can be researched today to 18 months as a rule (Schmoch, 1999). In addition, it can be observed that German companies compared with US companies, for example, engage in less patenting activities, which can lead to information distortion (Schmoch, 1999). Submissions to the European Patent Office (EPO) reached a new high, rising by 1.6% to 279,000 in 2015 (2014: 274,000). (EPO, 2015). According to António Campinos (EPO President) in 2018 the overall growth in applications from EPO member states was the highest since 2010 (3.8%). The largest number of patent applications, in which there was significant growth, was received in the three areas in 2018: medical technology, digital communication and computer technology (EPO, 2018).

In contrast, in the field of combustion engines, the DPMA reported a slight decrease of newly registered patents in 2018, for the first time since 2013, by 1.4% compared with the previous year. However, the number of applications from Germany and Korea increased by 15% and 23%, respectively. Overall, registrations from abroad in the area of combustion engines only accounted for 50.3%. In 2017 it was still around 57% (DPMA, 2018).

Furthermore the 90–10 / 85–15 approach has its own limitations, as the citing of a patent can be performed by the patent applicant as well as the patent officer. During the patent examination it is determined whether there are material protection requirements and citations also can be made in this procedure by the patent officer. (DPMA, 2021) Therefore it is possible that the real amount of explorative patents is higher and the 10-15% is an underestimation.

Nevertheless, following Campinos opinion, the importance and growth of patent applications is seen as an ultimate contribute to economic performance. When more inventions could come into market to improve our daily lives (based on increasing patent applications), a positive influence on innovation an economic performance can be achieved. According to the figures, 2018 was another growth year for patent applications - for the EPO member states, China, the United States and many other regions and countries. (EPO, 2018)

The following question remains: what influence does this have for the production system of the companies?

3.3.2. Influence on and of a Lean Production System of OEMs

Many companies have already established a highly advanced lean production system and are slowly reaching the limits of improvement. In the 1990s, automotive OEMs and their suppliers made their first steps in topics such as 5S, quick setup, Kanban, and group work (Womak and Jones, 2003).The present study conducted a regression analysis, which is presented in the following subsection, to create a deeper understanding of the ambidexterity (explorative strategies and exploitative strategies) and the effect on models, profit, and employees in the future from 2005 to 2015.

3.3.2.1.Regression Analysis

The Quotients of Pexplor and Pexploiare displayed as the independent variables (y) and the parameters other than x. Then, this study measure the influence of the quotient on the dependent variables profit, models, and number of employees.

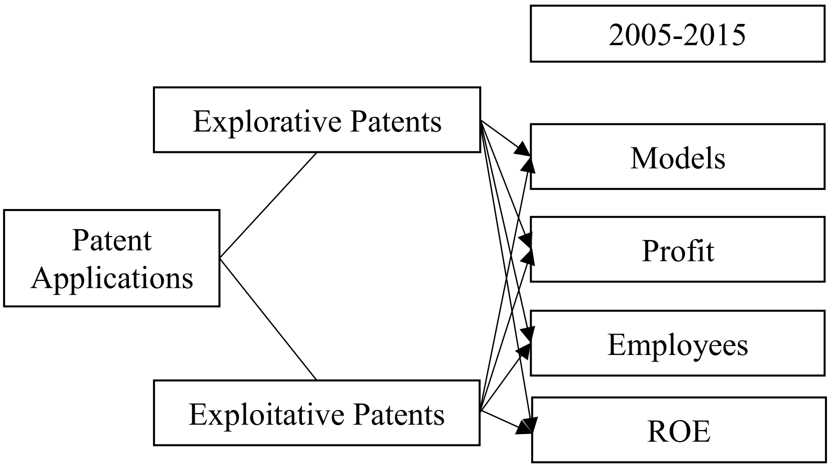


Figure 25: Model regression analysis.

3.3.2.2.Dataset Regression Analysis

To generate the data, the OECD, REGPAT database, February 2016 (no update available) as well as the OECD Citations database, September 2016, were used, as in the patent analysis before. Companies with a shareholding of more than 50% were included in the analysis. In addition, company homepages, annual reports, annual accounts, as well as the Statista database accessed through the University of Hohenheim were used for the analysis. The dataset consisted of 15 companies. The analysis concentrated on a time span of 15 years divided into three 5-year time spans based on the fact that in the automotive industry, model generations change every four to seven years depending on the manufacturer. For example, in the automotive industry of the 1980s, the average length of the product life cycle was 7 years; Japanese automakers replaced their models on average after 4.6 years, American manufacturers after 8.1 years, and European manufacturers only after 12.2 years (Womack, Jones and Roos 1991, p. 125; Clark and Fujimoto 1992, p. 95).

3.3.2.3.Results Regression Analysis

Descriptive results:

The analysis referred to the years 2005–2015. The development of exploratory and exploitative patent applications per employee was divided into annual slices. There wasa significant decrease in the number of explorative patent applications per employee for 90% of the analysed companies. Only at two companies (Peugeot Citroen and Tata) did the number of explorative patent applications per employee increase until 2011 and steadily decrease until 2016 (Figure 26 and Figure 27).

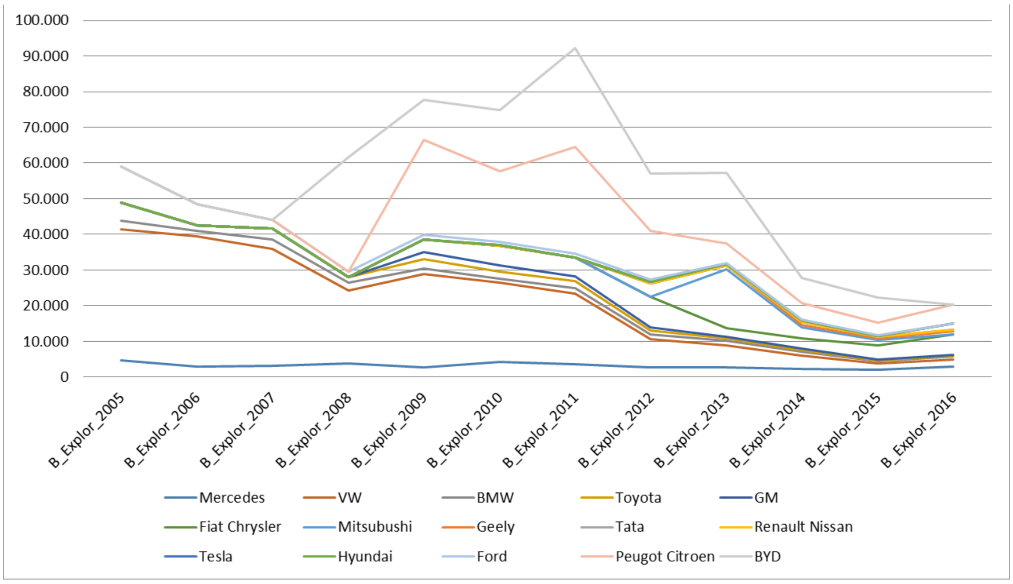


Figure 26: Explorative patents per employee.

In contrast to the explorative patent applications per employee, there was a slight increase from 2005 to 2015 in the filing of exploitative patents. Again, outbreaks for BYD and Peugeot Citroen from 2008 to 2012/13 could be seen.

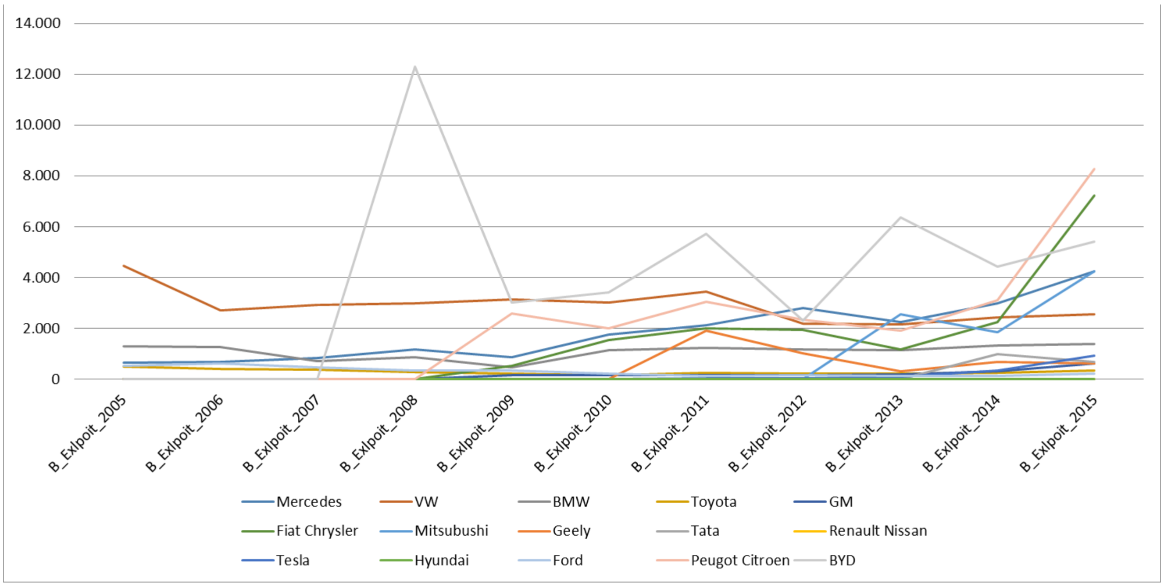


Figure 27: Exploitative patents per employee.

The analysis for explorative and exploitative patent applications per model referred to the years 2005–2015. The development of exploratory and exploitative patent applications per product was divided into five-year time periods, because the R&D of new cars takes five years (Warsen and Krinke 2013). From 2005 to 2010, there was a slight increase in exploratory patent applications. From 2010 to 2015, however, the registration curve increased exponentially (Figure 28).

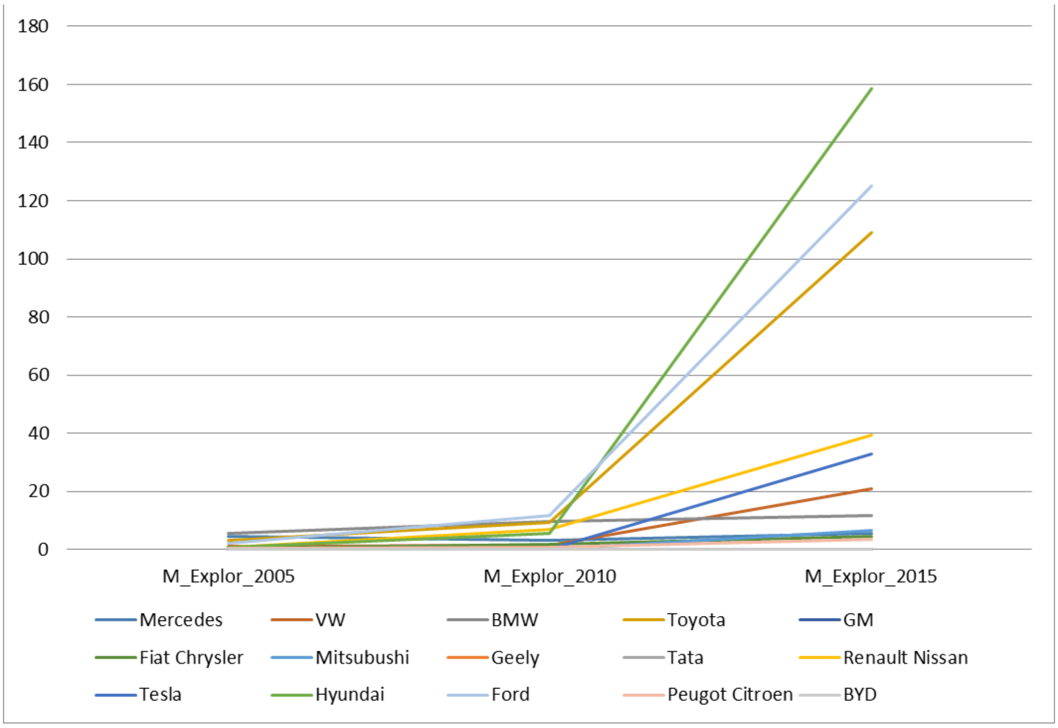


Figure 28: Explorative Patents per model / product.

In contrast to the explorative patent applications per product, there was a slight decrease from 2005 to 2010 in the filing of exploitative patents for 50% of the analysed companies and an increase for the other 50% (Figure 29).

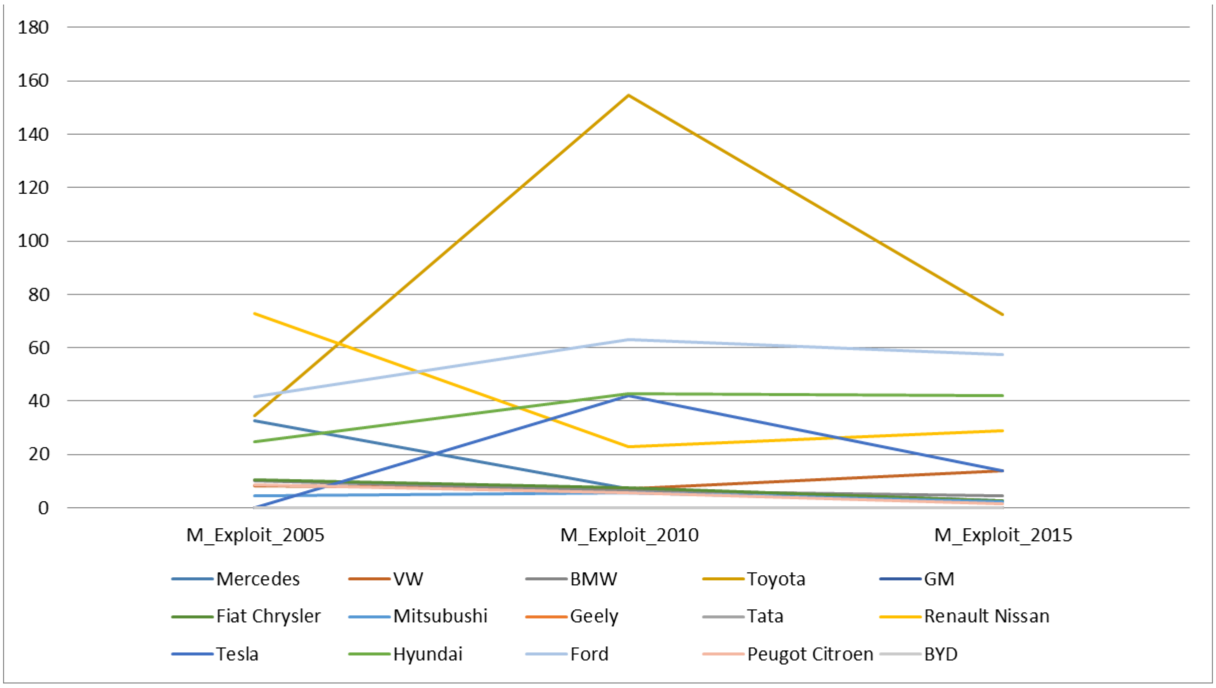


Figure 29: Exploitative patents per model / product.

Quantitative results:

Using a regression analysis, this study created a deeper understanding of the patent structure and the correlations between profit, employees, and return on equity (ROE). On the one hand, the overall model in terms of significance for the example companies was tested, reflecting how well the model set up generally fits the data structure. On the other hand, the equation for the dependent variable was analysed. For the regression analysis, four companies (Volkswagen, BMW, Toyota, and Ford) were chosen as examples to create a deeper understanding of the influence of explorative and exploitative innovations on the number of employees and amount of profit and ROE (table 5).

With the correlation coefficient r^2 the quality of polynomial regression can be judged. A value of 1 indicates that all courses are on the regression line, while a value of 0 indicates that the courses cannot be explained by the regression line. A negative regression line (trend line) stands for a falling trend and a positive regression line stands for a rising trend (Wolf and Best, 2010; Stimson, Carmines and Zeller 1978).

COMPANY	EXPLOITATIVE PATENTS	EXPLORATIVE PATENTS
VOLKSWAGEN	Employees r^2= 0.736 *t* = 5.286, *p* = .000	Employees r^2= 0.274 *t* = 1.942, *p* = .081
	Profit r^2= 0.639 *t* = 4.203, *p* = .002**	Profit r^2= 0.290 *t* = 2,022, *p* = .071
	ROE r^2= 0.159 *t* =-1.063, *p* = 0.329.	ROE r^2=0.094 *t* = 0.788, *p* =0.461
BMW	Employees r^2= 0.606 *t* =3.927 , *p* =0.003**	Employees r^2=0.273 *t* =1.940 , *p* =0.081
	Profit r^2= 0.679 *t* =4.608 , *p* =0.001**	Profit r^2=0.270 *t* = -1.925, *p* =0.083
	ROE r^2= 0.013 *t* =-0.260 , *p* =0.805	ROE r^2=0.0018 *t* =0.094 , *p* =0.929
TOYOTA	Employees r^2= 0.066 *t* =0.842 , *p* =0.419	Employees r^2=0.501 *t* = 3.167, *p* =0.01*
	Profit r^2= 0.595 *t* =-3.434 , *p* =0.009**	Profit r^2=0.543 *t* =3.080 , *p* =0.015*
	ROE r^2= 0.381 *t* =-2.483 , *p* =0.032*	ROE r^2= 0. 102 *t* = 1.068, *p* =0.311
FORD	Employees r^2= 0.344 *t* =-2.292 , *p* =0.045*	Employees r^2=0.096 *t* =-0.861 , *p* =0.409
	Profit r^2= 0.036 *t* =-0.610 , *p* =0.556	Profit r^2=0.029 *t* = 0.548, *p* =0.595
	ROE r^2= 0.666 *t* = 1.835, *p* =0.096	ROE r^2=0.155 *t* =0.211 , *p* =0.837

* Significance p=0.05; ** Significance p=0.01

Table 5: Comparison of employees, profit, and ROE between VW, BMW, Toyota, and GM.

When looking at the regression analysis including the patent application of VW, it can be seen that an r^2 =0.639 for exploitative patents and profit means that 64% of the variance in weight can be explained by the model (significance p=0.002). For employees as well as ROE, no significance can be seen concerning exploitative patents. Furthermore, there is no significant link between explorative patents, employees, profits, and ROE. Thus, it can only be said that a positive link exists between exploitative patents and profit (Figure 30).

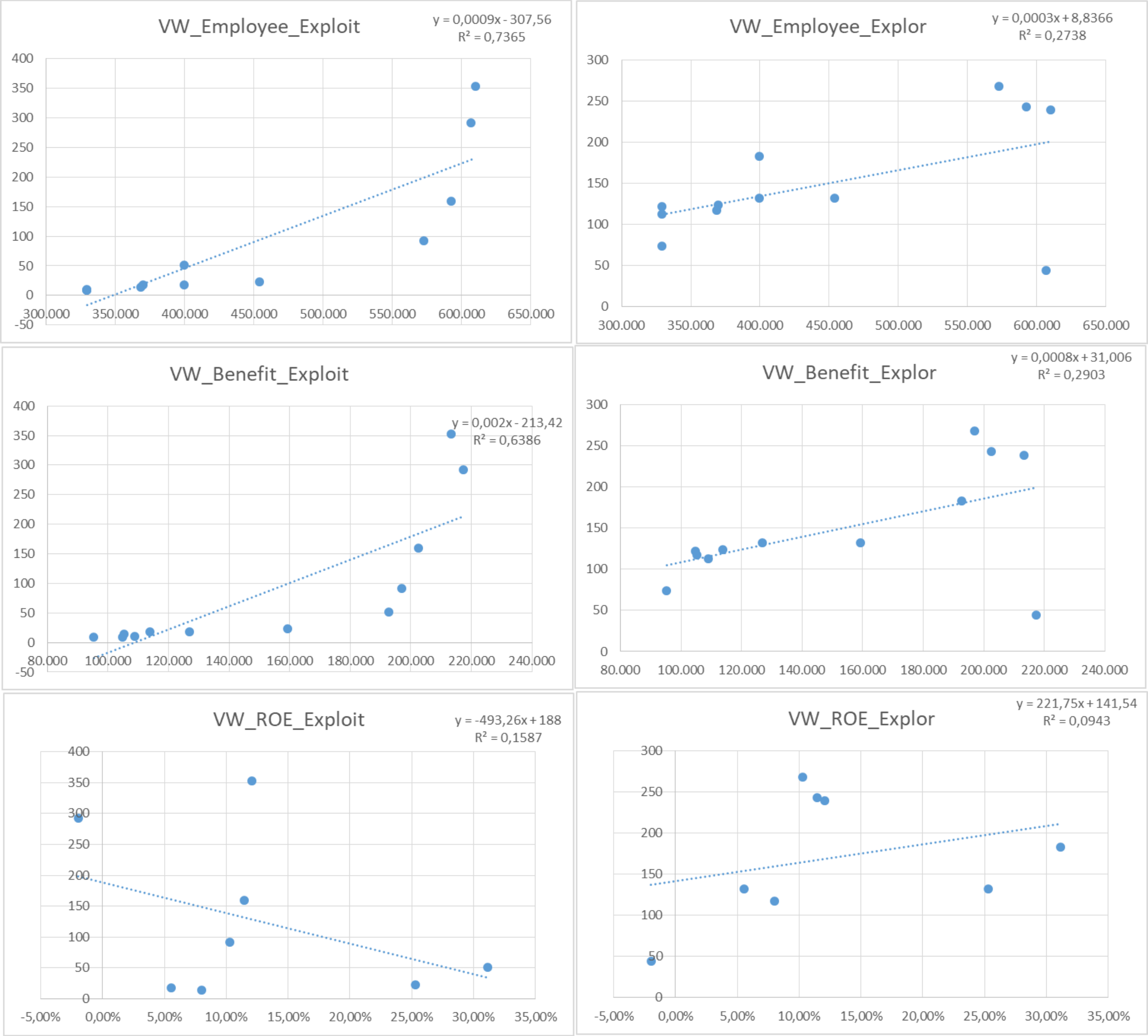


Figure 30: Regression analysis for VW—Impact of employees, profit, and ROE on exploration and exploitation.

By contrast, when looking at the regression analysis including the patent application of BMW, it can be seen that with an $r^2 = 0.73$ and 0.63 for exploitative patents and employees and profit means that 63–73% of the variance in weight can be explained by the model (significance $p=0.003$ and $p=0.001$) when looking at exploitative patents. There is a positive link between the number of employees, profits, and exploitative patents. Thus, with a rising number of exploitative patents, the number for employees as well as profit increases. However, there is no significant link between explorative patents employees, profits, and ROE (Figure 31).

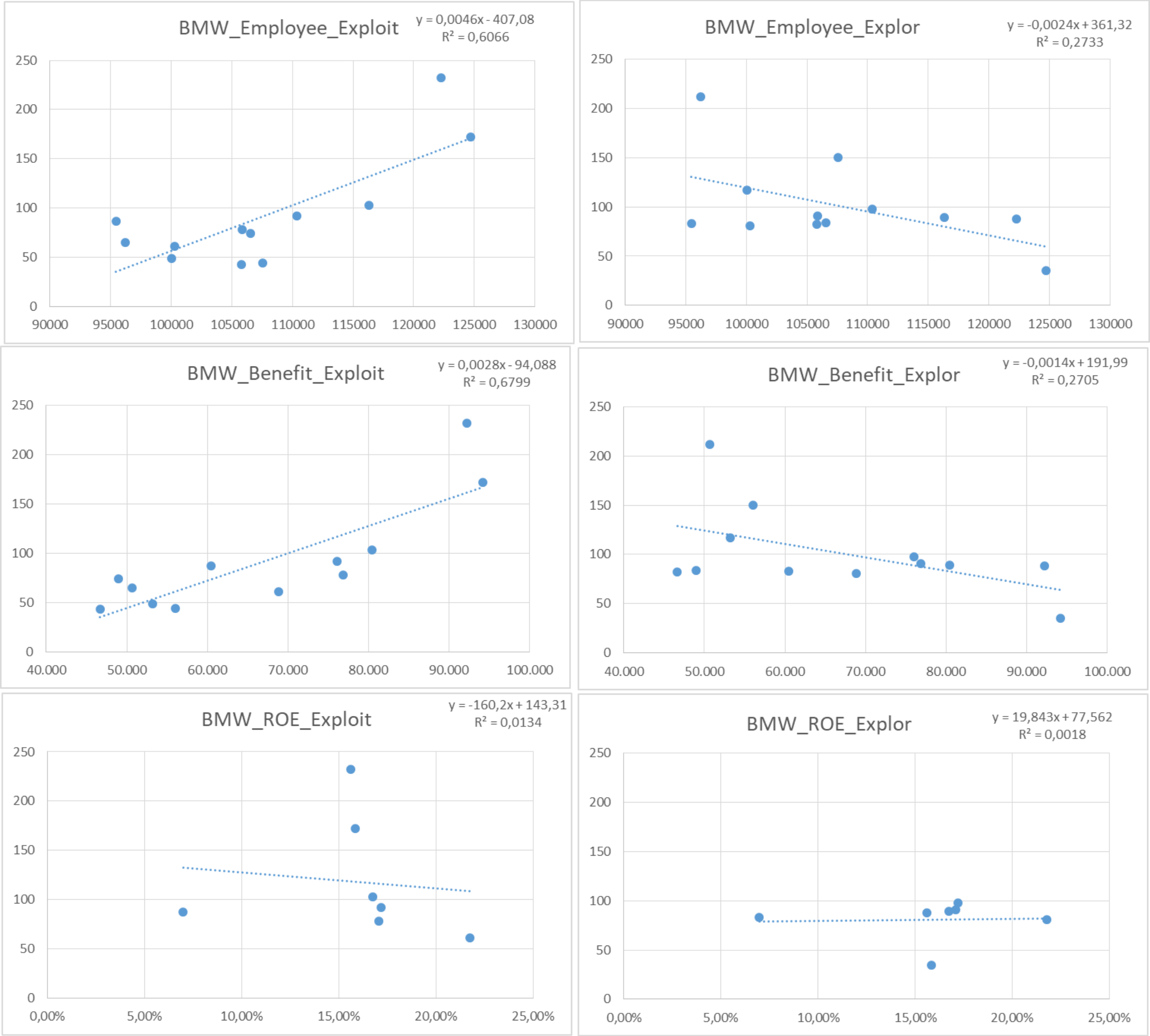


Figure 31: Regression analysis for BMW—Impact of employees, profit, and ROE on exploration and exploitation.

When looking at the regression analysis including the patent applications of Toyota, it can be seen that with an r² of 0.595 for exploitative patents means that 60% of the variance in weight can be explained by the model (significance p=0.009) when looking at exploitative patents and profit, and an r² of 0.50–0.54 means that 50–54%of the variance in weight can be explained by the model when looking at explorative patents (significance p=0.01 and p=0.015). Therefore, there is a positive link between profit, employees, and explorative patents as well as between profit and exploitative patents, and number of employees and profit. However, no significant link can be observed between exploitative patents and employees as well as ROE. Thus, with a rising number of exploitative and explorative patents, the profit increases. In addition, with a rising amount of explorative patents, the number of employees increases as well (Figure 32).

Figure 32: Regression analysis for Toyota—Impact of employees, profit, and ROE on exploration and exploitation.

When looking at the regression analysis including the patent applications of Ford, it can be seen that with an r² of 0.34 for exploitative patents means that 34% of the variance in weight can be explained by the model (significance p=0.045).When looking at exploitative patents and number of employees, there is a positive link between the number of exploitative patents and employees; however, no significant link exists between exploitative patents and profit and ROE. Moreover, there are also no significant links between number of employees, profit, ROE, and explorative patents. Thus, with a rising number of exploitative patients, only the number of employees increases (Figure 33).

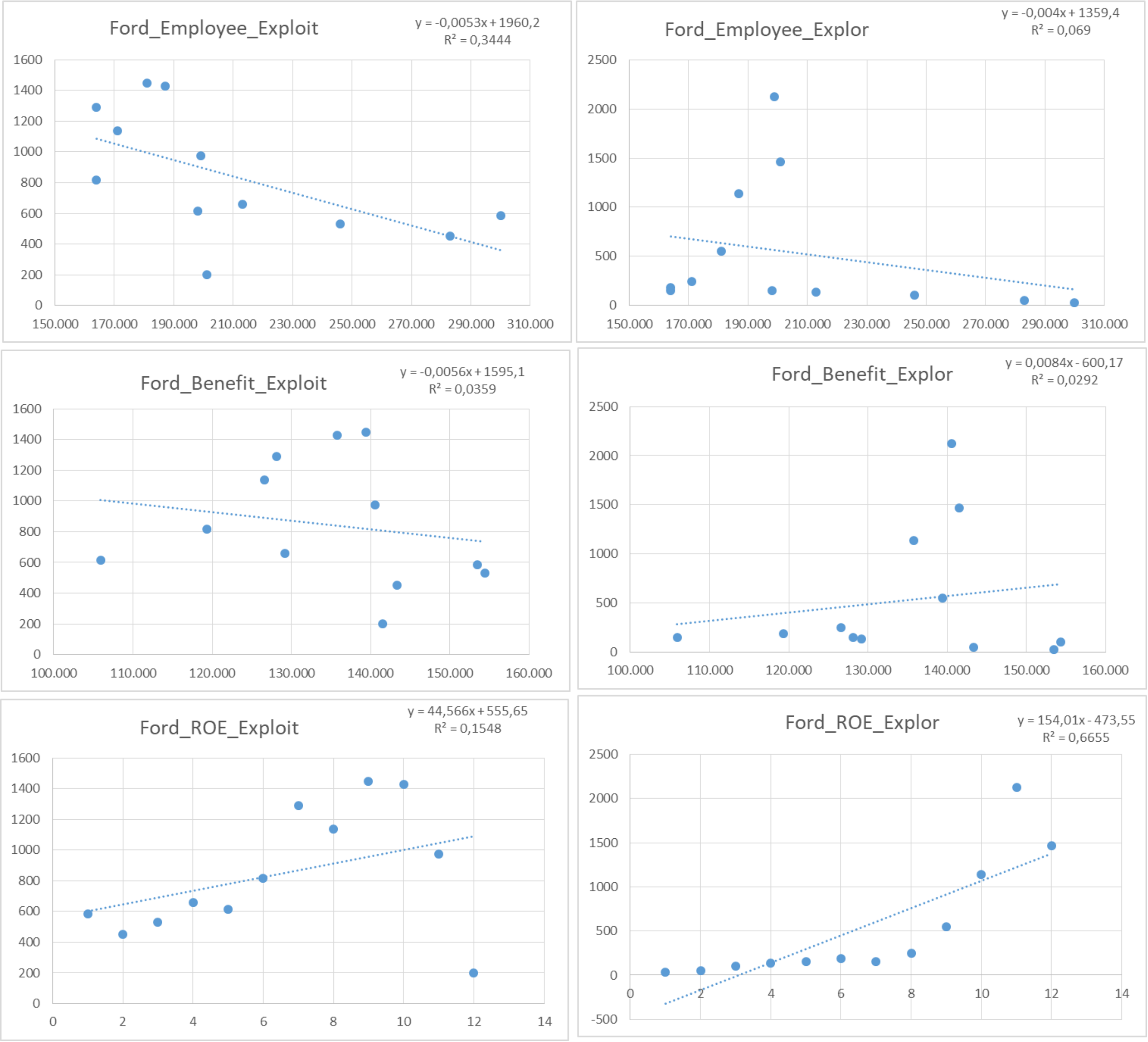


Figure 33: Regression analysis forFord—Impact of employees, profit, and ROE on exploration and exploitation.

3.4.Compatibility on a macro level—Industry development and remaining concepts

All in all, the research design investigates a multitude of questions that arise in connection with the compatibility of lean and innovation on a macro level. The combination of being agile and lean plays a key role within a lean production system and has a main influence on innovation. However, strengths as well as weaknesses can be clearly demonstrated. The patent analysis with the study of drive strain technology and technology output, an overview of the explorative and exploitative innovation strategies is given. Moreover, the objective of the patent system with promoting technical innovation, disseminating information, and increasing technology transfer is achieved, but regarding the priority period with the delay in data as well as the distortion of information regarding patent activities, weakness of the analysis remains. However, in general, industry trends can be derived. For example, no stagnant number of registrations/decline over a longer period of observation can be seen; by contrast, an increase in patent applications in the drive strain sector shows the importance and transformation challenges within this technology.

A high development potential of these technologies can be seen, which can be divided into exploration and exploitation strategies. However, with traditional thinking centred solely on immediate benefit and fear of change and failure, tomorrow’s big ideas are hard to find in today’s mainstream markets, especially in the field of drive strain technology.

In the 90–10/85–15 approach, the focus and the approach must be adapted to the current challenges, and even in the case of great uncertainty, the implementation of the ideas must not be stopped. Companies must realise that radical innovation will pay the most when the biggest uncertainty is accepted. It is a paradox that transcends classic benefit, enabling companies to change the world we live in. For the creation of this balance and the acceptance of uncertainty, the internal company structures as well as the project management strategy need to blend in. Concentrating on exploitative innovations such as improvements or extensions of existing products will ensure production costs are kept at a low level while increasing the returns on development, but without a focus on generational change and real market novelties OEMs will not be able to keep their position on the market. Therefore, it is all about keeping the balance between the ambidextrous strategies of exploration and exploitation.

As seen in the results concerning the drive strain technology, combustion and electric patents have been applied since 1978, but to force a real generational change new drive strain types such as the fuel cell and hydrogen engines must be developed. Furthermore, the infrastructure and the supplier network display great potential for innovation, attributed to the lack in flexibility of electric vehicles for long distances and the nationwide charging infrastructure.

Current political decisions and social pressure increase the need for a generational change and market novelties even more. A binding and holistic traffic concept, which takes into account ecological, economic and health criteria, is increasingly becoming the focus of social and political demands. In addition to drive strain technology, this also includes a quota for electric cars and a concrete exit date for combustion engines. Moreover, considerations must also be pushed forward, such as the technologies for storing renewable electricity (‘Power-to-X’), in particular for road freight, shipping, and air travel.

Sustainability as well as change potentials and opportunities will have a strong impact on the future of automakers and are a decisive factor in the fight for survival in the automotive markets.

The adaptability and exploration potential of companies in a situation characterised by the already named VUCA principles becomes more relevant than ever before. Strategy, organisation, cooperation, and leadership are the main areas in a company in which the right behaviour and VUCA handling are essential/critical for success. At the same time, the exploitation must not be lost sight of, by continuing to operate in good, stable, safe, simple, and unique environments. Therefore, it is essential to be able to act lean and agile at the same time, making it possible to keep the balance between exploitation and exploration. However, companies still struggle in today's application of lean approaches because of the massive barrier to the realisation of ambidexterity. An organisational cultural double bind arises, because on the one hand employees are required to organise themselves, to communicate without hierarchy, and to think creatively to realise exploration and agility, but on the other hand they are forced into the organisation with hard-hand efficiency programmes and exploitation only in the truly negative sense of the word. As a result, employees are disrupted and the organisation is paralysed. This in return leads to an increased complexity with making and optimisation approach impossible.

Thus, the meso level of the compatibility of lean and innovation plays an important role, and is thus the focus of the next chapter.

4. Compatibility of Lean and Innovations in a Company at a Meso-Level Perspective—An Integrated Framework Approach

The selection, implementation, and evaluation of innovations/innovation projects are critical factors in every company’s strategy. The key aspects, knowledge gain and prosperity increase, described already at the beginning, play a major role in the long-term success of companies. The strategic selection and evaluation of innovation and their adaptation in the production system as well as the evaluation of this adaptation process are the focus of this chapter. However, before the selection, conduction, and evaluation of innovations/innovation projects are discussed, to be able to choose the right approach (exploitation and exploration) for the project, it is necessary to understand the current situation fully. The Stacey matrix and the Cynefin framework, as described in subsection 2.4.3, are helpful decision models in companies to identify the current situation of a project landscape. Based on this addition of the theoretical framework, and therefore with knowing the importance of the situation, the focus is now how we can select and evaluate innovation/innovation projects that fit the vision and goal of the company and follow the correct path. The maturity model described in the following section allows consideration of the overall system- and target configuration in local/temporal operational decisions, and can therefore help to define the vision and goal for the project as well as the direction. Ata meso-level perspective, this fits directly into streams of aforementioned research that state getting to know the situation first is one of the most vital factors for the success of the project.

4.1.Selection and evaluation of innovation projects based on lean principles[16]

The value creation system of companies, especially within the production system of automotive companies, needs to be highly flexible and versatile due to increasing competitive pressure, growing customer demands, and rising desire for individuality in the field of product design. As a result of increasing requirements in flexibility, speed, profitability, and efficacy, the overall targets regarding costs, time, quality, and sustainability represent a key motivation not only for lean management approaches but also for Industry 4.0 approaches (Dombrowski *et al.*, 2017). Companies face the challenge of aligning their Lean and Industry 4.0 strategies and transferring respective strategy derivations into an operative level in terms of concrete concepts, methods, and technology projects. However, appropriate guidelines and models

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[16] Section 4.1. was created in coauthership by Burggräf, P., Lorber, C., Pyka, A., Wagner, J. & Weisser, T. (2020) Kaizen 4.0 towards an Integrated Framework for the Lean-Industry 4.0 Transformation. *Proceedings of the Future Technologies Conference (FTC)*, pp. 692-709.

uniting Lean and Industry 4.0 on an operative decision level are still missing. This section aims to close this gap by providing a range of contributions for the establishment of such standards. The first subsection conduces to a critical appreciation of related research as well as the definition of corresponding objectives. Maturity model creation, including evaluation criteria, is described in the second section and concludes in section four. The third section provides a procedural perspective to the field of observation. To conclude, a brief discussion and summary are given in the fifth subsection at the end of this section.

Womack and Jones (2003) defined five core principles of lean: First, the identification of the customer defined value; second, the continuous improvement of the value stream; third, the elimination of waste in order to convert the value flow smoothly; fourth, the synchronisation of information flow and customer demand to activate a demand driven pull system; and fifth, the perfection of all processes, products and services. Concentrating on these core lean principles enables manufacturing processes as well as whole organisations to achieve increasingly high levels of efficiency and to compete at a low cost level while maintaining high speed of delivery and gaining optimal quality (Rosário Cabrita et al., 2016). In order to accomplish a lean production system, lean processes need to be established. Those can be defined as ‘an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimising supplier, customer, and internal variability’(Shah and Ward, 2007). With the invention of lean production having taken place more than 50 years ago, however, it seems that the concept/management technique has reached its limit. In the future, production decoupled from market requirements will become increasingly relevant, as deviations in market requirements are already in conflict with levelled capacity utilisation (Erlach, 2013; Dickmann, 2007).

Furthermore, due to the increase of international supply chains, the environment has become increasingly complex, entailing the establishment of intelligent products and production systems (Vyatkin et al., 2007). The necessity of lean as an evolving concept was already described by Hines, Holweg, and Rich (2004). The goal of companies in the 21st century is to verify, examine, and perfect proven technologies continuously and to intelligently combine them with new methods (e.g., Industry 4.0). Industry 4.0 is a term for the increased integration of information and communication technologies with the aim to enhance and optimise value chains by implementing an autonomously controlled, dynamic production (Kolberg and Zühlke, 2015; Bitkom e.V. *et al.*, 2016). It is commonly considered to represent the fourth industrial revolution, a new level of organisation and control of the entire value chain beyond the product life cycle (Hirsch-Kreinsen, 2014). Kolberg and Zühlke (2015) suggested that the successful merging of Lean and Industry 4.0 can be achieved on four different operational levels:

Smart Operator: Reduction of time from failure occurrence to failure notification by real-time error detection and direct employee localisation through Cyber Physical Systems (CPS).

Smart Product: Collection of process data for the analysis during and after the production tailored to each product through the utilisation of sensors and CPS.

Smart Machine: Collection of process data by every machine with connectable sensors and CPS to achieve fast and flexible predictive maintenance.

Smart Planer: Decentralisation of planning processes to find the optimum between highest possible capacity utilisation per working station and continuous flow of goods, using working stations integrated in CPS to negotiate cycle times.

4.1.1. Industry 4.0 and Lean Management

Shortly after the technology-driven Industry 4.0 paradigm emerged, researchers tended to examine potential ties to the traditional best practice-driven paradigm of lean production. Whereas a consensus concerning the complementarity of both paradigms has been developed so far, concrete cooperative specifications are still subject to current research. The subsequently used classification of scientific approaches serves to allocate the field of research chronologically.

Compatibility of the Lean and Industry 4.0 Paradigms. Examinations originate at the executive principles of the respective paradigm. Through reciprocal comparison of those principles (geared to operational functions), different goals become apparent to some extent, as Roy *et al.*(2015) and Quasdorff and Bracht (2016) demonstrated. Thus, an exhaustive conformity of both paradigms cannot be assumed. For example, Ganschar *et al.*(2013) discussed the issue with the discrepancy between FIFO/Flow (Lean) and a decentral, case-based control (I4.0) as part of a difference between the goals of standardisation and complete information of technological pervasion. Despite the determination of certain characteristic differences and partial incoherency, most researchers see a benefit in the complimentary application of the two paradigms (especially Wagner *et al.*, 2017; Roy *et al.*, 2015; Kolberg and Zühlke, 2015. Cf. a detailed record on this in Dombrowski *et al.*, 2017). Leveraging Industry 4.0, higher lean maturity levels are expected, as well as a reasonable integration of Industry 4.0 being possible with the aid of lean. Accordance prevails with the assumption that process orientation and especially lean production represent a key prerequisite for Industry 4.0.

Paradigm transformation. Besides the consensus of general complementarity, a plethora of research focuses on the transformation process to Industry 4.0. In this regard, there are different approaches to enhance contemporary lean methods unidirectionally using technologies of Industry 4.0 (cf. Kolberg and Zühlke, 2015 and Sanders *et al.*, 2016). Sanders and his colleagues responded in a very detailed manner to 10measurable lean manufacturing dimensions developed by Shah and Ward(2007) and described the respective capabilities of Industry 4.0. Beyond that, Metternich *et al.*(2017) provided a first proposal for capability maturity levels with the attempt of arranging the principles and methods of the paradigms in a hierarchical stage model from lean across digitisation to Industry 4.0. Concerning specified transformation options, approaches have thus far merely concentrated on a production technological view, which is only preliminary to the value-added/production systematic view (cf. Baena *et al.*, 2017, Erol *et al.*, 2016, Morlock *et al.*, 2016, with low consideration of lean, respectively). Also concerning maturity based assessment, dedicated lean maturity models are unintegratedly confronted with dedicated Industry 4.0 maturity models; for example, Nightingale and H. Mize(2002) and Maasouman and Demirli (2015), finishing lean optimised, and Leyh *et al.*(2016), with the SIMMI 4.0 maturity model, starting at the digitization level.

Semi-integrated approaches. Consecutive to the paradigm transformation, semi-integrated approaches exist that are oriented on specific methods. Meudt *et al.*(2017) expanded the value stream mapping to a 4.0 level by the integration of a data view. Rauch *et al.*(2016) focused on operational functions, in detail on the transformation from lean product development to smart product development. Likewise, semi-integrated approaches represent a sub-step in the direction of a holistic paradigm integration and a detailed elaboration of an artifact thereof. Schuh *et al.*(2017) developed an Industry 4.0 maturity index, also classified as being semi integrated, because their approach included both an applicable procedure and accurately detailed maturity model, both giving direction to the research at hand. Though dignifying lean in terms of organisational and cultural contributions, complementarities to established principles and methods of lean manufacturing were not examined by Schuh *et al.*, however.

Fully integrated approaches. Burggräf *et al. (2017)* proposed a fully integrated procedure model emanating from a company’s value stream analysis. Through the identification of mission critical lean principles, a digitised value stream is designed by serving the three perspectives of Human–Technology, Human–Organisation, and Technology–Organisation (to the H-M-T approach cf. also Morlock *et al.* 2016) with applications and related technologies from Industry 4.0. Burggräf *et al.* concluded their work by questioning evaluation and comparison methods for digital solutions. Regarding this, Bauer, Pokorni, and Findeisen (2018) provided, with ‘Production assessment 4.0’, a first integrated approach for a maturity level-based representation and consequently the measurability of the transformation from lean to Industry 4.0. Their model allows an assessment of the production systems’ maturity within 33 criteria with up to eight sub criteria each. Additional to the traditional development fields of lean production (e.g., standardisation and continuous improvement), scopes of Industry 4.0 are reasonably integrated (e.g., M2M, digital image of the production system). A further allocation is achieved by aligning strategy, processes and value stream, organisation, methods and tools, as well as labour. However, the model of Spath *et al.* does not exceed the allocation of general development fields and a proposal for potential maturity levels.

> The integration and further development of Burggräf *et al.*’s procedure model in terms of bidirectionality, as well as Spath *et al.*’s assessment model in terms of operationalisation are thus subject to the subsequently presented work under consideration of the following:
>
> - Operationalisation and value oriented model usability
> - Decision base for transformation interfaces
> - Transfer and individual application of artefacts
> - Bidirectional paradigm view within a reference procedure model

Subsumable as framework consisting of procedure and evaluation model for the lean Industry 4.0 transformation is missing.

4.1.2. Methodology and Aim of the Research

The explanations above yield three main questions that the presented works attempt to answer:

1. Which *interrelations* occur between lean production and Industry 4.0 considering an evolutionary *transformation*?
2. How can companies *evaluate* concepts, methods, and technologies on an operative level to develop the production system in the context of lean and Industry 4.0?
3. How can companies *proceed* to develop their lean production systems in the context of Industry 4.0?

Interrelations result in our field of observation from the diversity of concepts, methods, and technologies, serving similar requirements in different areas of a company while being individually adapted and embedded into the local system environment. With regard to this circumstance, a multi-dimensional model intends to contribute in particular to a complexity reduction in the given context. Contemplating possible interdependencies, the continuity of transformation processes has to be likewise considered, requiring a temporal perspective of the evaluation of concepts, methods, and tools. To answer questions (1) and (2), we suggest the development of a multi-dimensional capability maturity model, which depicts the spatial factor of interdependencies as well as the temporal factor of transformation processes. The model development process performed in our research follows the procedure of Becker *et al.*(2009), proposing a reference procedure for maturity model development focusing on information technology. Commencing with a problem definition, a review of hitherto relevant approaches to the subject matter is now complemented by a development strategy. Thus, the further procedure consists of an iterative maturity model development. In addition to a plausibility evaluation, a quantitative evaluation regarding specific assessment criteria for deployment is performed in a different paper (cf. explanations on related research). The iteration of model development is carried out across each of the following levels: design level selection, approach selection, design of model section, and testing. As maturity models according to Becker *et al.* only allow a systems' posterior appraisal, our maturity model is complemented by a procedure model. Through this, the consideration of adequate concepts, methods, and technologies (C/M/T) referring to the system configuration shall be enabled a priori. The procedure model development is based on the idea of hierarchic views as an Enterprise Architecture principle (cf. Josey, 2018, Zachman, 1987; Sowa and Zachman, 1992). Passing through the procedure model, the maturity model in turn allows an evaluation on each view/level, which is why both models have to be seen interconnected.

4.1.3. Results—A Multi-Dimensional Capability Maturity Model

4.1.3.1.Maturity Model Development

Field of observation. As shown above, the synthesis of lean production and Industry 4.0 is not comprehensively discussed. It can, however, be asserted that the transformation to Industry 4.0 is based on a lean production and develops in an evolutionary process of single elements in a systems' configuration. Referring to a further development of the production assessment model of Spath *et al.*(2017), modelling is particularly performed under consideration of an operative assessment and decision-based scope and rests upon the foundations of de Bruin *et al.*(2005) and Becker *et al.*(2009) on capability maturity model development.

Model development. Starting at an ontology, describing diverse development fields derived from a company's vision or strategy, lean production and Industry 4.0 are company-specifically integrated as paradigms using associated principles (cf. also enterprise architecture frameworks). The latter is then differentiated into characteristic sections (partitions) in the field of observation (objects to be designed) as, for example, 'real-time mapping of production processes' or 'labour organisation'.

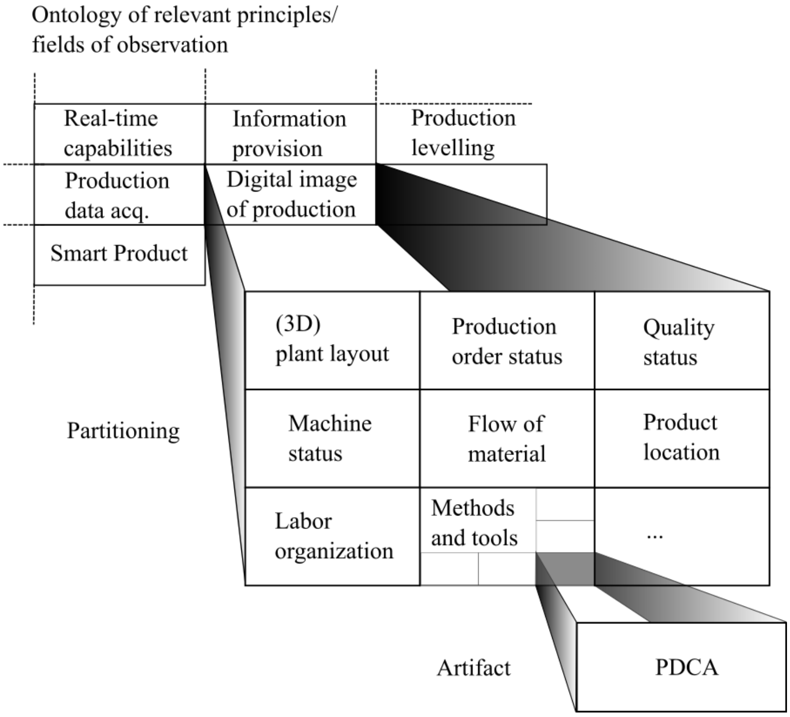

Figure 34: Exemplary itemization for hierarchical domains within the capability maturity model, extending the model of Spath et al. (2017).

These sections, representing an operational function and an associated paradigm, can be detailed in artefacts at various aggregation levels, depending on the scope and complexity of the particular section. The artifact with the highest level of detail contains concepts, methods, and technologies, which contribute as elements to the particular maturity level of the major artifact. As an example, KANBAN is a method for realising the pull principle as a concept and is supported by (electronic) KANBAN-cards as the technology. Because concepts, methods, and technologies are highly integrated, meaning they interact or rely on adjacent artefacts, interdependencies occur between the artefacts.

Maturity level development. Parallel to the model development, maturity levels (MLs) can be derived from each abstraction layer, representing successive steps for the achievement of objectives. The ML's specificity thus depends on the design criteria of the particular field of observation’s respective artifact (based on meta-maturity levels). The initial highest degree of aggregation for MLs in the production is provided by the four following global levels and the definition of their production paradigm (focus on capabilities):

- Lean: Subsumable as perfection in the disciplines clustered by the lean philosophy as, for example, exhaustive exploitation of naturally available (from planning imperfection) potentials in the spatial-temporal control of products and operational resources(Karlsson and Åhlström, 1996).
- Digitisation: Represented by the computerisation of repetitive or long lasting manufacturing tasks enabling high quality at high efficiency, as well as connectivity of operational technology combined with a digital representation and execution of operational functionalities(Schuh *et al.*, 2017).
- Industry 4.0: Visibility as an up-to-date digital model enriched by sensor data achieving a company’s digital shadow (e.g., with real-time KPIs and Dashboards). Transparency: Contextualised semantic linking and aggregation of data ‘to support complex and rapid decision-making’. Predictive capacity enabling automated and adaptive decision-making in terms of data-based real-time optimisation in contrast to determined rule/process-based decision making(Schuh *et al.*, 2017).
- Target configuration: Operational optimum system-configuration of subsequent maturity levels aspired by the company or a partition, concerning economic viability and the interest of all stakeholders. Referring to individual business venture success, this does not require overreaching accomplishments in the a foregoing maturity levels.

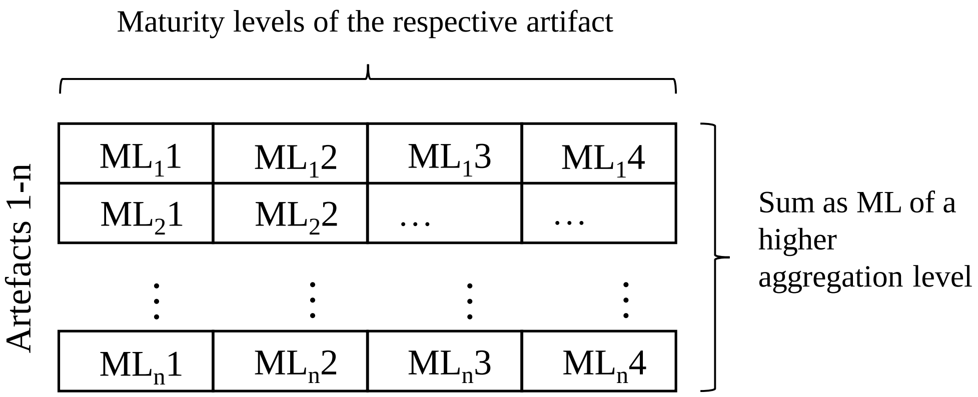

Figure 35: Schematic of the capability maturity levels across aggregation niveaus.

The definition and quantity of capability maturity levels are highly abstract at the lower levels of aggregation (e.g., shop floor transparency for automatic, personalised, and timely information of employees about relevant events in the labour organisation). This requires a separate set of evaluation criteria for all artifacts to be included in the artifact configuration during a transformation process. The criteria are elaborated in the following sections. For a further specification of the model, particularly with regard to the problem definition, we identify four mission-critical building blocks, including specific sub criteria to be applied to the C/M/T: synergies and interdependence, trajectory, sustainability, and leanness. Each C/M/T is represented by one specific/individual artefact that is in the focus of the maturity assessment.

Synergies and interdependence between the artefacts' C/M/T. Artefacts as artificial constructs originate from a complexity reduction in modelling. However, their fit into the holistic information system landscape has to be considered thoroughly (for the artefact as a result of R&D, cf. Hevner *et al.*, 2004 and especially Simon, 1996). Synergies and interdependencies occurring between artifacts thus need to be harmonised. Although synergies do not contribute to any build-up of competencies, they derive from existing internal competence and therefore enable improvement at low risk (Eversheim, 2009).

For example, an artefact configuration emanating from a successful pilot project into contiguous departments/zones causes interdependencies between different artefacts to arise from mutual influences and dependencies amongst elements from concept, method, and technology. Thus, it is crucial to consider the impact on contiguous artifacts, as well as the overall configuration while manipulating an artifact element. Interdependencies can likewise lead to positive effects increasing the maturity level of surrounding artefacts but also result in reciprocal restrictions or even exclusion. For instance, the adoption of a new technology to record operational data, which has no interface or is incompatible with other departments/zones inside the value stream. Approaches for a methodical assessment of interdependency and synergy within the C/M/T portfolio only exist rudimentarily. Although generic methods exist in the related field of technology assessment and product development (e.g., Multiple Domain Matrix or Design Structure Matrix; see Eppinger and Browning [2016] and Bartolomei *et al.*[2012]), they have not been transferred to the field of observation at hand thus far.

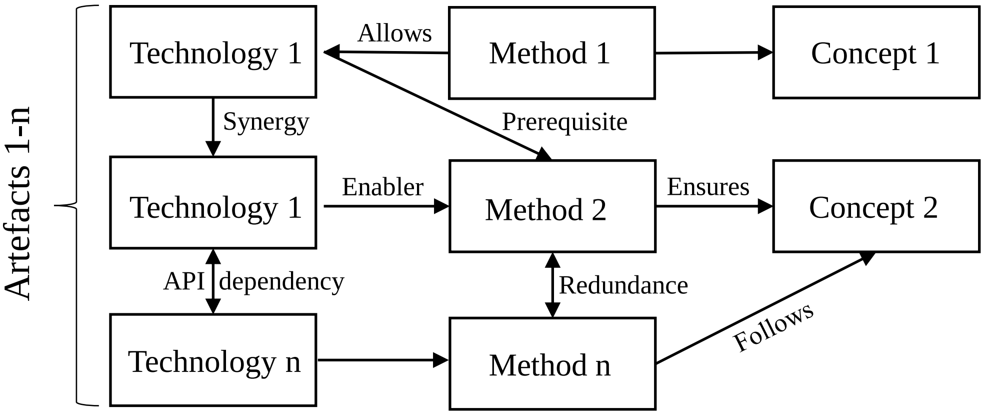

Figure 36: Exemplary artefact interdependencies across concepts, methods, and technologies.

C/M/T - Trajectory development. Within an artefact, it makes sense to describe the development process as a vector to the target configuration, whose trajectory ideally points to a dedicated target point. The vector itself consists of C/M/Ts and is therefore directionally influenced when a new C/M/T is applied. In terms of a transformation process to Industry 4.0, process and vector describe the evolutionary trajectory.

With this kind of perspective, it becomes possible to evaluate potential improvements not only quantitatively (e.g., monetary) but also qualitatively with regard to possible influences on the trajectory and the transformation process to a target configuration.

If a value stream analysis under consideration of information flow is set as a target, an organisational optimised, manual method, for instance, would lead to a deviation of the target vector. However, any methodological update via a data-based information density would shift the target vector to the target point as a building block within the target configuration.

Assuming that a lean maturity model represents the (area specific) optimal configuration, an intersection to Industry 4.0 exists initially with the digitisation of the optimised processes of that configuration. With the application of Industry 4.0, the target convergence needs to be realigned and evaluated, but this must be done starting from the lean C/M/Ts. The validity of the one-piece flow as opposed to a decentralised, flexible production system serves as an example.

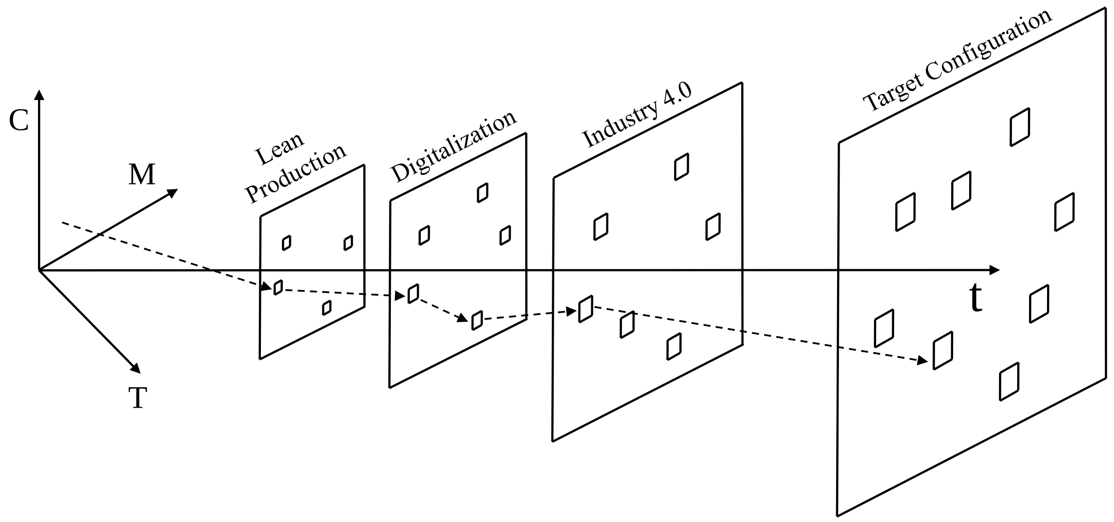

Figure 37: Trajectory of the target vector in dependency to the aspired configuration (based on Schuh et al.[2017] and Morlock et al.[2016]).

C/M/T's future viability as a function of achievable maturity levels. An assessment of the maximum achievable maturity level by applying a C/M/T involves projecting the specific C/M/T to its ultimate stage. For a vector-based viewpoint, this describes the vector length and, at the same time, the achievable proximity to a target point. For example, a new visualisation tool based on MS Excel would therefore only achieve a very small step, compared with web applications, as they might be developed much further, such as by continuous integration of web services.

The explanation above leads to a concept of strong analogies to the established S-Curve model for technology lifecycles and specifies it with concepts and methods, especially at the operational level. The latter implies that decisions must be made in the constant awareness of the known innovator dilemma (Christensen, 1999).

CMT's Continuous Improvement Phase. Since no C/M/T is implemented at the highest maturity level, a continuous improvement process must be performed. This process represents the distance between the target points (figure 38). There are four implicit phases within the continuous improvement process, namely sensitisation, start, implementation, and stabilisation (Kostka and Kostka, 2013):

- Sensitisation: Not yet implemented, but already communicated
- Start: Ready for implementation and responsibilities defined
- Implementation: C/M/T is productive
- Stabilisation: C/M/T is productive and optimised

For instance, a new visualisation tool that was implemented six months ago (implementation phase, almost stabilisation phase) can hardly be compared to a tool that was implemented two days ago (starting phase).

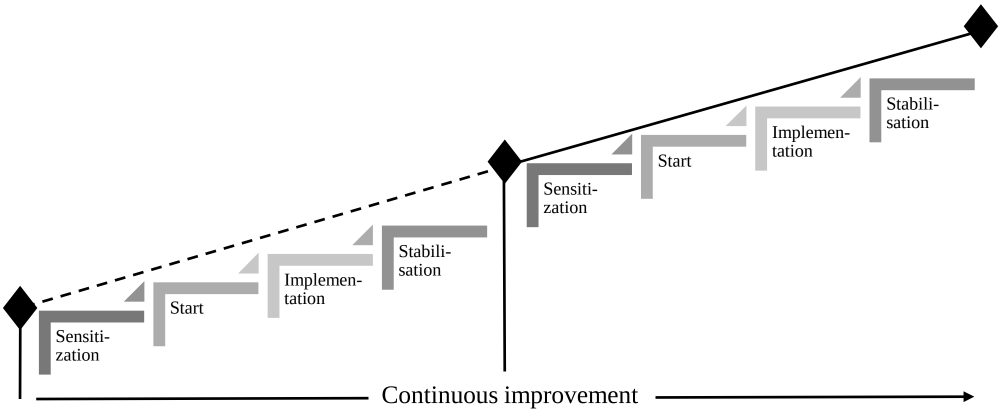

Figure 38:Continous improvement steps (based on Kostka and Kostka, 2013)

C/M/T's leanness. Lean is already described in the maturity level as an abstract level. In addition to transparency, standardisation, and optimisation/continuous improvement, the principles of tact, flow, pull, zero defects, and zero waste must be taken into consideration when evaluating the artefact leanness of C/M/Ts. The C/M/T was evaluated from two perspectives of leanness. First, whether the C/M/T itself is lean, and second, to what extent can the C/M/T contribute to increasing the leanness of the system.

To evaluate whether a C/M/T is lean, the performance capacity, the effort of method maintenance, and the technology acceptance must be taken into consideration.

Performance capacity (time, cost, and quality). The time, cost, and quality triangle derives from the project management research field and is used in this article to determine the artifact capacity (capacity management). Time, cost, and quality are interlinked, and thus concentrating on one point of the triangle affects the other two points (Atkinson, 1999). Therefore, we propose the evaluation of the three categories of time, cost and quality, including their interrelations. *Time* is defined as the temporal expenditure that is necessary for the use of the C/M/T.

Costs are divided into short-term (development), mid-term (introduction), and long-term costs (maintenance).

Quality is defined as the responsiveness to customer demands and encompasses every element that has an impact on customer satisfaction such as dimensional accuracy, product performance, specifications, or basic functionalities (Frits and Fujimoto, 2007). When the production quality of the product rises, production time as well as the production costs increase initially. In the short term time, cost, and quality as critical success factors of a production system may outweigh the subsequently explained criteria, however long-term they scale moderately.

Effort of usage and maintenance. Regarding the cost–benefit ratio of a method or technology, two key factors must be taken into consideration. At first the people, in particular their effort to maintain the method or technology, and second the software itself, particularly “waste” within software development and handling. Especially when decisions about potential digital replacements are pending, the effort of usage and maintenance has to be scrutinised.

People are the centre of resources, information, process design, decision making, and organisational energy. Organisation structures have to be centred around the flow of value, not on functional expertise. For the assessment and the degree of depletion it is essential that the digital information is presented and handled dedicated to the people who are adding value to the system (Poppendieck & Poppendieck 2003). It is therefore crucial that new methods or technologies do not cause more effort for the people than established ones.

Waste in software development consists of seven different categories: extra features and requirements, extra iterations, information gathering, unexposed defects during tests, waiting, and handoffs (Poppendieck & Poppendieck 2003). The usage of multiple software systems additionally leads to interface- and architecture complexity. Thus, it has to be ensured that these seven categories of waste are fundamentally eliminated.

Technology acceptance. With regard to the target configuration, the technology acceptance model of Davis (1986) is used to evaluate whether the usage of the C/M/T is evaluated positively or negatively. The use of the C/M/T is dependent on the intention of the user (Davis, 1986). The intention or attitude towards the usage results from the perceived usefulness as well as the perceived ease of use. These two categories can be influenced by different factors such as job relevance, output quality, subjective norms, or personal experience (Venkatesh und Davis, 2000).

For example, a visualisation tool based on MS Excel may seem quickly introducible at a low cost level, but it lacks many of the already introduced criteria (e.g., efficiency or future viability) compared with a web application. The Excel tool has further restrictions concerning usability and compatibility, which decreases the method maintenance by creating work-arounds (waste), which are not necessary in the web application. The technology acceptance for the prevalent

MS Excel may be high in the beginning, but regarding its limited usability the acceptance will decrease with rising application complexity. To evaluate to which degree the C/M/T can help to increase the leanness of the system, it has to be taken into consideration how new levels of tact, flow, pull, zero defects, or zero waste are achieved. For instance, production activities of one specific area are mapped on a physical board with printed sheets containing basic information about the machines that are used in the system (e.g., overall equipment effectiveness), people who are working in the area (e.g., shift schedule and accidents at work), and the key performance indicators (e.g., output per hour), contain high transparency but also a high effort of usage and maintenance. Therefore the introduction of a manually handled Excel tool that unites the information about the machines, the people, and the key performance indicators in one Excel sheet that is digitally accessible is a first step in increasing the leanness of the whole system. A web application that unites all information automatically without needing a person to summarise the information that is digitally accessible will be a next step.

Model consolidation. In figure 39, the successive conceptualisations of the components of the maturity models are now recapitulated and presented as an overall model. The nature of concepts, methods, and technologies influences the direction of a target vector, which in an ideal case, is aligned to a point of the systems' target configuration[17]. As the latter is not achievable by implication, a CIP is necessary, which is represented by the distance to the target point and can be evaluated by the maturity levels. Kaizen 4.0 then describes an aggregated view to improve artifacts that integrates both lean and Industry 4.0 to obtain the target configuration (figure 34, for example, aggregation levels). As a C/M/T (depending on the aggregation level) enters an artifact, it passes through the phases depicted in figure 38. There are several potential reasons for a C/M/T shift, and the question of whether and when is also the core topic of this work as well as what makes Δt the focal point of the model. As already discussed, a shift may either arise from saturated process optimisations pulling new approaches, or from C/M/T pushed towards apparent inefficiencies. For the assessment of single C/M/Telements concerning their integration in the overall system configuration, and to determine their potential for an achievement of objectives, leanness plays an important role. Deviations within the trajectory may occur, caused by temporary target configurations, either requiring interim solutions or economic optima. Synergies and interdependence across multiple artefacts are shown between the maturity levels, as their influence directly relates to adapting, facilitating, or interlocking of adjoining capabilities.

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[17] The vectors‘ ascend therby serves a better visualization, however the orientation has to be understood as solely dependent of the spatial and temporal location of the target point.

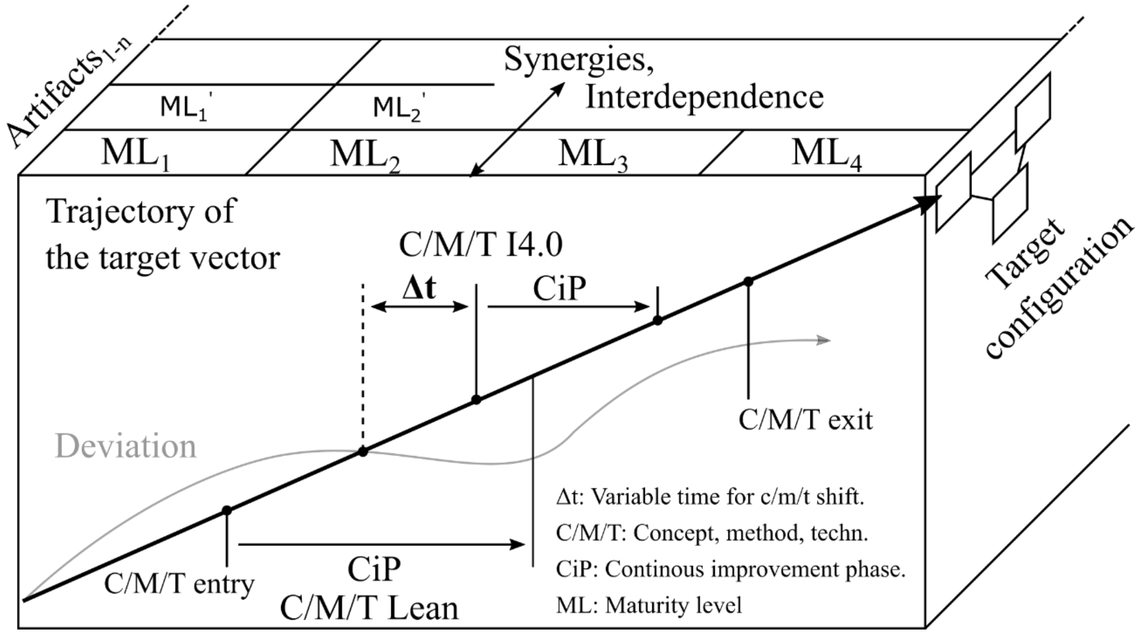

Figure 39: Schematic of the functionality of the paradigm integrated capability maturity model.

4.1.3.2.Procedure Model Development

Responding to the maturity model for an identification of the need for action, beyond the scope of lean production and the evaluation of potential for improvement, a procedure model has to be developed, which enables the ‘how’ within a sustainable transformation towards of a new paradigm. Since the operationalisation of both Paradigms is of the highest perceptibility and manageability, presupposed principles and concepts are often neglected. This may also be a reason of the matter’s maturity itself and a previously missing long-term strategic approach. At the operational level, however, the visibility of methods and technologies is just as high as the demand for improvements that lead to problematic (limited) approaches:

I) *Problem of the unidirectional approach:* Either lean principles or Industry 4.0 principles manifest in a range of lean development technologies, or a boost of qualified Industry 4.0 technologies to lean methods and tools. Even if the initial paradigm is necessarily considered (see above), this can ultimately lead to contradictions with the opposite paradigm. An example would be the big data-driven establishment of redundant data lakes distributed across a company. Although each may later be kept as lean as possible for the use cases it serves, a missing comprehensive architecture (also caused by low Industry 4.0 principles’ maturity), will violate the mature lean principle of waste avoidance.

II) *Problem of the bottom-up, least common denominator approach:* Paradigm synthesis initiated on technology/process level based on 'best match' decisions. Even though a technology-induced reengineering of lean is performed, disregarding the paradigms' methods and principles may lead to problems at the long-term oriented, strategic level. The prime example and source of this chapter are fast digitisation gains with technologies with little potential for development and thus outdated in a long-term Industry 4.0 strategy.

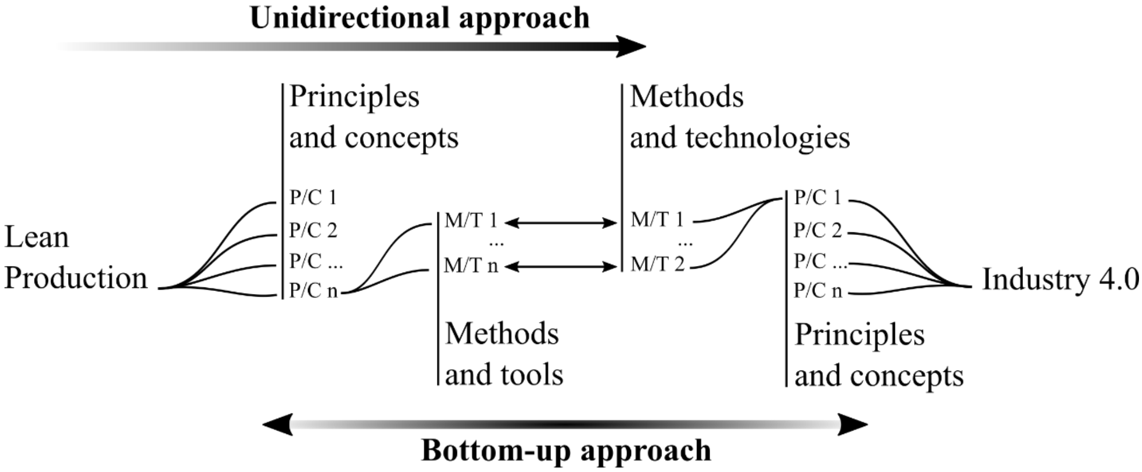

Figure 40: Unidirectional and bottom-up approach as a result of operational visibility of methods and technologies.

The problems arising from (I) and (II) are shown in figure 40 and demonstrate the need of a holistic view of both paradigms in the development of a procedure model. The conceptualisation therefore refers to the holistic perspective of established Enterprise Architecture Frameworks (EAF) and incorporates the accomplishments of Henderson and Venkatraman's (1993) Strategic Alignment Model. The latter requires the strategic adaptation of business and IT strategy to processes and infrastructure as well as the functional integration of IT and business. The corresponding top-down approach starts with a synchronisation at the principle level and enables further synchronisation on the successive levels of methods and technologies (see EAF business-, application-, and technology view). At the principle level (resp. concept level), supra-principles such as the elimination of waste can remain unchallenged, while sub-principles compete. The resulting consensus allows synchronisation at the method level without methods that use outdated principles. Conducted methods that exist on both sides, however, must be revalidated, possibly combined or discarded if outdated. Technology or tools must then essentially serve the consolidated method base and be evaluated under the considerations given with the maturity model (e.g., trajectory). figure 41 outlines the explanations on the holistic procedure model. The completion of each process step within the procedure model demands an evaluation under the perspectives given by the maturity model. Both models are therefore seen as strongly interwoven.

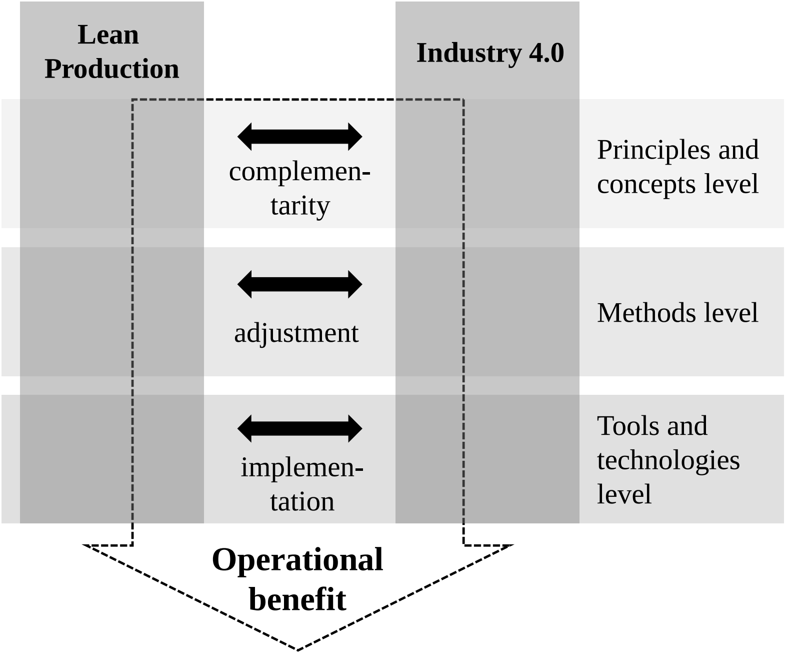

Figure 41: Procedure model for the lean–Industry 4.0 transformation.

4.1.4. Limitation

As the complexity of the developed framework increases with the number of considered C/M/Ts as well as the target configuration, a further investigation of complexity reducing methods must be performed. Although the framework can be fully applied to less complex subsystems, such as production sites, departments, or zones, an integration into the overall system is from an economic perspective obligatory, especially with regard to cross-artifact interdependencies. An essential approach is already found in the principles of architectural frameworks and includes the standardisation, multiple/re(-) use of artefacts from a repository. A second approach is the application of decision support methods dedicated to highly cross-linked systems: Design Structure- and Multiple Domain Matrix (continuative to this, see Eppinger(2016) and Bartolomei *et al.*(2012))

4.1.5. Prospects

Building on the work of Spath *et al.*(2017) and Schuh *et al.*(2017), a model-based approach is presented, which contributes to a complexity reduction for challenging decision-making at transformation interfaces from lean to digitisation and Industry 4.0.

Perspectives given by the construction of the maturity model allow considerations of the overall system- and target configuration at local/temporal operational decisions. Based on the developed evaluation criteria, the decision-making process can be deployed as user-friendly. The model recognises lean, in particular the standardisation of processes, as the basis for Industry 4.0. With regard to open questions concerning the compatibility of lean and Industry 4.0 concerning, for example, decision processes and people centricity versus decentralised responsibility through the use of artificial intelligence, further empirical validations of the model must be conducted. A methodologically integrated application and the validation of the model, in particular the operational evaluation criteria, will be subject to further examination and published in following papers. Although the development of the framework was dedicated to the integration of lean and Industry 4.0 paradigms, its generic structure also allows for its application on transformation processes without a concrete paradigm reference. Project, technology, and change management are mentioned here as exemplary at different levels. A parameterisation or a further mathematical description of the model would allow use for simulations. For this, the vector character of the model has to be elaborated. Further investigations should also focus on the organisational and management perspective of the subject matter in terms of employee centricity, as a success factor of the lean philosophy and a major bias against digitisation and Industry 4.0. In addition, the ambidexterity of lean and Industry 4.0 must be explored. With Industry 4.0 requiring standardised processes as a basis for sensible crosslinking and automation on the one hand, as well as Industry 4.0 supporting leanness by gathering process data to enhance the transparency within the production system on the other hand, the chicken-and-egg problem becomes obvious. Thus, a further aspect that needs to be explored within this transformational process is whether lean remains a basis of a value-added production system and potentially only the tools are changing from, for example, Ishikawa diagrams to advanced analytics or from Kanban to intelligent carriers.

4.1.6. Future Work

The research performed for this article was based on the analysis of operational digitisation measures in the automotive industry. It became clear that the digitisation of similar (lean production) processes using different methods and technologies was carried out in discrete departments. This leads to a high variance of the performance and integrability of these methods and technologies. This fact is included in the descriptive aspects (e.g., dependencies) of our maturity model. For subsequent research, the performance and integrability of these already implemented artefacts will be assessed using a set of operational a priori evaluation criteria. Subsequent validation can underpin and extend the process model proposed in this chapter with an operational decision support component. As the advancement of digitisation in industry is a major problem, and not least because it often affects traditional lean production structures, we also encourage other researchers to explore this field of observation in future research.

4.2.Compatibility on a meso level—Vision and goal formation of companies

As described above, to be able to choose the right approach for the project, it is necessary to understand the current situation fully. As already discussed in subsection 2.4.3, methods such as the Stacey Matrix or Cynefin framework can be used to create a better understanding. However, the selection and evaluation of the innovation project is a crucial factor for success. Therefore, current methodologies must be expanded. The maturity model described above allows considerations of the overall system- and target configuration at local/temporal operational decisions, and can therefore help to define the vision and goal for the project as well as the direction. It can be used in companies to identify the current situation of a project landscape. It follows the same logic as the Stacey Matrix and Cynefin framework. In simple and complicated areas, it makes sense to exploit efficiency by exploiting standardisation, since the necessary stability, security, simplicity, and uniqueness are given. Efficiency programmes such as those from the Lean environment make sense here. By contrast, in complex areas characterised by volatility, uncertainty, complexity, and ambiguity, exploring agile ways of working is most suitable.

The procedure of choosing and evaluating innovation projects plays a key role within a lean production system and has a main influence on innovation. However, strengths as well as weaknesses can be clearly demonstrated. The strategic selection and evaluation of innovation and their adaption in the production system through using the created framework and procedure model will help companies to face the future challenges and create internal project structures to stay competitive. Not only project structures but also the people who are working within them have to be understood and supported.

Thus, the meso level links the compatibility of lean and agile/innovation at the macro level, as discussed in Chapter 3, but is influenced by the subordinate micro-level perspective, in which the compatibility of lean and innovation on an individual level plays an important role. Thus, it is the focus of the next chapter.

5. Compatibility of Lean and Innovations in a Production System from a Micro Level Perspective—Empirical Use Cases

In this chapter, the use of augmented reality (AR) with head-mounted displays (HMD) serves as empirical validation to demonstrate the compatibility of lean and innovation under the aspect of conducting innovation projects, taking lean principles into consideration. This use cases serve as an example comparing traditional training in the automotive industry with new learning approaches using AR-based technologies (using the example of the BMW Group's VPS Center/Lean Training).This will provide answers to how, at a micro level perspective, the compatibility of lean and innovation at an individual level can be achieved.

5.1.Performance/execution of an innovation project using lean principles in production training 4.0[18]

The Value-added Production System (VPS) is BMW's application of lean management principles, methods, and mindset. It is furthermore the foundation of the BMW Production System. To qualify employees within the theme of lean and offer a place where participants can get in contact with the matter, the BMW Group founded a central VPS Center with the VPS Learning factory for the production network in 2011. Contemporary existing solutions were examined and a prototype was created that, after circuits of improving concept and content, ended in a final set up and opening in 2012 at the BMW Group Academy in Munich. The main focus of the installation is the qualification of management and lean experts within the company. Since 2015, trainings are also offered to suppliers. To fulfil the kaizen mindset, the VPS Learning factory pursues not only qualification targets but also research targets concerning the continuous improvement of lean tools and methods.

On the 600 sqm of the VPS learning factory (Figure 42), the value stream of a heat protection plate from the receipt of raw materials over pressing, welding, to assembling on the engine is mapped. Because the engines are not sold, the parts are disassembled and returned to the lifecycle of the VPS learning factory. This realistic learning setting serves as the environment for the empirical validation of the consideration of lean principles in the successful implementation of innovation/innovation projects.

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[18] Section 5.1. was created in coauthership by Lorber C. & Stäudel T. (2019) VPS Center. In: Abele, E., Metternich, J., Tisch, M. (eds) *Learning Factories. Concepts, Guidelines, Best-Practice Examples* (Berlin: Springer), pp. 458-459.

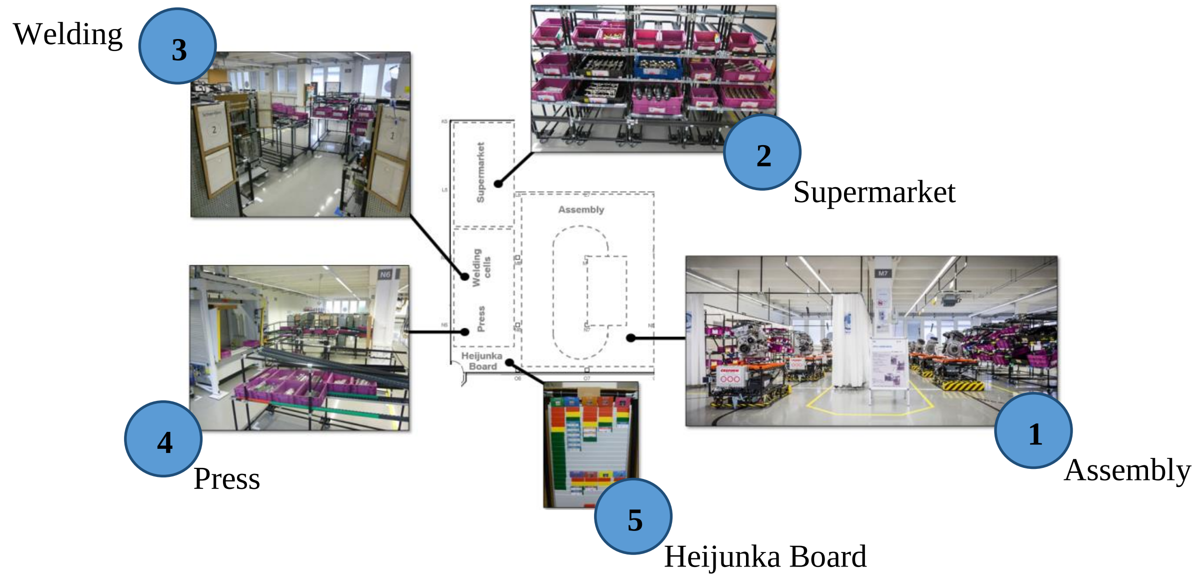

Figure 42: Fabric layout learning factory.

One major challenge of the sustainable competence development of employees will be the update of existing training to meet the growing skill demands raised by digitisation/industry 4.0. Whereas multimedia learning and e-learning were the state of the art in teaching and learning settings in classrooms, in most of the operational learning subjects, laboratory exercise with haptic learning experience rather than theoretical knowledge building played a fundamental role (Morrison et al. 2011). With the rapid evolution of information technology, the concepts of traditional training methods will be clearly influenced and learning sessions will change towards a mixed-reality learning environment (Guo, 2015). Devices already used daily such as laptops, smartphones, and projectors, but also new technologies such as head-mounted displays, support this development by visualising augmented data into our real world—augmented reality.

Furthermore, with advantages such as epic meaning (the feeling of achieving something great an inspiring when achieving a task in a video game (McGonigal, 2011), the positive effects on intrinsic motivation, as well as the development from situational interest to individual interest (Guo 2015) and Holm et al. (2016) stating the chances of a working environment that looks more like a videogame, the necessity of integrating gaming elements into learning sessions becomes increasingly obvious. Characteristics of augmented or virtual settings are the vivid depiction of complex topics and application orientation (Schwan & Buder, 2001), the possibility of first-person experience (Bricken, 1990), and the self-controlled learning process ensuring learning success (Schiefele & Pekrun, 1996). Furthermore, the development of different training modes extends the existing degrees of freedom of the learner, and thus significant additional potentials for learning actions can be developed (Blümel & Jenewein, 2005).

Table 6 presents a comparison of real-life training versus virtual/augmented training (Jenewein & Schulz 2007):

Realities	Real work environment (RE)	Virtual work environment (VE)	Didactic Consequences
Issues			
Complexity	Always 100 % Reduction mostly not possible	Always < 100 % Reduction possible	Didactic reduction of the complex environment
Dynamic	Influence possibilities strongly limited	Influence possibilities available	Visualisation by time-lapse and extension
Network	Often unimaginable and limitedly influenceable	Degree of networking can be influenced	Targeted orientation to learning prerequisites
Transparency	Depending on visibility and accessibility	Accessibility and visibility artificially expandable	Better comprehensibility and clarity
Learning activities			
Reversibility	Rarely possible without consequences (costs, time, material)	Always possible without consequences	Possibility: Learning from mistakes
Cost dependency	Learning actions always cause costs	Low usage, high development effort	Depending on the number of participants and the application
Time dependency	Work process and system partly only limited available	Principally unlimited availability	Individualisation and flexibility of learning times and place
Place dependency	Location Dependence Tied to work environments	Principally unlimited availability	

Table 6: Reality areas of learning in real and virtual work systems (based on Jenewein & Schulz, 2007).

Several studies have already proven the benefits for industrial trainings sessions, such as an increase in quality in maintenance procedures (Rios et al. 2013)as well as a time improvement and fewer attempts in fulfilling an assembly task (Holm et al. 2016) when employees are trained with AR features (Hořejší, 2015). However, missing contributions such as the realisation in a real industrial setting, tasks not matching the complexity of industrial learning settings, and participant groups consisting of students without prior production knowledge along with software and hardware challenges complicate the transferability and scalability of the benefits achieved.

The explanations above yield two main questions, the answers to which are thoroughly addressed in the following section:

1. Can AR be used in industrial training sessions and how can lean principles help/support innovations?

2. Can AR training also be used in complex industrial tasks such asvalue stream analysis and how should AR training sessions be designed for more complex industrial training tasks?

5.2.Face to face training vs. head mounted display training—Can AR be used in training sessions and how can lean principles help/support innovations?[19]

The apprenticeship of new employees is one of the crucial aspects for ensuring high-quality processes and products. Assembly and maintenance training aim for the acquisition of procedural as well as fine-motor skills (Loch, Quint and Brishtel, 2016). Trainees have to learn how to assemble a specific object in a predefined order and cycle time, using the correct parts and tools. Depending on the scope of work, this skill-acquisition usually takes several days. The underlying job instructions are based on a four-step methodology (Figure 43) invented by the training-within-industries (TWI) institute, which was founded during the Second World War (Graupp and Wrona, 2016). The main purpose at that time was to train millions of unemployed people to increase the production outcome of military goods such as weapons, tanks, and warplanes. The concept of TWI was adapted by the Japanese government at the end of 1945 to reconstruct their industries. It became an integral part of the TPSand a role model for the entire automotive industry up until today.

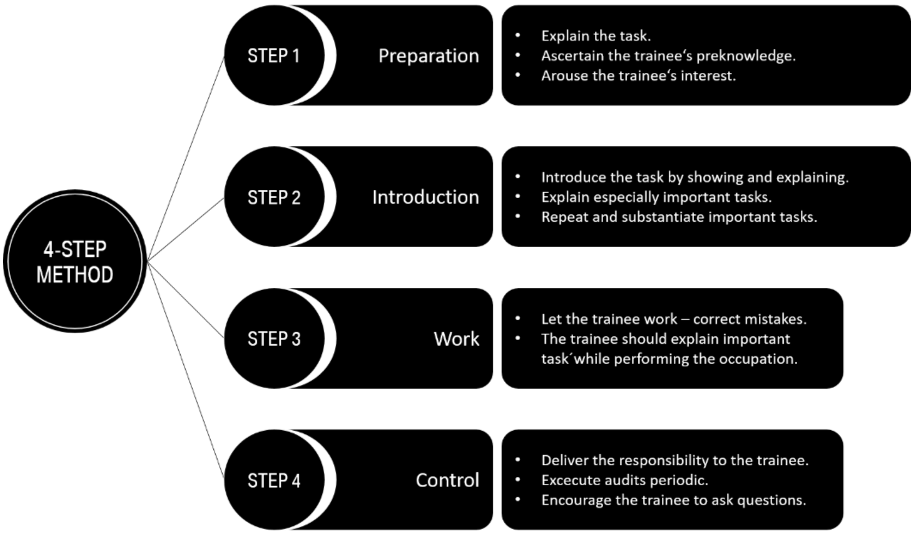

Figure 43: The 4-step methodology for work instructions.

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[19] Section 5.2 was created in coauthership by Werrlich, S., Lorber, C., Nguyen, P. A., Yanez, C. E. & Notni, G. (2018) Assembly Training: Comparing the Effects of Head-Mounted Displays and Face-toFace Training. In: Chen J., Fragomeni G. (eds) *Virtual, Augmented and Mixed Reality: Interaction, Navigation, Visualization, Embodiment, and Simulation*, pp. 462–476.

The first step aims to explain the task in detail while creating a pleasant work environment to make the trainee feel comfortable. The trainer further arouses the trainee’s interest and ascertains any prior knowledge. The second step represents the introduction to the task itself. Demonstrating the task while showing and explaining important details, the trainer provides a first overview and understanding of the occupation to the trainee. In the third phase, the trainee starts working on and explaining the tasks while the trainer pays attention and makes corrections in case of any mistakes. After repeating the work process several times, the trainee is able to work independently. The trainer delivers full responsibility to the trainee and executes audits at regular intervals.

This methodology is a standard procedure in the automotive industry and other industrial domains, but not a contemporary one. Due to increasing globalisation and several causes for migration, the world population is mixing. Naturally, this social phenomenon also affects the entire workforce of a company. Employees of different origins and various language backgrounds are required to work together in the same work environment. Depending on the extent of a possible language barrier and the trainer’s pedagogical abilities, the learning time and success vary between employees. In addition, a trainer is assigned to one and the same trainee until the training is completed, which does not add value and should be reduced to a minimum to save human resources. Furthermore, assembly training is realised during the actual production at the assembly line, which provokes stress because of short cycle times. Most trainees are not able to assemble a specific object in the given cycle time at the beginning of a training session. The learning process takes mostly three to four days, depending on the task complexity (Werrlich, Nitsche and Notni, 2017). Because of these reasons, assembly training needs to be optimised. Therefore, AR is being introduced to the industrial domain and promises to increase the efficiency and quality of procedural tasks. We present respective approaches in the following sections.

5.2.1. AR-based training

Holm mentioned that it “(…) *would be really good if we could create a working environment looking more like a video game”* (Holm, Adamson, Moore and Wang, 2016). Especially for young people, who will be the future shop-floor operators, such fascinating work environments become increasingly interesting. Established technologies such as laptops, smartphones, and projectors as well as new technologies such as HMDs can support this idea by visualising augmented data into our real world. These approaches not only affect our daily life but also promise to increase the efficiency and quality of procedural tasks, such as assembly training tasks. Previous studies reinforcing this potential are presented in the following paragraphs.

A mobile solution using a tablet was developed by Rios et al. (2013) to enhance the maintenance procedures of the Engine Air Bleed System on the Boeing 737. A study was executed with 34 students comparing the impact of written instructions to those of AR features. The assembly time and assembly quality were measured using a 46-point scale. Participants performed 17.22% slower when using the AR learning approach but reached a quality increment of 24% compared with the traditional method.

Another study (Hořejší, 2015) compared the effects of paper-based instructions to a screen-based solution, where augmented instructions were presented on a screen at the workplace in front of the participants. Twenty volunteers participated in each experimental group while the assembly time was measured. Results indicated a two-minute time improvement for the first attempt of assembling a gully trap compared with the paper-based method. Participants in the AR group further were able to fully assemble the gully trap after 10 attempts; the other group required 12 attempts, which indicated quicker learning success when using AR.

An experiment with 20participants compared HMD-based training with face-to-face training (Gonzalez-Franco et al. 2017). A modified Oculus Rift HMD equipped with two additional cameras was used as a video-see-through HMD. An aircraft maintenance task was chosen for this study; 24 were randomly assigned to one of the two conditions using a between subject design. Trainees had to perform a multiple choice questionnaire in order to assess how much knowledge was retained during the training session. An additional second evaluation aimed to gather the captured knowledge. All of the participants were asked to perform the task step by step until completing the entire operation. Results indicated no significant differences between both tests.

More evaluations using AR for assembly and maintenance training tasks were presented in comprehensive contemporary surveys (Wang, Ong and Nee, 2016). Although AR's potential has been proven promising and the advantages seem obvious, it is not in practical use in the automotive industry due to several scientific limitations (Werrlich, Eichstetter, Nitsche and Notni, 2017):

- Most of the assessments examining AR are realised under laboratory conditions.
- Participants are mostly students without prior knowledge of assembly tasks.
- Procedural tasks do not match the complexity of industrial assembly tasks.
- Reliable comparisons between HMD-based and face-to-face training are still missing.

- Researchers are rather measuring the training time instead of gathering the training transfer, which is the main KPI for training assessment.
- There are only a few scientific contributions evaluating the advantages of HMD-based assembly training in industrial settings.

These missing contributions, along with hardware and software challenges, make it difficult to transfer, adapt, and scale the established knowledge to real industrial use cases. A profit-oriented domain such as the entire automotive industry is not inclined to use a technology without a clearly proven benefit. Hence, in this chapter, we provide a first approach to overcome this deadlock.

5.2.2. Lean Approach in AR-Based Assembly Training Sessions

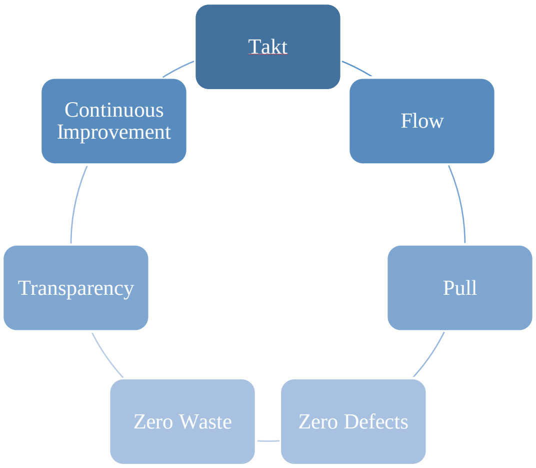


Figure 44: Lean principles.

To overcome the uncertainty of how to present information within AR-based training, the whole teaching process as well as the visual and auditory information being presented in the Microsoft HoloLens in this study are based on lean principles (Figure 44). The use of lean principles enables manufacturing processes as well as whole organisations to achieve increasingly high levels of efficiency and to compete at a low cost level, while maintaining high speed of delivery and gaining optimum quality (Werrlich, Eichstetter, Nitsche and Notni, 2017). Eight main principles are taken into consideration for the creation of the AR application used in this study (table 7).

Takt	The training with the application can be performed at an individual speed level. The trainee controls the time he or she needs for the training steps autonomously (takt time).
Pull	The trainee is able to get the necessary information at the time he or she needs it. No information is pushed in the process as the trainee retrieves the subsequent information about the task autonomously by saying ‘next’ or ‘back’. Thus, the information is pulled by the demand of the trainee.
Flow	By using a step-by-step presentation of the task with visually and auditory congruent information, the trainee is given a one-piece flow of information.
Zero Defects	Only the correct order, position, and process are demonstrated. Showing how to do it incorrectly can increase the failure rate.
Zero Waste	Constant transparency of all process steps with all necessary information reduces the time for questions and errors. Every step can be repeated as many times as desired. This creates an individual, autonomous training session.
Transparency	Transparency of all process steps and all teaching content is provided. No information is left out. All information can be repeated autonomously.
Standards	Every trainee receives the same information in the same order along with the same visual and auditory stimuli. The best practice is provided to all trainees.
Continuous improvement	Trainees can improve their performance immediately while completing the task. No model learning is necessary because there is immediate learning by trial and error.

Table 7: Lean principles applied for the AR application.

If AR applications are construed taking these eight principles into consideration, procedural tasks will more likely match the complexity of industrial assembly tasks.

5.2.3. Technology

In this section, we describe the hardware and software used in our experiment.

5.2.3.1.Hardware

We used a Microsoft HoloLens (HL) which is an optical see-through HMD with a field-of-view (FOV) of approximately30 * 17 degrees. The HL allows enriching the real environment with 3D virtual information. It works alone with a 32-bit architecture without any additional computer and includes a CPU, GPU, and HPU. Several sensors constantly collect data about the internal and external environment to synchronise the AR world with the real world (figure 45).

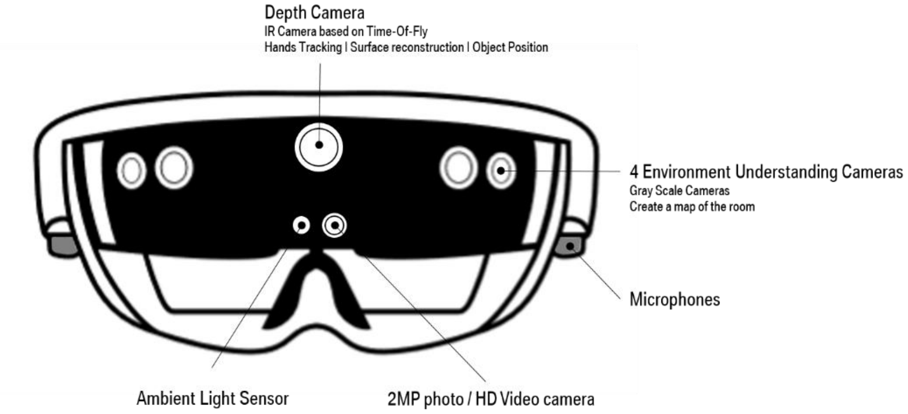
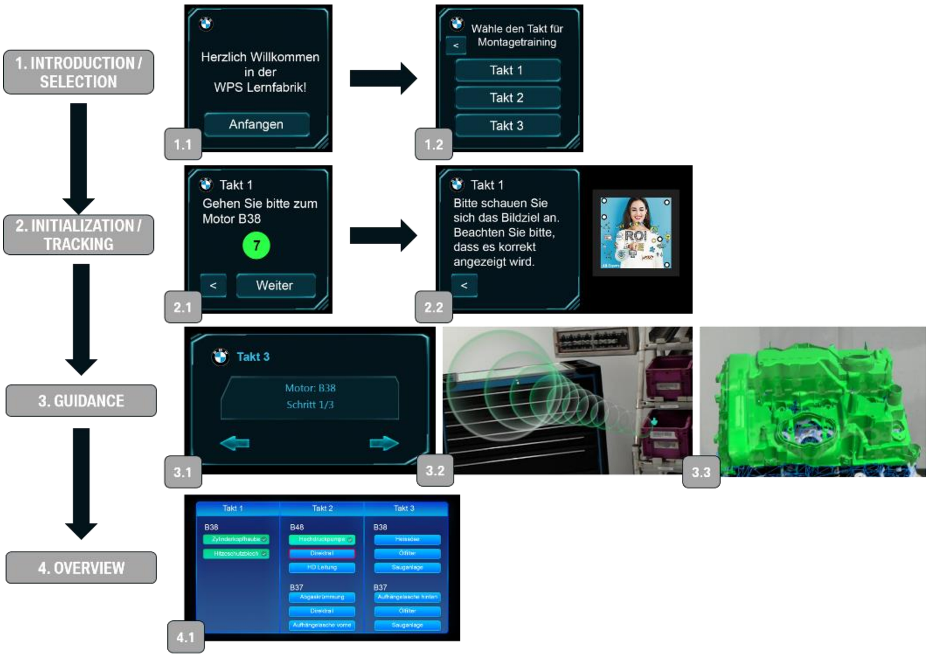


Figure 45: Microsoft HoloLens front view sensor overview.

The inertial measuring unit (IMU) composed of an accelerometer, a gyroscope, and a magnetometer measures the velocity, orientation, and gravitational forces of the HL. Therefore, it is responsible for the three degrees of freedom (DOF) and six-DOF tracking system. The tracking systems consist of three-DOF rotations and three-DOF translation tracking to ensure a truly immersive AR experience. A depth camera in front of the HL is used to capture the gesture tracking (input data). Four more cameras, two on each side, are used to gather the room orientation, which is known as inside-out tracking. The ambient light sensor measures the light intensity in the surroundings and adjusts the hologram brightness accordingly. An additional 2MP photo/HD video camera is integrated in the front of the HMD. The four microphones are used to capture voice input and display audio files.

5.2.3.2.Software

We developed software for the HL using the game engine Unity3D. This game engine offers several advantages for HL application development. Microsoft provides a software development kit (SDK) which is fully compatible with Unity3D, and therefore it is easy to create immersive AR applications. We also used Photoshop for our user interface (UI) design. Our application followed a four-level structure, which is shown in Figure 46.



Herzlich Willkommen in der WPS Lernfabrik!

Wähle den Takt für Montagetraining

Gehen Sie bitte zum Motor B38

Bitte schauen Sie sich das Bildziel an. Beachten Sie bitte, dass es korrekt angezeigt wird.

Figure 46: Software level structure.

At the beginning of the application, the user gets a short audio introduction, combined with a welcome hologram visible in the users FOV (1.1). The user can choose between three different work cycles (1.2) through either air tapping (gesture interaction) or voice command. Every work cycle has a different work content. Once the user selects one of the three work cycles, he or she is asked to walk to the respective workstation. As soon as the user arrives at the given destination, he or she can go to the next step by either air tapping “weiter” or using the voice command next (2.1). The initialisation follows immediately afterwards. The user is encouraged to track the given imagine displayed in the hologram by looking at it (2.2). We used Vuforia image-based tracking for the initialisation and placed the image target relative to the engine using a photogrammetry approach to realise a sufficient overlay. The superimposition remains unaltered as long as the distance between the image target and engine remains unchanged. The training starts after a correct initialisation. We implemented an instruction panel (3.1), which is always visible above the engine, where the user receives text-based instructions about the current task. The user can go further or back by either air tapping the arrows or by using the voice commands ‘next’ and ‘back’. We further implemented a Bezier curve (3.2), which was recommended in [12] as a best-practice approach for guidance at picking tasks. The user receives text information in the instruction panel, additional audio guidance and the Bezier curve to pick the correct part from the shelf. This multimodal learning approach was recommended in a previous study[13]. By saying ‘next’, the user gets to the next visual feature which is a 3D virtual overlay (3.3) and helps to understand the part orientation and location. After successfully assembling the part at the predefined location, the user can continue with the next step.

Building a mental representation of a given procedural task was found to be critical for the learning success (Loch, Quint, and Brishtel 2016). Therefore, we implemented an overview panel (4.1) where the user receives information about finished, current, and upcoming tasks. This holistic overview can help strengthen the mental model building.

The entire software was developed based on previous comprehensive demand analysis (Werrlich, Nitsche and Notni, 2017), general software design guidelines according to the DIN EN ISO 9241-110 [14], and domain specific recommendations (Ergonomics of human-system interaction, 2006; Regenbrecht, Baratoff and Wilke, 2005). We evaluated this software product in order to find weaknesses and compare this learning approach to the established face-to-face training. The next chapter section describes our methodology in detail.

5.2.4. User Study

We conducted a user study with 36 participants to compare the effects of HMD-based assembly training with traditional face-to-face training. This section describes the study design, explains the procedure, introduces the hardware setup, gives detailed information about the participants, and reports the results of our measurements.

5.2.4.1.Design

We used a repeated measure experiment as a study design with one independent variable, namely instructions given by a person (group A) compared with instructions given by an augmented reality application (group B), to test the following hypotheses:

H0: No significant difference exists between face-to-face training and AR-to-face training.

H1: A significant difference exists between face-to-face training and AR-to-face training.

As dependent variables, we considered instruction time, quality (measured by correctly installed parts, correct order of installed parts, picking mistakes, maintaining the required cycle time [45sec] and forgotten parts), system usability scale (SUS) according to Bangor [17], and gained knowledge about the task (questionnaire).

5.2.4.2.Apparatus and Setup

The workplace used for the setup was the VPS learning factory with an assembly line of seven engines. We chose an identical task description for each instruction system (face-to-face, AR-to-face) to ensure that the instructions as well as the tasks featured the same complexity level. The trainees assembled the engines B37, B38, and B48. The workplace is formed by three assembly spots and automated guided vehicles (AGV) that carry the engines on top of them.

The following figure (figure 47) displays the training situation viewed from above. There are three assembly training spots (AP1, AP2, and AP3) and two disassembly spots (DM1, DM2). The engines rotate on the AGVs. For visualisation, imagine a B38 is placed in front of an AP1 where the first trainee assembles all the parts in 45 sec, and subsequently this engine moves in front of AP2, where another trainee assembles the B38, and finally the AGV moves to AP3 and the trainee on this spot assembles the final parts. Finally, the engine B38 is completely assembled. Analogous to this logic, B48 and B37 are assembled.

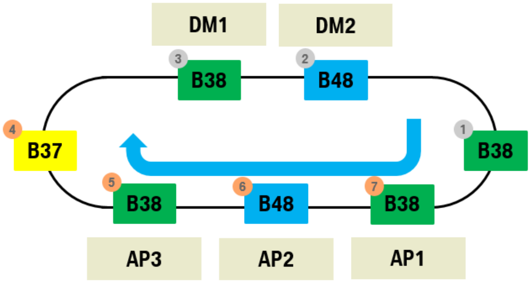


Figure 47: Working space.

This user study is divided into two parts. In the first part, trainees received instructions on how to assemble the engines, whereas in the second part trainees were encouraged to assemble the engines without any assistance. In one group (A), three trainees were provided with instructions on how to assemble the engines by three trainers at the same time, while allocated to their assembly spots. In another group (B), trainers were replaced using the application in the HoloLens. Afterwards, the trainees assembled the engines at the same time following the logic described above.

5.2.4.3.Procedure

Because of the number of participants, the study was conducted on two different days. The procedure was identical on both days. After informing the participants about the main interest of the study and obtaining consent, demographic information (age and sex) was collected. Groups A and B each had a maximum of 20 min to learn how to assemble the engines during the instruction part. Group A was given the relevant task information by a trainer face-to-face. Group B received all relevant task information by an AR application using the Microsoft HoloLens as mentioned above. While the instructions for groups A and B were identical, group B was given an additional 10 min to learn how to handle the device before the training session started. After the training session, each of the two groups assembled the engines without any assistance for 15min. During the assembly, the number of correctly installed parts, the correct order of installed parts, picking mistakes, maintenance of the required cycle time (45sec), and number of forgotten parts were measured.

After the training and assembly session, participants completed the SUS and a questionnaire retrieving the gained knowledge about the task. Fisher's exact test was used to analyse the data.

Figure 48: Instructions by trainer (group A).

Figure 49: Instructions by HoloLens (group B).

5.2.4.4.Participants

We recruited 36 participants (35 men, 1 woman), aged from 16 to 26 years (M= 19.91 SD=2.31). All participants were production mechanic trainees working for an automotive company with no prior experience in using or working with AR. Informed consent was obtained from all participants.

5.2.4.5.Results

During the training, we measured the time needed for installing the required parts. The results showed that assembly training takes more time when using a HMD (H1). Trainees needed 60% more time to complete the training task (Group A: M= 9 min 40 sec; Group B: 15 min 51 sec) in the HMD condition compared with those in the face-to-face condition. This result was to be expected, because trainees first needed to familiarise with the gesture and voice interaction methodology. Once users become used to the HMD, their performance speed is expected to increase. During the immediate recall, we measured numbers of picking mistakes and assembly order mistakes. Results showed that trainees who performed the assembly task with HMD support made 10% fewer picking mistakes, 5%fewerassembly order mistakes, and caused 60% less rework.

During the assembly session, we measured the quality of the training outcome by considering the number of correctly assembled parts. The data analysis showed that a significant difference existed between being trained by a trainer and being trained by AR. The overall quality (Qg) and the quality per tact (Qt1, Qt2, Qt3) were higher when a trainer had given the information. The reason for this outcome was that essential parts of the different tacts were not assembled correctly in the AR condition (HSB, HDP, HDL, HÖ) and therefore overall quality and the quality per tact were higher when the information was given by a trainer.

	N	Fisher´s Exact Test (p)	Significant Difference?	Which method is more effective? (Trainer/AR)
Qg * Group	132	0,009	Yes	Trainer
Qt1 * Group	132	0,011	Yes	Trainer
Qt2 * Group	144	0,004	Yes	Trainer
Qt3 * Group	156	0	Yes	Trainer
ZKH * Group	132	1	No	Equal
HSB * Group	108	0,007	Yes	Trainer
HDP * Group	120	0,097	Yes	Trainer
DR * Group	144	0,49	No	Equal
HDL * Group	120	0,037	Yes	Trainer
AK * Group	24	0,4	No	Equal
AL * Group	24	1	No	Equal
HÖ * Group	156	0,00	Yes	Trainer
ÖF * Group	156	0,183	No	Equal
SM * Group	156	0,198	No	Equal

Table 8: Significance test Days 1 and 2.

Splitting the dataset according to the two study days (day1/day2), it becomes apparent that on day one there was no significant difference between being trained by a trainer or being trained by AR, whereas on day two, there was a significant difference between being trained by a trainer and being trained by AR.

	N	Fisher's Exact Test (p)	Significant Difference?	Which method is more effective? (Trainer/AR)
Qg * Group	66	0,427	No	Equal
Qt1 * Group	66	0,606	No	Equal
Qt2 * Group	72	0,245	No	Equal
Qt3 * Group	78	1	No	Equal
ZKH * Group	66	1	No	Equal
HSB * Group	54	0,583	No	Equal
HDP * Group	60	1	No	Equal
DR * Group	72	0,144	No	Equal
HDL * Group	60	0,143	No	Equal
AK * Group	12	1	No	Equal
AL * Group	12	1	No	Equal
HÖ * Group	78	1	No	Equal
ÖF * Group	78	1	No	Equal
SM * Group	78	1	No	Equal

Table 9: Significance test Day 1.

	N	Fisher's Exact Test (p)	Significant Difference?	Which method is more effective? (Trainer/AR)
Qg * Group	66	0,011	Yes	Trainer
Qt1 * Group	66	0,005	Yes	Trainer
Qt2 * Group	72	0,009	Yes	Trainer
Qt3 * Group	78	0	Yes	Trainer
ZKH * Group	66	1	No	Equal
HSB * Group	54	0,002	Yes	Trainer
HDP * Group	60	0,015	Yes	Trainer
DR * Group	72	0,806	No	Equal
HDL * Group	60	0,195	No	Equal
AK * Group	12	0,545	No	Equal
AL * Group	12	1	No	Equal
HÖ * Group	78	1	No	Equal
ÖF * Group	78	0	Yes	Trainer
SM * Group	78	0,013	Yes	Trainer

Table 10: Significance test Day 2.

After finishing the immediate recall assembly-cycle, trainees were further asked to accomplish a knowledge retention test consisting of four questions. This test aimed to capture the knowledge acquisition of the performed assembly task. The knowledge retention test indicated that trainees using HMD gathered the same knowledge as participants trained face to face (Group A: 94% and Group B: 93% correct answers). The HMD training group was asked to additionally fill out the system usability scale (SUS) questionnaire. This questionnaire, featuring 10items, aimed to rate the usability of our training software to examine whether the HMD-based application fulfilled required acceptance standards for software by the user. Participants were asked to score the items with response possibilities ranging from 'strongly agree' to 'strongly disagree'. Scores from 0 to 100 allowed rating the usability of our system, where 100 meant 'best imaginable'. Results indicated an average SUS of 73.5 which means 'good'. Overall, our HMD-based application constitutes a suitable option for assembly training but still has potential for improvement.

In this study, we compared two different methods of how to train an assembly task (face-to-face vs. AR-to-face). We built an application for a real engine assembly training task and tested the effects on time, quality, picking mistakes, assembly order mistakes, rework, and knowledge retention. The significant quality differences between the two study days could be traced backed to several influencing factors. First, possible process instabilities with regard to the training process itself could have caused these differences. Using HMDs influenced the training preparation, training conduct, and training follow-up. Furthermore the face-to-face training process was well known by the trainer because it has been performed for several years, whereas the AR training process had only been performed for a few months. Therefore, not every process step in the AR training was performed as fluently as in the face-to-face training. Second, individual differences in using communication and information technology and the personal motivation in using new technologies could also affect the variable quality.

In conclusion, it seems AR-based training can be an alternative to face-to-face training but still retains some weaknesses that could not entirely be overcome by including lean principles into to the application. Considering future work, we want to improve our application by providing more user control, adding gamification elements, offering different user modes ranging from a tutorial level to an expert level, and using multimodal information as well as various feedback modalities. Furthermore, we plan to conduct more user studies using a more complex assembly training tasks.

5.3. Value stream analysis—Can AR training also be used in complex tasks such as value stream analysis and how should AR training sessions be designed for more complex industrial training tasks?

This section deals with the following question if and how AR training ca be used effectively in complex industrial tasks and how the AR training sessions should be designed for more complex industrial training tasks to achieve the best results. As an example an AR based Training for value stream analysis will be used to answer the questions empirically.

5.3.1. AR-Based Value Stream Analysis

The term ‘value stream’ describes all stations with associated processes and actions that a product or service undergoes from the supplier to the customer. Value stream analysis/value stream design is one of the most important elements in a lean production system with a focus on improving all processes of a company. In the value stream analysis, the current state of a process is detected and visualised, whereas in a value stream design the target process is presented. The value stream analysis is the basis for optimising a process by reducing waste (Rother and Schook, 2009).

The central idea of value stream analysis is always to take the customer’s point of view, because the customer determines the requirements for the production as a whole and for each individual production process. The value stream is based on the customer and defines added value and waste exclusively due to its needs (Erlach, 2010). With rising digitisation, the customer perspective is moving even further towards the centre. While in the common value stream the customer had no or just a little contact with the different stations within the value stream, the digitisation of products and processes allows an interaction between both. At each station, customer-specific demand can be included as well as different information displayed along the production process, such as the current state of completion, test results, or instructions for the future product utilisation (Hartmann, Meudt, Seifermann and Metternich, 2018).

The goal is to enable a continuous product flow with the shortest throughput time. However, not all activities within a process increase the value of a service or product. Value-adding activities are those activities that increase the value of a product or service from the customer’s perspective. Non-value-added activities are those activities that are currently being performed, although they do not increase the value from the customer’s perspective. The elimination, reduction, or simplification of non-value-added activities in the development of the target state are essential in the value stream design. The value stream analysis creates a high level of transparency of the process flows. Clearly recognisable are the processes that do not contribute to value creation (waste/non-value-adding activities). The value stream analysis is used in addition to the identification of waste mainly for the presentation of delivery and lead times (Rother and Schook, 2009; Erlacher, 2010).Whereas information in this classic view of waste within the value stream was used primarily for production control, with new upcoming methods for collecting and analysing data, information flows play an even more important role and must be designed efficiently. Today, information flow is not only used for production control but also for preventing equipment downtime and the interpretation of real-time data. Therefore, it must have a reasonably defined usage to prevent waste (Hartmann, Meudt, Seifermann and Metternich, 2018).

Every process participant has different ideas about a process. It is crucial to find a common language and a common understanding of the current and future process. To know the true state of the process, there is no need for discussions at the desk. It is essential to go the production area and watch the process (Hartmann, Meudt, Seifermann and Metternich, 2018).

5.3.2. Lean Approach in AR-Based Value Stream Analysis Training

The agile mindset has found its way into the corporate strategy, with business model innovation and lean startup. To protect themselves from the digital disruption of their business models, established companies adapt the innovation methods of lean startup and business model innovation for their innovation projects as previously described in Chapter 4. However, how can traditional methods of lean management such as value stream analysis and design cope with these upcoming methods? The management of ideas and visual design as well as iterative prototyping and design thinking are in their basic understanding not counterpoints to the classic lean principles of pull, takt, flow, zero contraction, and so on. Meaningful use and interaction of these approaches must be forced by companies to cope with future market and industry challenges. Moreover, not only must a rethinking of traditional production methods be made to innovative approaches on the production side, but also the currently used training methods of lean management must be accompanied by technological progress and new thinking.

In contrast to the previously mentioned use case, the focus hereafter does not lie on taking lean principles into account during the creation of the application, but on using new technology/innovation to display lean methods.

5.3.3. Technology—Hardware and Software

In this section, we describe the hardware and software used in our experiment. The study was conducted with the HL as already described in detail in subsection5.1.3.2.Again, the software for the HL was the game engine Unity3D. Our application followed the same four-level structure, which is shown in Figure 50.

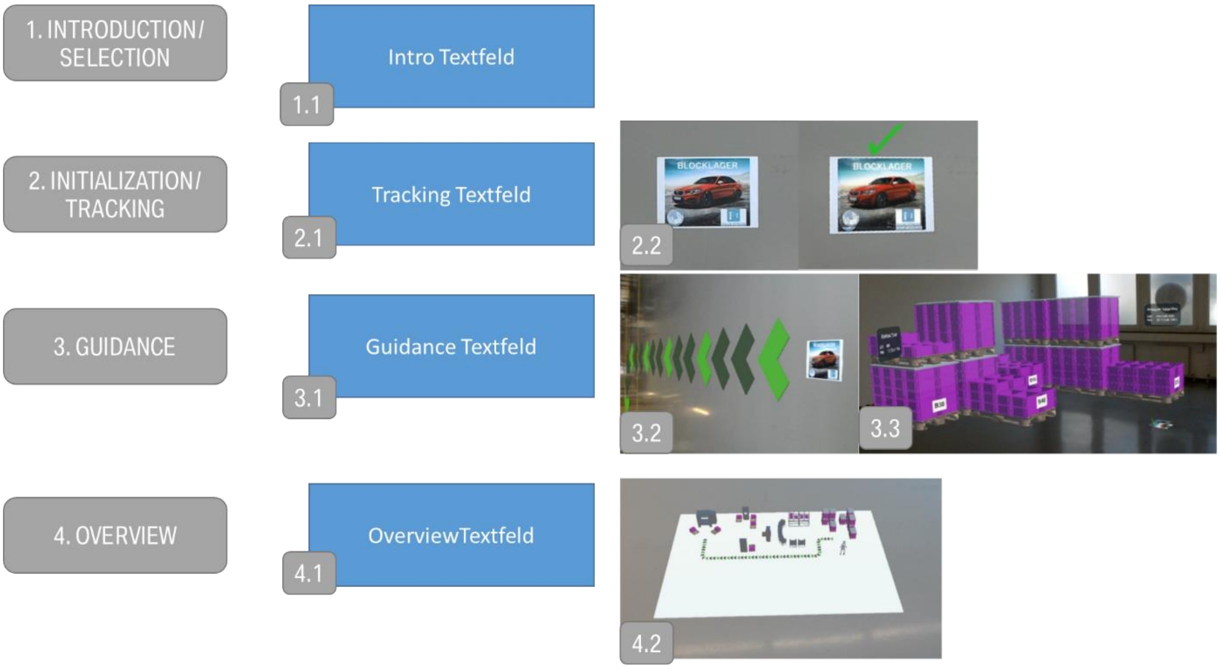


Figure 50: Software level structure value stream analysis.

At the beginning of the application, the user receives a short audio introduction, combined with a welcome hologram visible in his or her FOV (1.1). As soon as the user arrives at the given destination, he or she can go to the next step by either air tapping “weiter” or using the voice command ‘next’ (2.1). The initialisation follows immediately afterwards. The user is encouraged to track the given imagined displayed in the hologram by looking at it (2.2). We used Vuforia image-based tracking for the initialisation and placed the image target relative to the engine using a photogrammetry approach to realise a sufficient overlay. The superimposition stays unaltered as long as the distance remains unchanged. The training starts after a correct initialisation. We implemented a map (3.1) that is visible in front of the user when he or she says ‘map’. The user receives visual instructions about the work area and his or her current location in the area. Furthermore, the user receives text information in the instruction panel and additional visual guidance. This multimodal learning approach was recommended in a previous study[13]. By saying ‘next’, the user gets to the next visual feature, a 3D virtual overlay (3.3), which helps to understand the surroundings and the parts in the location. After scanning the area and writing down the key aspects that can be seen, the user can continue with the next step.

Building a mental representation of a given procedural task was found to be very important for the learning success (Loch, Quint and Brishtel, 2016). Therefore, we implemented a map (4.1) where the user receives information about his or her location in the area and all workstations in the area. This holistic overview can help to strengthen the mental model building.

The entire software was developed based on previous comprehensive demand analysis (Werrlich, Nitsche and Notni, 2017), general software design guidelines according to the DIN EN ISO 9241-110 [14], and domain-specific recommendations (Ergonomics of human-system interaction, 2006; Regenbrecht, Baratoff and Wilke, 2005).We evaluated this software product to find weaknesses and compare this learning approach with the established face-to-face training. The next section describes our methodology in detail.

5.3.4. User Study

We conducted a user study with nine experts to analyse how the app needed to be designed and optimised for the training sessions. The aim was to identify formative weaknesses through a formal-analytical procedure and inspection method (walkthrough) and to optimise the method/application based on these results. The basis for this was the generated qualitative data.

The following subsections describe the study design, explain the procedure, introduce the hardware setup, provide detailed information about the participants, and report the results.

5.3.4.1.Design

A qualitative study design was employed by conducting expert based evaluation in combination with walkthroughs. For this usability evaluation technique, experts were chosen based on their special knowledge and experience resulting from their specific functions within the organisation (Dünser, Grasset, Billinghurst, 2009).Obtaining answers for the following hypotheses was the main focus of the interviews:

H0: AR cannot be used in a reasonable way for the value stream analysis training without any limitations/influence on ergonomic aspects, information intake, and interaction.

H1: AR can be used in a reasonable way for the value stream analysis training without any limitations/influence on ergonomic aspects, information intake, and interaction.

5.3.4.2.Apparatus and Setup

The application starts with an introduction to provide the user with an understanding of the task and individual voice commands.

Subsequently, the user is guided through the predetermined stations of the value stream. This starts with goods receipt (1), followed by block storage (2) for the press. Then, it goes to the actual press (3) and back to the block storage (4) with the focus on the storage for welding. The welding (5) is followed by the supermarket (6) and it finally ends at the assembly (7).

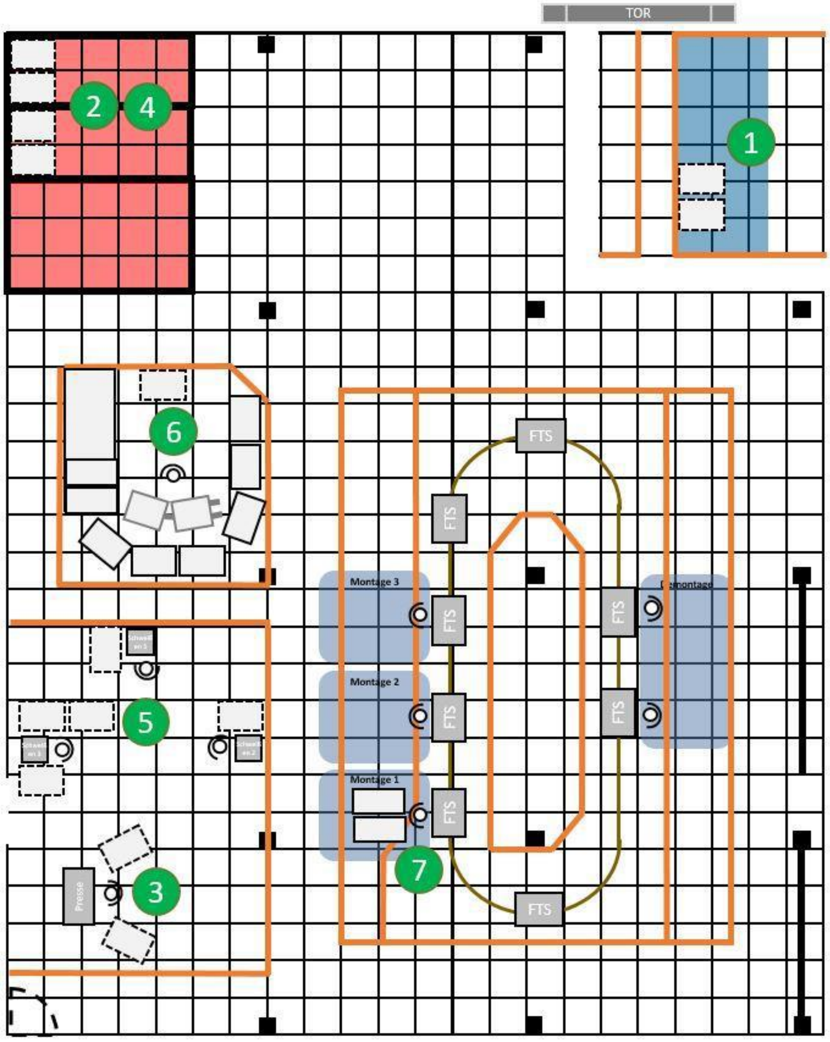


Figure 51: Fabric layout of the VPS Center.

At each station of the value stream (1–7), information about the parts and processes is provided for the learner. Thus, in the end every participant in the training is able to demonstrate the value stream in the logic presented in Figure 52.

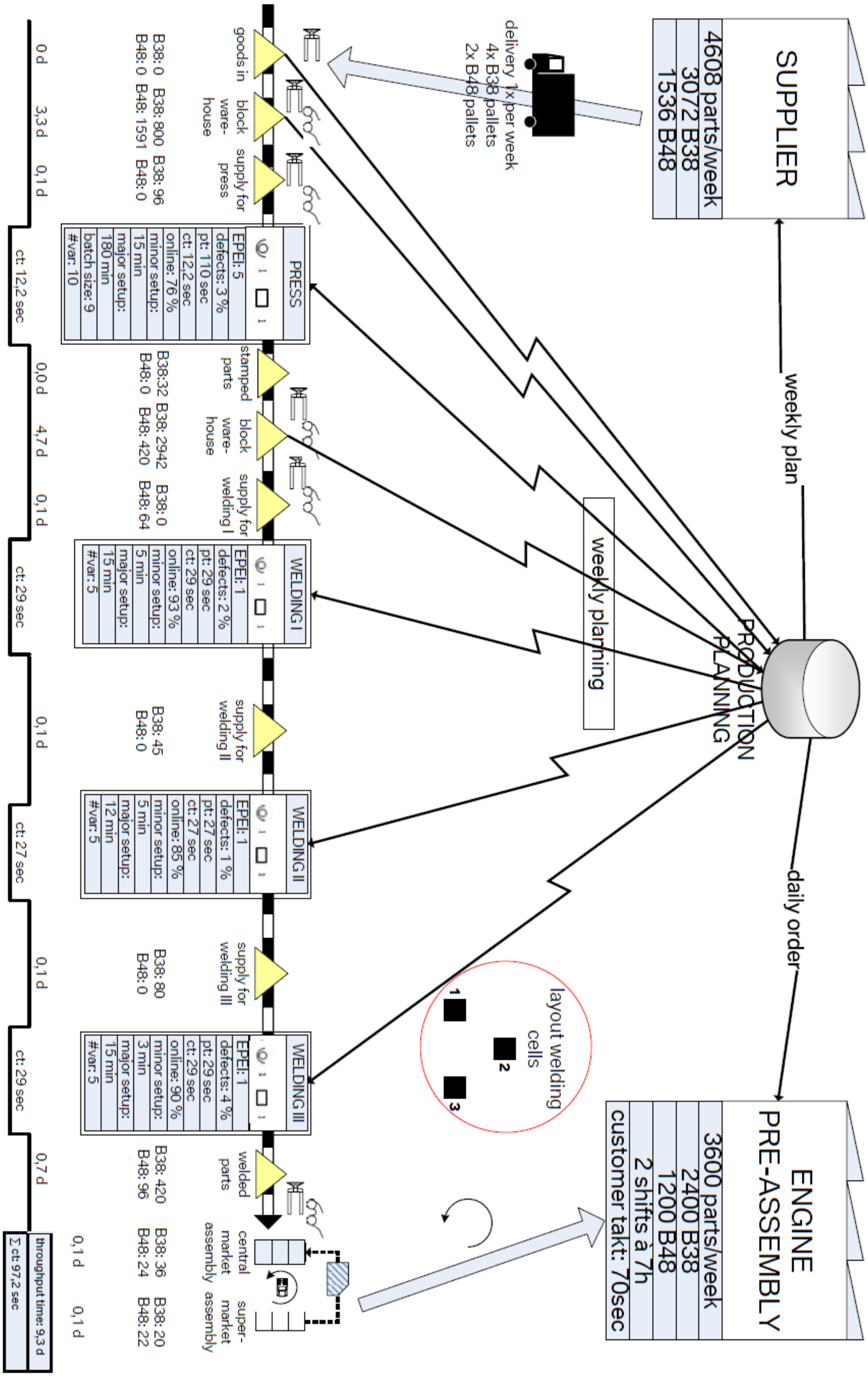


Figure 52: Value stream heat shield.

5.3.4.3.Procedure

A total of three expert groups tested the value stream application with the HL. The interviews were conducted with the think-aloud method while testing the application in the VPS Center Training area. All sessions were recorded and influencing or disruptive factors were noted by the interviewers.

The interview was semi-structured focusing on the five main categories of ergonomics, instructions, interaction, information take in, and general usability. The interviews with the expert groups were conducted on three different days and every session lasted 1 hour and 30 minutes.

5.3.4.4.Participants

A total of nine experts tested the application, comprising six men and three woman aged from 27 to 60 years. Group A consisted of two IT specialists of the BMW Group having at least 5 years' experience in AR applications and AR training; Group B consisted of three consulting experts of the BMW Group who conduct value stream analysis and design projects on a daily basis in the organisation; and Group C consisted of four VPS trainers of the BMW Group who conduct lean management trainings on a daily basis. Therefore, Group A evaluated the application methodology from a technological point of view; Group B evaluated it from a practitioner/methodologist point of view; and Group C evaluated it from a training point of view.

5.3.4.5.Results

As a result of the interviews, the various experiences of the experts regarding value stream projects, AR-technology, and training resulted in five influencing factors (ergonomics, instructions, interaction, information take in, and general usability), so-called fields of action that, in regard to the transfer process in the training session may have a driving or inhibiting effect. Below, the fields of action are named and their meaning, conduct, and optimisation are briefly described.

Ergonomics. One of the most crucial factors that must be taken into consideration while creating an application is the ergonomic aspect. Typical for AR applications is the so-called simulator sickness, motion or cyber sickness that can occur while using HMDs. Symptoms such as nausea or/and visual-induced dizziness appear while wearing an HMD, because the virtual image cannot adapt to the head movement of the user in real time (Biocca, 1992;Dörner & Steinicke, 2013).

The large size of the training area as well as the high number of virtual objects that must be displayed by the HL led to several ergonomic limitations. First, based on tracking problems when placing objects into the real world, the visual objects were distorted and flickering (Groups A and B). Second, getting used to seeing virtual elements needs time. Perception in general includes the interpretation of information in a reasonable way for the individual to react to their surroundings (Malim, 1994).

Third, the limited field of view is a problem in large training areas because the head must be moved even more often, and that extra head movement results in the aforementioned motion sickness symptoms.

In addition, the weight of the HMD in combination with the wearing duration of 60 minutes was mentioned as a negative ergonomic aspect (Groups A and B). In particular, the guidance arrows on the floor intensified this feeling.

As a solution, the guidance arrows were placed higher to eliminate looking at the floor to reduce strain on the back, neck, and shoulders. In addition, the training concept was customised in a way that participants were not wearing the HL for the whole training session but were able to take it off every 10–15 minutes. A high intensity and contrast of colours used, for example, on the white map and magenta boxes were minimised to decrease intensity on the eyes.

Instruction. The user only benefits from the application if he or she understands what to do. Therefore, the structure of the application as presented in figure 50 is one of the most vital aspects. Instructions can be divided into three main categories—textual, visual, and acoustic (Brough, Schwartz and Gupta, 2007).

Textual: A well-maintained home screen, a so-called intro, can thus be of great use to introduce the user to the functionality of the application. Experience has shown that it is often the case that overly-long running texts are only skimmed over by users because they simply do not want to have to read a lot within the application.

Visual: The timely display of a microphone symbol reminds the user of the voice commands and provides guidance in the application. In addition, the display of arrows to move from one learning station to another is featured to ensure guidance in the application.

Acoustic: For example, an audio file can be played at the welding station, which tells the participant which welding cell should now be started (Ackermann, 2018). Furthermore, acoustic instructions always depend on the environment in which the application is used. Since the volume level in the WPS centre is relatively low, the instructions would be clear; however, it may still happen that audio instructions are easily overheard.

Only the combination of textual, visual, and acoustic instructions achieves the best effect and increases the attention of the participants.

Interaction. Game-based learning is already commonplace in schools and can be beneficial in training situations as well (Werrlich, et al., 2018). Human–device interactions are a critical issue in AR knowledge. While most people are willing to learn new knowledge, they want to have more fun during training because these sessions often take a lot of time and are designed to be very serious. To implement these gamification elements that create a playful effect for the participant, green glowing animated arrows on the ground were realised in the value stream app, which were regarded as ‘very good’ (Schilberg, 2018) as well as ‘cool’ (Nguyen, 2018). Within the training area, however, the pathfinding must be well-engineered and optimally functioning so that under no circumstances is it possible for participants get into areas that are not part of the training session. The animation of the arrows was seen as a first good start but, to create an even more playful impression, a pathfinding solution should be added and the arrows that have already been passed should be virtually deleted, which was suggested by Group A. The first version of this more playful interaction is the creation of a virtual route train guiding the user from the supermarket to the assembly, responding to the movements of the participant. The route train as a signpost was very well received across groups, especially by Group A (Nguyen, 2018) and was even referred to as ‘unbelievable’ (Group B). One should, however, make sure that the route train remains within the field of vision while following it. If necessary, it should only show the way symbolically to reduce head movements and to protect the neck again (Group B).

The mini-map schematically shows a miniature version of the layout of the training area of the value stream. Users receive a top view and locate themselves immediately in the value stream on the basis of a tiny avatar. Expert group B suggested additional information, such as measurements, to what extent the individual stations stand apart from each other, and that the map should not only represent the value stream schematically but also display the complete layout of the area, including ancillary areas that have nothing to do with the value stream to obtain the overall picture, providing more information to the user. Thus, the learner is integrated into the virtual world in the first-person perspective and as an avatar, the graphical counterpart of the user in the virtual world. The presentation as an avatar promotes the presence experience of the learner (Slater & Usoh, 1993).

To convey the processes and information at individual stations even more playfully, pressing equipment**,** virtual and animated employees should be implemented at the station; for example, removing the parts from the corresponding boxes to machines (Group B). In addition the process times should be taken into account, such that the virtual employee really takes the time and the participant receives and controls this information (Group C). This would enhance the first-person experience and depict the complexity of the task. Adding to this a background noise, which is typically present within a factory, should be played (in a certain volume) in the glasses to generate an even more immersive experience (Group C). This enhances the principle of sensory scaling, in which directly perceptible sensory impressions (e.g., sound) can be directly experienced by subjects by being transformed into perceptible stimuli (e.g., by setting noise; Jenewein & Hundt, 2009).

Regardless of gamification elements, the AR application needs to be designed to receive positive feedback, which is realised with an acoustic positive confirmation sound in the application. This sound was seen as very helpful by Group A.

Furthermore, a help command should be integrated that can be called at any time. The most intuitive method for the participant to call this function would be by means of the voice command ‘Help’ (Group A). Information that is not familiar to the participant should have a small help button that displays a window with more detailed explanations after selection. With a high number of participants, it may occur that individuals do not dare to ask something. This is useful, for example, for abbreviations in machine descriptions of the systems, as they should not simply be written out. This is justified by the fact that in reality they are also abbreviated in the respective data boxes of the machines (Group B).

Information intake. Using AR technology, it is possible to create learning environments that are impossible to implement with conventional training strategies, and therefore stand out from traditional pedagogical approaches (Kozma, 1991). In connection with augmented learning environments participants are regarded as active information processors (Reinmann-Rothmeier & Mandl, 1998) (constructive instruction theories: Kontogiannis, 1999, Schaper, 2000). The acquisition of knowledge and skills is a result of a targeted examination of the learning content. Using AR, virtual objects can be faded into the user’s field of vision in a way that they appear to be actually present. One main focus of the value stream application is to keep the responsibility for collecting required information for the analysis in the hand of the participants. That is achieved by presenting a complex system that is oriented specifically to the learning requirements of heterogeneous learning groups through the attention to realistic sizes, geometries and materials and a degree of networking (Group B). A better understanding is achieved through the use of transparencies (Group C). In general, in augmented training sessions, learning from mistakes is easier to realise and an extensive flexibility and individualisation of learning times and places is guaranteed (Jenewein & Schulz, 2007). Thus, machines should display even more signs than needed, such that the participant can filter them by relevance and only write down the most necessary ones (Group B). The training is not just about gathering information, but also recognising it, sharpening the focus, and possibly even missing some of it (Group B). However, virtual learning environments carry the risk of losing themselves in the variety of possibilities (Heiß, Eckhardt & Schnotz, 2003, Schwan & Buder, 2006). For example, the suggestion to show the complete block warehouse of a production with several different parts virtually (Group B) could increase pressure on the participant to find the necessary stocks for the first time and result in cognitive overload (Group C). Particularly in the case of little prior knowledge, cognitive overload of the learner is threatening, since the learning process itself already requires the capacities that are needed for the orientation and successful application of learning aids (Jenewein & Hundt, 2009). By contrast, virtual vision automatically places a focus on the fields that are displayed (Group B). The focus continues on a sequence of snapshots presented to the participant (Group C). Thus, the danger exists of missing the overall picture and the information behind the actual stations, such as ergonomic aspects (Group C).

In addition, for value-adding activities, employees and work processes should be virtually animated (Group C).To insert employees in order to see from which pallets parts have been taken and where these are forwarded after the activity enhances the process understanding of the learner/participant, which cannot be achieved by traditional training methods.

Consciously renouncing strict image loyalty and eliminating irrelevant learning aspects with the learner focusing only on the essential contents is defined as schematic illustration. Thus, the balance between the presented information needs to be found in the application, not leading the participant too much, because in reality there is always some confusion, but leading him or her enough to minimise the risk of cognitive overload.

Furthermore, the degree of networking and knowledge sharing in the actual value stream analysis are critical because they are about discussing the individual stations within the group to discover even more than the participant actually sees in advance (Group C). The importance and necessity of sharing knowledge in training sessions as well as in organisations has already been proven by several studies (Yang, 2004). The sharing climate itself always seems to be informal. It has been confirmed that the stronger the knowledge sharing climate an organisation has, the greater the degree of organisational effectiveness it attains (Yang, 2004). Thus, it is absolutely vital that the use of AR technologies for training sessions does not destroy or negatively influence that.

General Usability. The usability of a learning programme is a crucial prerequisite for a system being used without complications and successful learning sessions (Niegemann, 2008). The detection of usability should not only take place when the application is already completed (as seen in the use case before) but also needs to be a part of the development stage of an application as well (predictive evaluation).

As suggested by Jenewein and Hundt (2009), usability is categorised into satisfaction, efficiency, and effectiveness of the application, which are described as follows:

- **Satisfaction** can be grasped by means of spontaneous utterances or explicit questioning of the learners (Jenewein & Hundt, 2009). The approach of the application to the topic was considered as very positive (Group A, B, C) and referred to as ‘awesome’ (Group B).
- **Effectiveness,** in this context, describes the learner’s ability to achieve his or her goal due to the design of the learning programme. Criteria for effectiveness are the achievement of the goal itself as well as the information about which and how much relevant information was retrieved, and also which information was not included in the solution of the problem (Jenewein & Hundt, 2009).Displaya value stream supported by AR is basically possible. Basically, the optics and the ability to represent the previously seen number of parts is seen as a great advantage. Thus, not only snapshots but also the entire volume of the material are displayed. If this is compared with the analogue version, where the stations are only partly built up, itis also a big leap to understanding the number of parts. In addition, there is an understanding of the dimensions; in value stream training, not only are ways spared but also areas with their management and transport are cost factors (Group C).
- **Efficiency** is defined as the ‘ratio of resources to results’ (Niegemann, 2008). In this context, AR creates a great remedy because set up times are reduced and the flexibility can be increased by creating a different training mode that reacts to limitations

> according to the training area or the knowledge/learning level of the learner. Thus, the value flow is expanded further and the trainers receive more flexibility and complexity in the training session (Group C). However, it should be noted that the training with AR, according to the estimation of the trainers, will take significantly more time. This is because the participants can walk through the value stream at their own pace, which in itself causes a good learning effect; however, the time windows of the training agenda are tense. In addition, there is a risk that the curiosity about this new technology at the beginning of the training is so great that the actual task becomes negligible (Group C).

Taking these and all aspects from the previous chapters into account, it becomes clear that it is not yet advantageous to convert the value stream analysis training to 100% AR with the HL.

Several use scenarios are going to be possible for the use of the application. First, a handful of HL scan be provided in training, with the aim of enabling the participant to retrieve the value stream again after the analogue value stream recording with a trainer is finished. If the participant during the classic training session has not understood something, he or she can retrieve this quickly and even collect the missing information on their own (Group B). Second, the classic value stream analysis would not be replaced completely, but could be performed in parallel with three participants using AR. These three people then receive an HL and join the normal group. A mix of different trainings methods can be achieved and a first impression of an AR value stream training can be created (Group C).

Overall, it must be kept in mind that learning in the transformation processes that companies are undergoing today in the automotive industry faces two challenges: first, it has to convey new knowledge about digital technologies and contexts that are necessary for the further development of the production system (AR-Assembly Training), and second, it has to place known or existing contents in a new context in an harsh industrial environment with synchronised workflows (AR-Value Stream Training). This increases the demands on the trainers as well as on the learners (Quandt, Knoke, Groldt, Freitag and Thoben, 2018).

For this reason, technological developments and the sensitisation of employees to developments must not be overlooked, but the existing requirements of a manufacturing company must also be taken into account. Again, the concept of ambidexterity and the balance between exploration and exploitation are clearly reflected.

Therefore, how and to what extent the compatibility of lean and innovation and the resulting ambidexterity can be achieved on a micro level is discussed in the following section.

5.4. Compatibility at a Micro level—Conclusion of the Use Cases

Overall, the research design of the two use cases investigated a multitude of questions that arose in connection with the compatibility of lean and innovation on a micro-level. However, strengths as well as weaknesses of the two different forms—namely lean principles used in supporting an innovation and innovation used to support lean principles/methods—particularly with regard to their suitability for learning processes, can thus clearly be demonstrated.

First, using lean principles when conducting innovation projects helped to successfully create an application, but not all weaknesses were overcome. It was shown that the inclusion of lean principles does not represent a sufficient method to implement innovation projects meaningfully. The main principles defined by Schuh et al. (2015) should be taken into consideration, and lean innovation should be applied not only within the innovation process itself but also even more so in concrete implementation phases of projects, to achieve the goal of a waste-free and customer-oriented innovation project—this can be a sufficient solution. Already following the main lean innovation principles such as human-centred, focused, and pragmatic design, the principles of failing fast and staying flexible must be enhanced even more in future projects. The focus of lean innovation is the learning speed, and it cannot only be about pure profits at first. Attempting to test many solutions and not stiffening up early was neglected at some point in the AR assembly training, but needs much more attention to get an even better result by using lean to support innovation projects.

Second, the use of innovations to train and transform classical lean methods helps employees to clarify the compatibility of lean and innovation on an individual level and enhances the creation of a basic understanding of the meaningful networking and application of both elements. The goal must be to sustainably rationalise the entire innovation process as well as mastering complex product and project programmes in the production system. Data and information are easier to obtain and evaluate and even accelerate lean principles and methods. That is why digital idealisation can enormously enhance existing ideals and ideas, as many more decision-making options are available. The main aim is to be digital but intelligent and to avoid waste, as demonstrated by the value stream analysis training. By promoting and advancing quickly and transparently with correct standards and simultaneously being agile, improvements and concepts will be of even greater importance. Furthermore, the focus must continue to be on exchanges and networks, because only through the exchange of information at the digital and personal/informal levels can progress can be achieved.

People continue to be one of the most important factors a company possesses to survive on the market. Therefore, the micro level of compatibility of both elements should by no means be ignored. It could be shown that, especially at a project level, it makes sense to strengthen the mindset regarding the compatibility and usability of lean for innovation and vice versa. As already shown at the macro and meso levels, it is not only crucial to anchor new and radical ideas in existing systems but also to further develop the existing/old proven technologies and methods with new ones.

A central result of the scientific explanatory approach to the mechanisms of change, with reference to the basic ground for development, is that it is ultimately network actors on an employee and project level who drive the transformation of production systems. This applies both to change impulses and change strains within the system. Thus, the decline of manufacturing companies cannot be attributed to radical changes but rather to the inability to adequately respond to these changes (Ehrenmann, 2014). This is where ambidexterity and complexity play a crucial role by influencing the establishment of an efficient social system (e.g., employees and organisational culture) that can overcome these inabilities. As mentioned earlier (subsection2.4.3.),the parallelism of the necessary but not economically resilient investment in strategic innovations on the one hand, and the profitable, efficiency-oriented optimisation of the core business on the other, becomes obvious and resembles the paradoxes and contradictions that inevitably arise in the organisation and therefore need to be explained by managers. The classical management instruments obviously do not take into account the peculiarities of the challenges faced by the automotive industry and are able to solve the paradoxes and contradictions in the organisation. It is therefore necessary to examine the extent to which these instruments are able to support the necessary ambidexterity without losing sight of the human factor and simplify complexity at a social system level.

6. Conclusion

In this work, the importance of lean and innovation—as a relevant form of ambidexterity for the development as well as production and distribution of innovative products and processes—was demonstrated. It is only through cooperation or the ability to combine the two approaches/strategies (exploration and exploitation) that the strengths of the individual network members can lead to efficient process management. The increasing importance of this ambidexterity on all levels—macro, meso, and micro—can be proven both theoretically by the evolutionary-economic approach and empirically by a survey with different empirical tools. After considering the advantages and disadvantages as well as the attempt to classify OEMs in their use of exploration and exploitation within patent applications, the innovation project within the company with AR underscored the areas in which competitive advantages can be achieved compared with conventional forms and strategies. The remarks in this chapter illustrate the great competitive potential of lean and innovation within a whole industry and the participating companies on the market.

Moreover, with the transformation of the automotive sector towards e-mobility and the anticipated structural changes along the value chain as a result of digitisation, industry and especially OEMs must reassess and, if necessary, redefine their position on the market. 2019 and 2020 are challenging years for the international automotive markets. In 2019 the European passenger car market (EU-28 and EFTA) exceeded its 2018 result. While in Europe a growth from 1.0 % for newly registered passenger cars can be seen, other large volume markets returned varying results. Asian markets showed weak development, Russian market contracted and in the US, the light vehicle market (passenger cars and light trucks) showed a decrease of -1.0%. (VDA, 2020)

In terms of global competitiveness and market access, the analysed OEMs are in a strong position in the automotive industry and are now competitive. In this way, opportunities offered by new technologies, innovations, changes in demand, and growth in international markets can be exploited. However, today, what still contributes to being able to compete in the future can slow or even prevent the future viability of tomorrow. Thus, the balance between exploitation and exploration strategies is more necessary and important than ever before.

Furthermore, a holistic rethinking of the macro, meso, and micro levels is required. At each level, stable structures and methods must be linked to new ideas and technologies, as illustrated in this work in the example of lean and innovation. Programmes to rebuild the electro mobility market, technology leaps, national and international laboratories for new mobility, reorientation of infrastructure policy, research funding, employment and skill initiatives, and structural policy initiatives are measures that must be taken to ensure a competitive industry in the future (Wells, 2010; Goodwin, 2012; Manderscheid, 2014)

Referencing the increase in patent applications from 1979 until 2007/2008, the decrease during the financial crises, followed by an increase since 2010, it was shown that companies have applied for more patents in the field of H01/H02 (electrical drive strain) from 2010 onwards, due to the innovation potential in battery technology and charging infrastructure. The fact that an average of only 10% of all patents are explorative innovations and the percentage of explorative innovations of the electrical drive strain (15%) is 5% higher than the percentage of explorative innovations of the combustion drive strain (10%), shows that the automakers, with their 90–10/85–15 approach, have found a balance between radical and incremental innovation, thereby being lean and agile. This balance seems to blend in with the corporate culture, leadership, and other industry-specific challenges. Moreover, it could therefore be displayed that it is crucial to establish a form of innovation that suits the respective area and topic, but also the company’s own organisational culture.

Especially in times of transformation, stronger investments in R&D are future-oriented and a prerequisite for the continuation of technological leadership and ensuring the competitiveness of OEMs. However, by setting the right framework, it is still essential that innovations must find their way into the market.

As new topics always require new skills, the qualification and further training of employees is more crucial than ever. People continue to be one of the most valuable factors a company has to survive on the market. However, people becoming impeded in the transformation of the sector due to a lack of qualifications must be prevented. The shift in mobility offerings require a creative inclusion and the compatibility of innovations to secure good working conditions along old and new value chains. The micro-level of compatibility of both elements, lean and innovation, should by no means be ignored. It could be shown that especially at a project level it makes sense to strengthen the mindset regarding the compatibility and usability of lean for innovation and vice versa. As already shown at the macro- and meso-levels, it is not only significant to anchor new and radical ideas in existing systems but also to further develop the existing/old proven technologies and methods with new ones. The combination of being agile and lean therefore plays a key role within a lean production system and has a main influence on innovation. However, with traditional thinking centred solely on immediate benefit and fear of change and failure, tomorrow’s big ideas are hard to find in today’s mainstream markets. In future research, the question should be answered of to what extent the potential can best be exploited through the use of business management instruments. Due to not considering the peculiarities of the challenges faced by the automotive industry, the classical instruments of innovation management evidently are failing. Therefore it is crucial to identify possible deficits and adapt the instruments to the changed conditions by means of the modification, redesign, or design of new methods. Moreover, it is necessary to examine the extent to which these instruments are able to support the necessary ambidexterity without losing sight of the human factor. Subsequently, indispensable requirements for efficient and effective use of classical instruments as well as the use of new methods must be defined.

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Appendix

Data categorization patent application combustion and electric drive strain

Drive reference	Acquisition method	Object reference	Criterion
combustion	IPC-Classification	Subsystem combustion drive strain	IPC classification F01: prime movers and work machines or prime movers, power plants, steam engines
			IPC classification F02: internal combustion engines, engines operated with hot gas or exhaust gases
electric	IPC-Classification	Subsystem electric drive strain	IPC classification H01: Basic electrical components
			IPC classification H02: Generation, conversion or distribution of electrical energy

Results Patente Citatios vs Company

Cit_Total * Company Kreuztabelle

Amount

		Company															
		Bayerische Motoren Werke AG	Daimler AG	Volkswagen AG	Toyota Motor Corp	Tesla Motors, Inc	Hyundai Kia Automotive Group AG	Tata Motors Ltd	Lucid Motors	Mitsubishi Motors Corp	Renault-Nissan BV	Ford Motor Company Corp	General Motors Corp	Fiat Chrysler Automobiles N.V	PSA Peugeot Citroën SA	Zhejiang Geely Holding Group Co	Gesamt
Cit_Total	0	514	1264	1209	3111	4	22	53	0	28	1763	280	105	165	628	58	9204
	1	39	62	84	331	0	6	4	0	27	152	44	55	30	34	4	872
	2	159	224	293	1210	8	18	8	0	74	663	183	225	158	146	8	3377
	3	495	585	613	2532	27	60	33	6	170	1554	572	499	601	378	19	8144
	4	774	774	1077	3235	17	112	54	0	219	2253	907	721	957	582	67	11749
	5	761	945	1153	3360	42	99	35	0	274	2427	1047	828	1033	869	125	12998
	6	613	629	937	2317	24	80	18	0	167	1873	855	450	939	661	44	9607
	7	497	371	759	1505	21	52	0	7	107	1411	732	345	688	425	37	6957
	8	311	356	576	1078	24	24	18	0	60	1072	512	108	377	385	40	4941
	9	325	252	427	764	27	12	10	0	54	751	325	153	411	149	9	3669
	10	128	126	351	275	0	10	0	0	20	470	181	133	294	80	25	2093
	11	67	44	151	279	0	31	0	0	11	204	78	22	102	78	11	1078
	12	60	50	122	162	0	12	0	0	0	175	62	38	139	37	0	857

13	53	13	85	78	0	0	0	0	13	132	40	0	30	14	0	458
14	28	56	87	115	0	0	0	0	14	85	28	14	14	14	0	455
15	30	20	95	0	0	0	0	0	0	15	15	0	32	15	0	222
16	35	0	66	17	0	0	0	0	0	58	49	0	36	0	0	261
17	0	0	70	17	0	0	0	0	0	0	53	17	34	0	20	211
18	0	0	19	0	0	0	0	0	0	36	0	0	0	0	0	55
19	21	0	19	0	0	0	0	0	0	0	0	0	38	0	0	78
20	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20
21	0	0	0	21	0	0	0	0	0	0	21	0	21	0	0	63
22	0	0	0	22	0	0	0	0	0	0	24	0	0	0	0	46
25	0	0	26	0	0	0	0	0	0	0	0	0	28	0	0	54
26	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	30
30	0	0	0	0	0	0	0	0	0	0	0	0	31	0	0	31
31	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	32
Gesamt	4930	5771	8219	20429	194	538	233	13	1238	15094	6008	3713	6220	4495	467	77562

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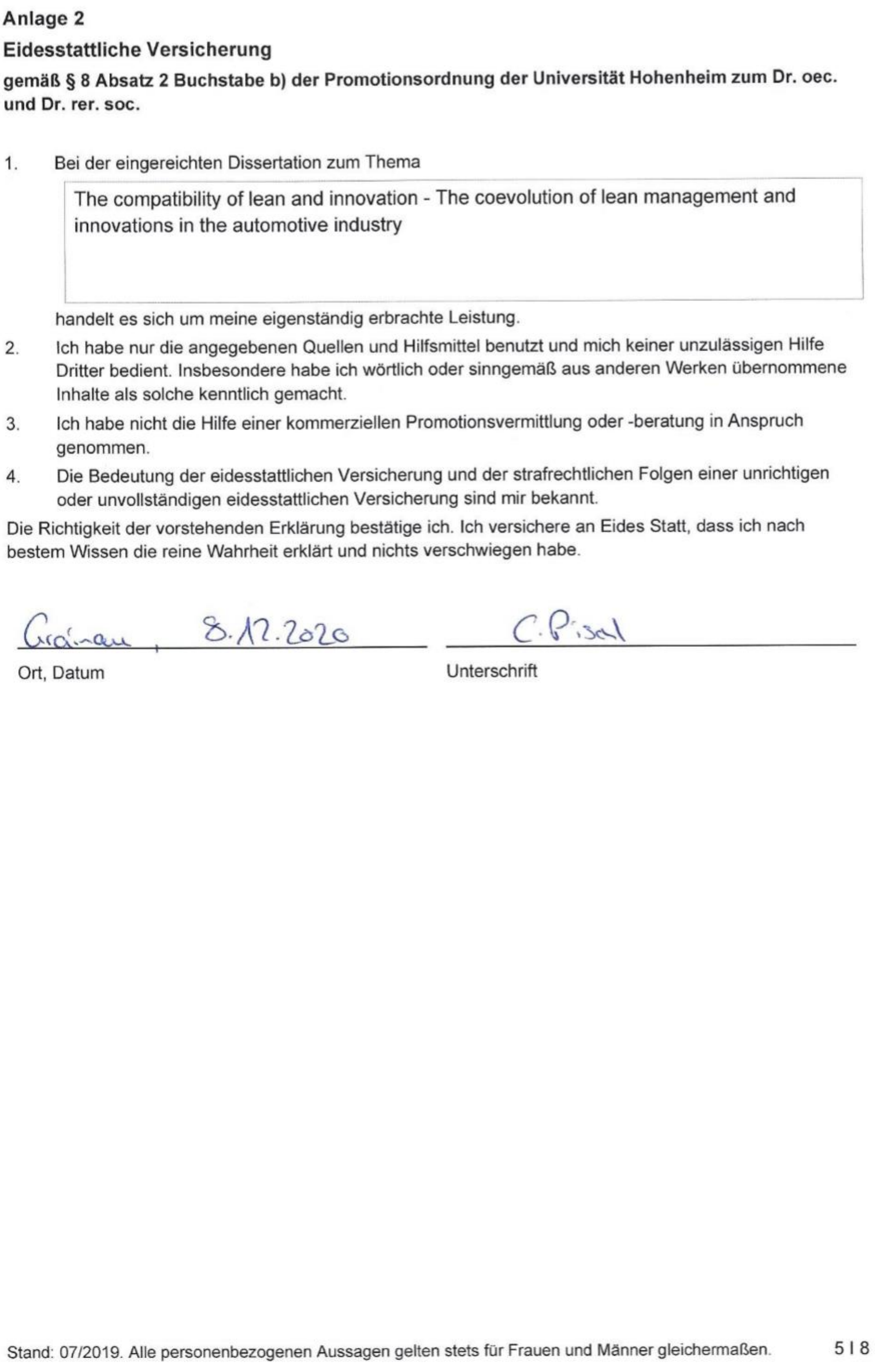
Carolin Pischl



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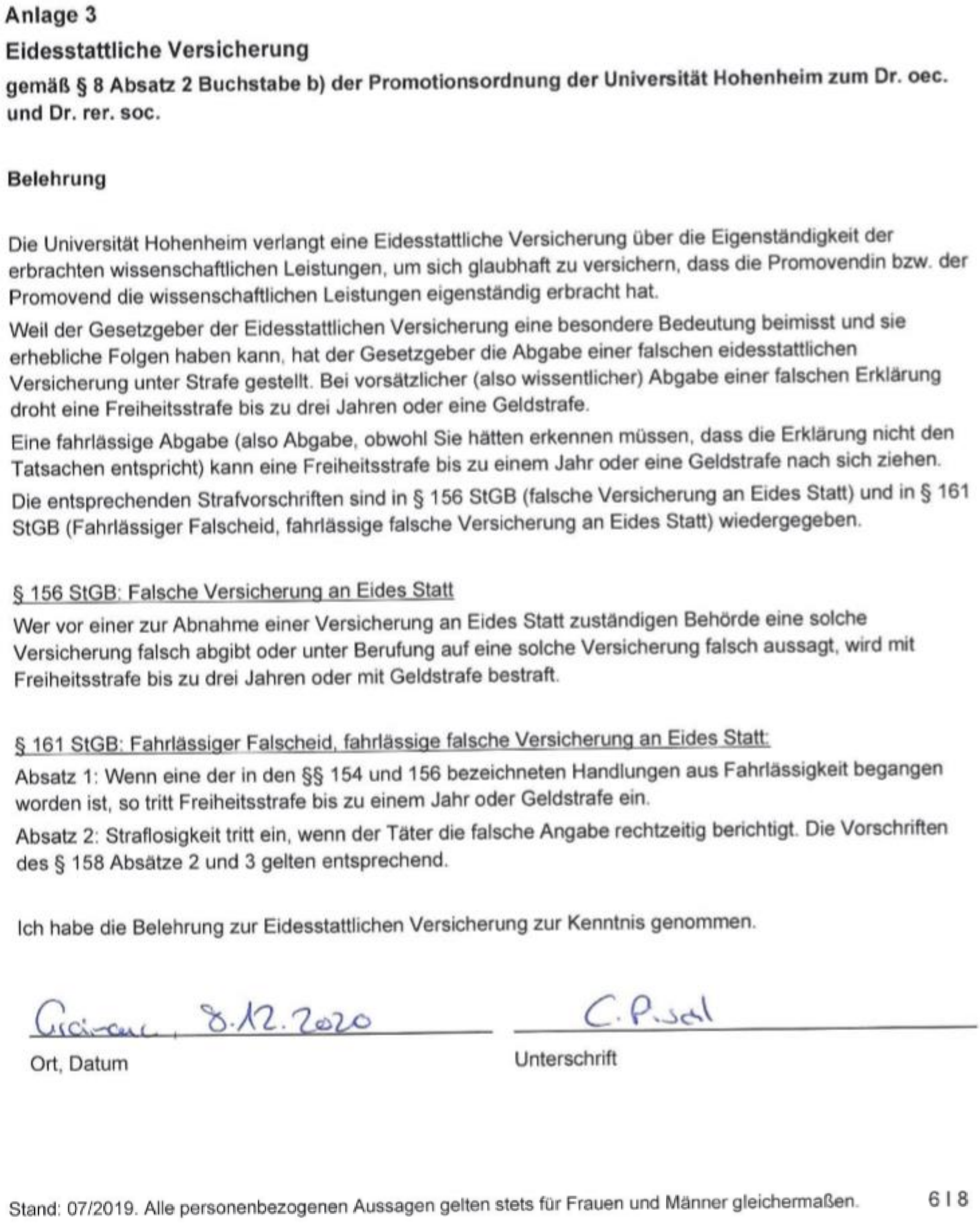

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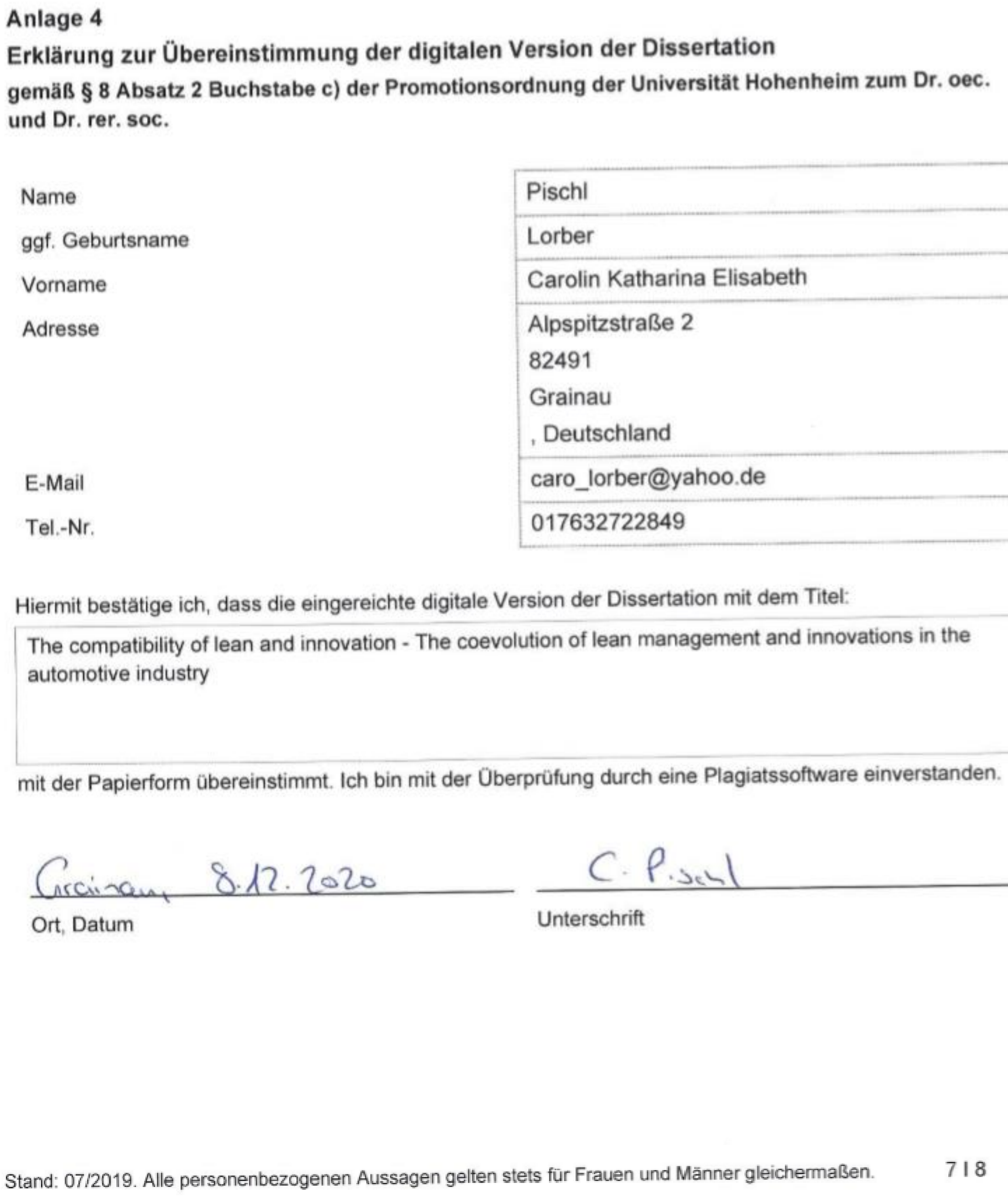

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7 | 8

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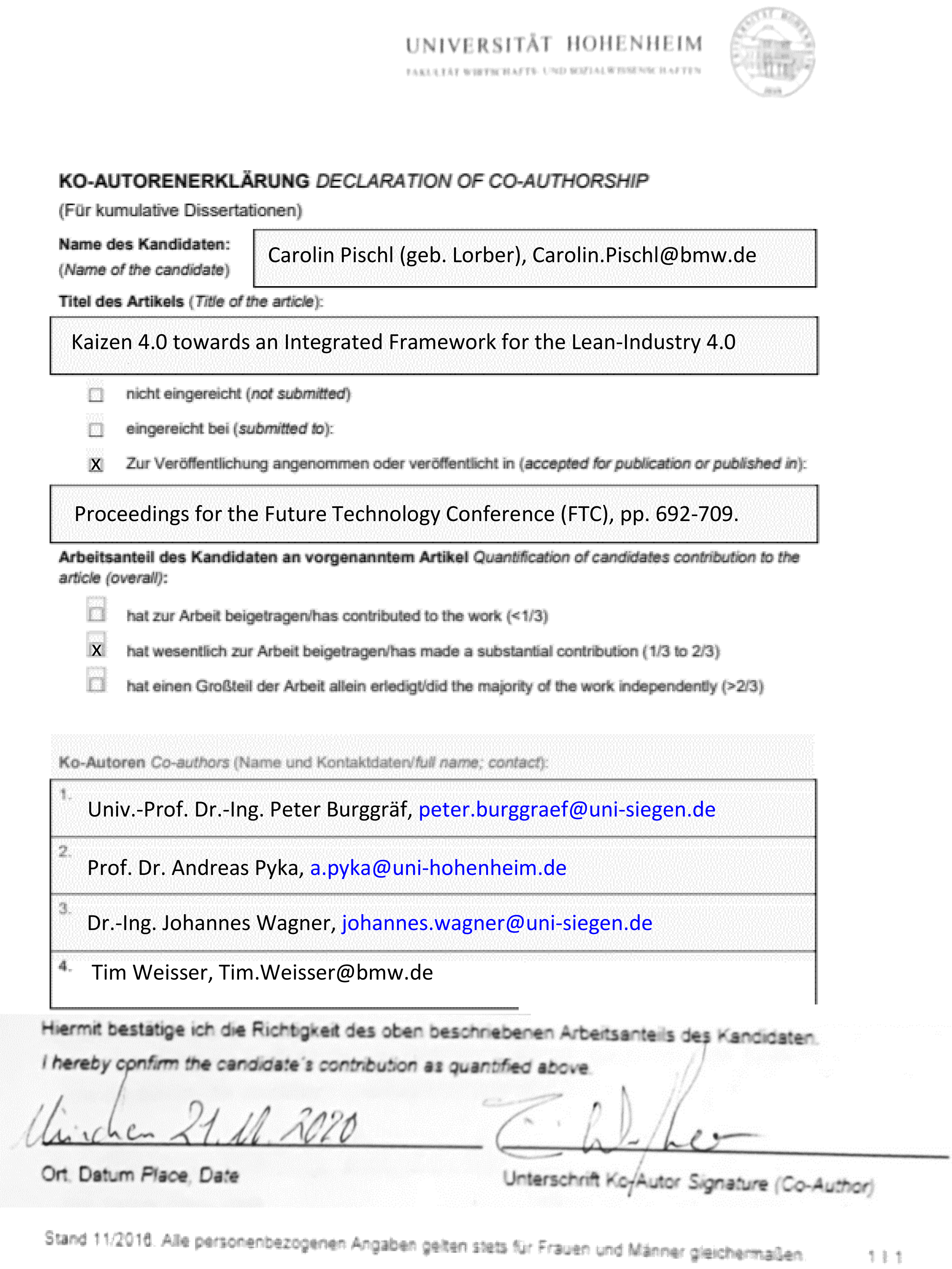

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Kaizen 4.0 towards an Integrated Framework for the Lean-Industry 4.0

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- ☐ eingereicht bei (*submitted to*):
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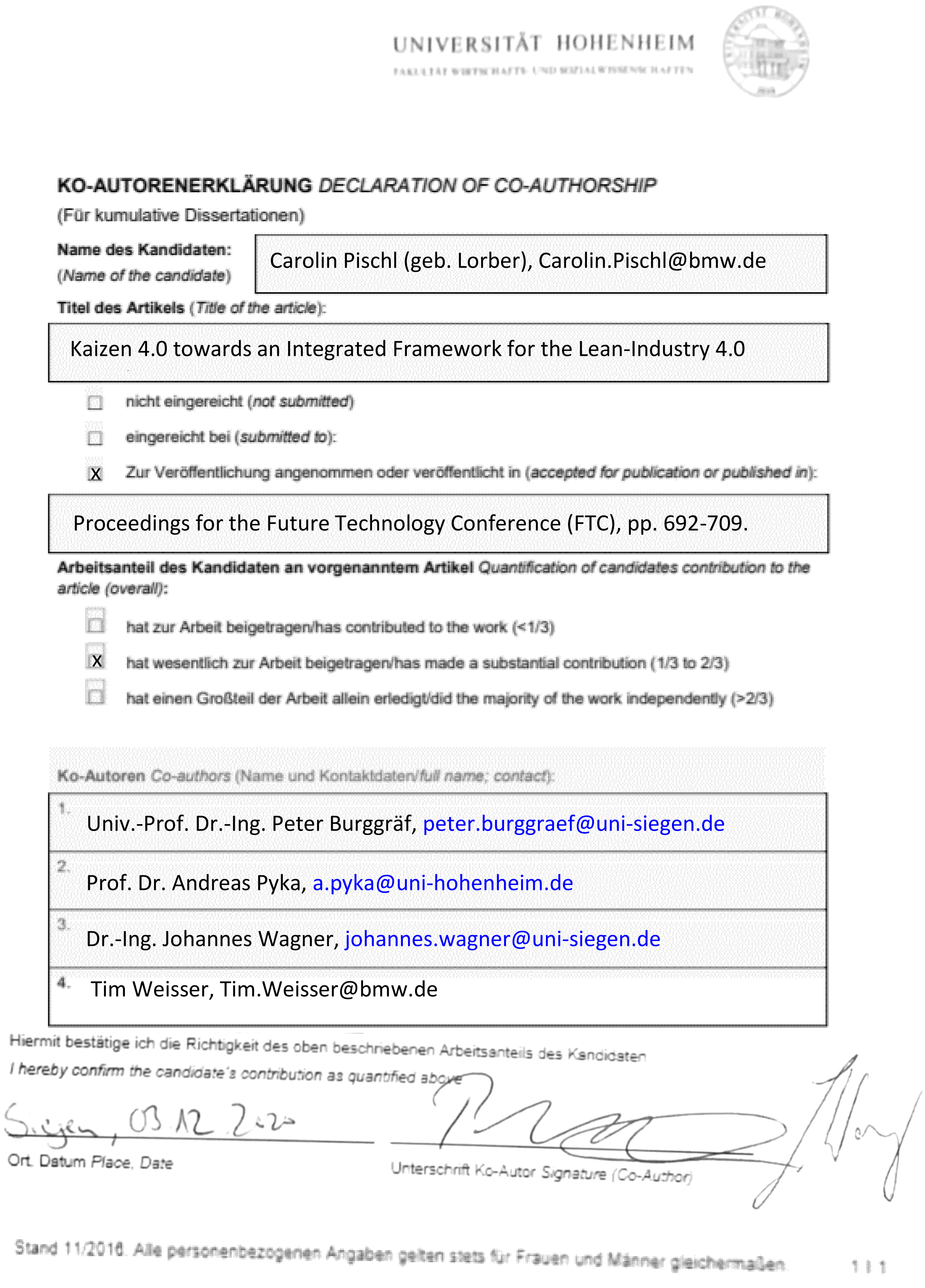

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Prof. Dr. Andreas Pyka

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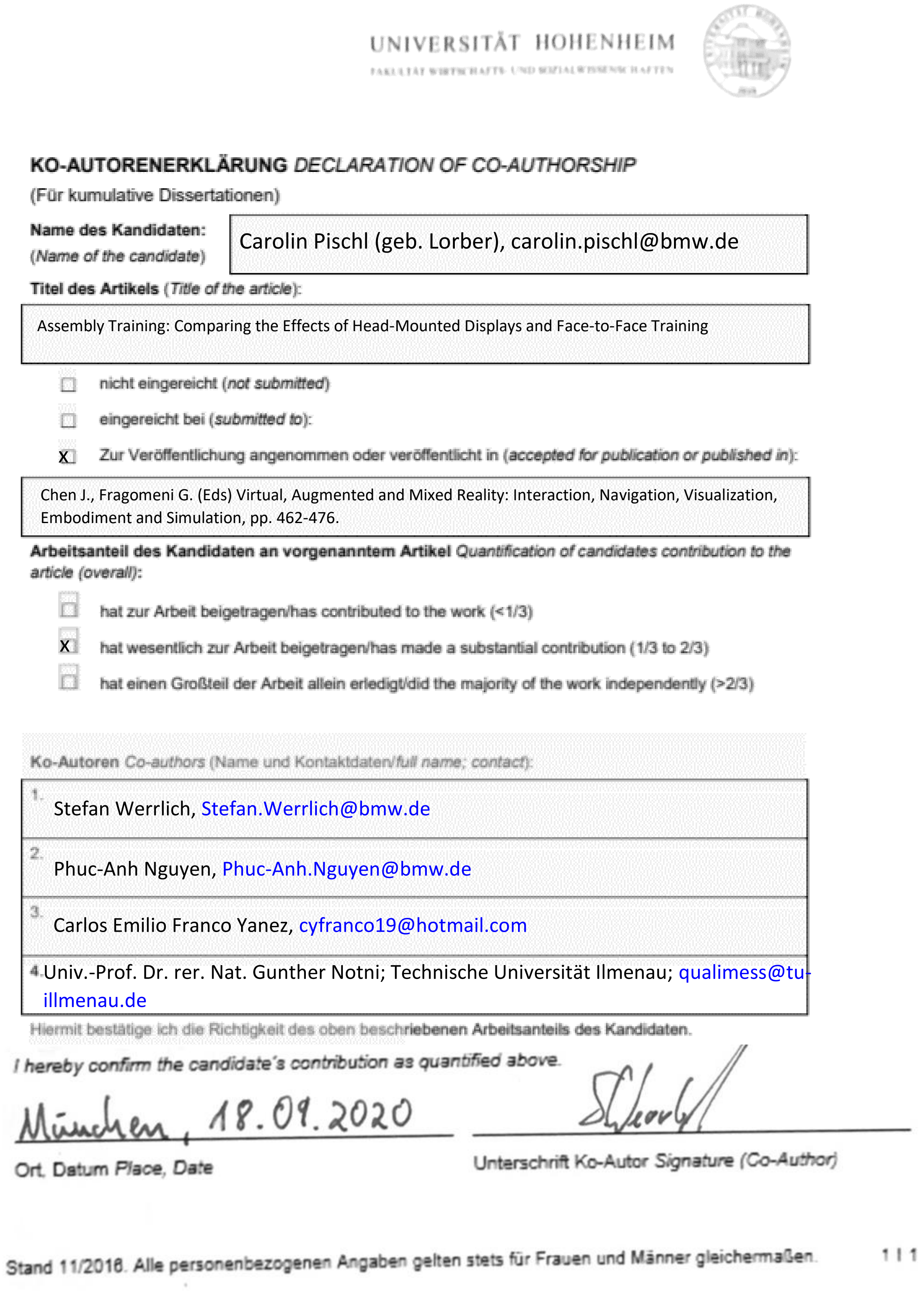

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Chen J., Fragomeni G. (Eds) Virtual, Augmented and Mixed Reality: Interaction, Navigation, Visualization, Embodiment and Simulation, pp. 462-476.

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☐ hat zur Arbeit beigetragen/has contributed to the work (<1/3)

☒ hat wesentlich zur Arbeit beigetragen/has made a substantial contribution (1/3 to 2/3)

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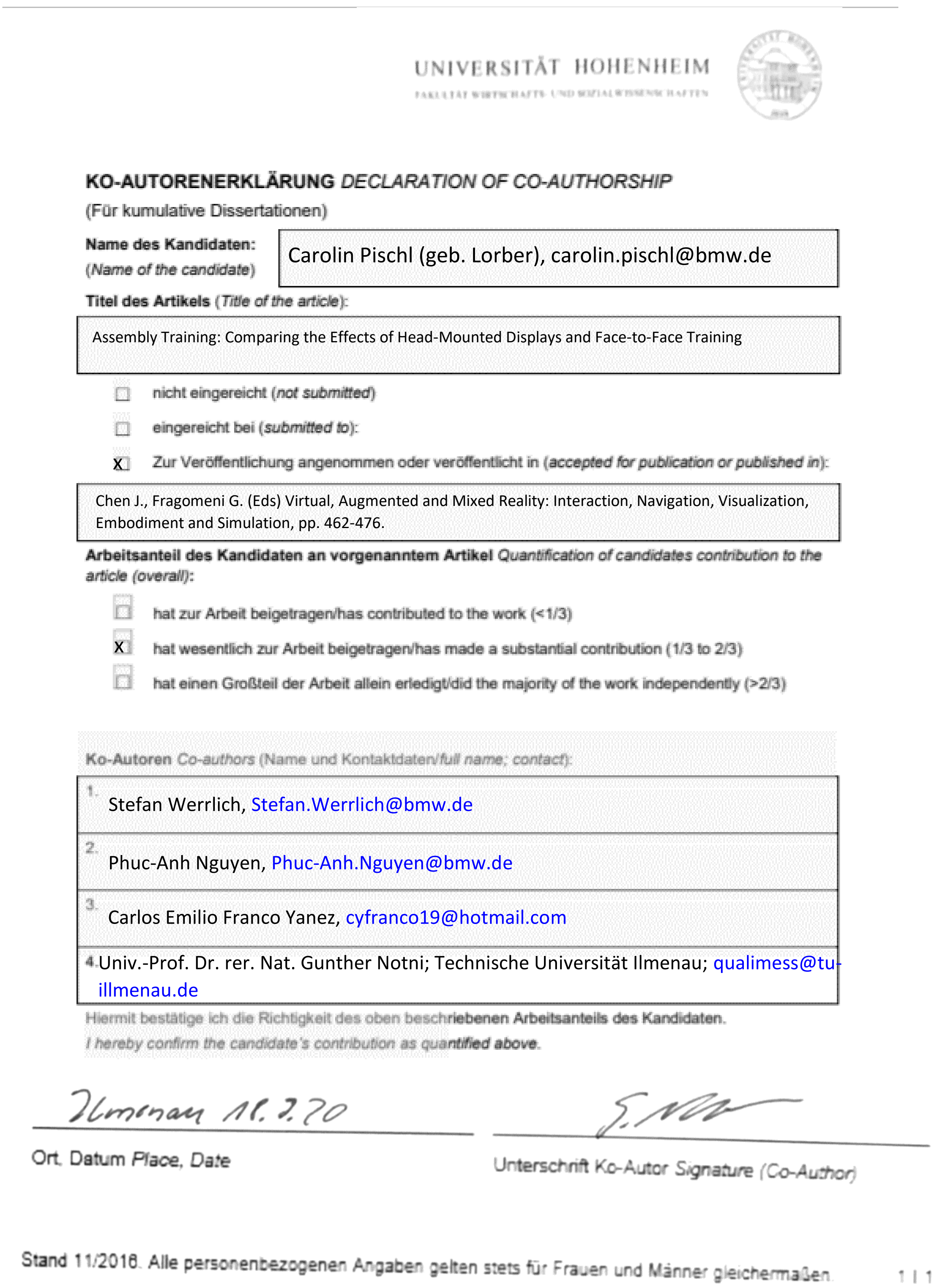

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KO-AUTORENERKLÄRUNG *DECLARATION OF CO-AUTHORSHIP*

(Für kumulative Dissertationen)

Name des Kandidaten: (*Name of the candidate*): Carolin Pischl (geb. Lorber), carolin.pischl@bmw.de

Titel des Artikels (*Title of the article*):

Assembly Training: Comparing the Effects of Head-Mounted Displays and Face-to-Face Training

☐ nicht eingereicht (*not submitted*)

☐ eingereicht bei (*submitted to*):

☒ Zur Veröffentlichung angenommen oder veröffentlicht in (*accepted for publication or published in*):

Chen J., Fragomeni G. (Eds) Virtual, Augmented and Mixed Reality: Interaction, Navigation, Visualization, Embodiment and Simulation, pp. 462-476.

Arbeitsanteil des Kandidaten an vorgenanntem Artikel *Quantification of candidates contribution to the article (overall)*:

☐ hat zur Arbeit beigetragen/has contributed to the work (<1/3)

☒ hat wesentlich zur Arbeit beigetragen/has made a substantial contribution (1/3 to 2/3)

☐ hat einen Großteil der Arbeit allein erledigt/did the majority of the work independently (>2/3)

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Hiermit bestätige ich die Richtigkeit des oben beschriebenen Arbeitsanteils des Kandidaten.
I hereby confirm the candidate's contribution as quantified above.

Ilmenau 11.2.20

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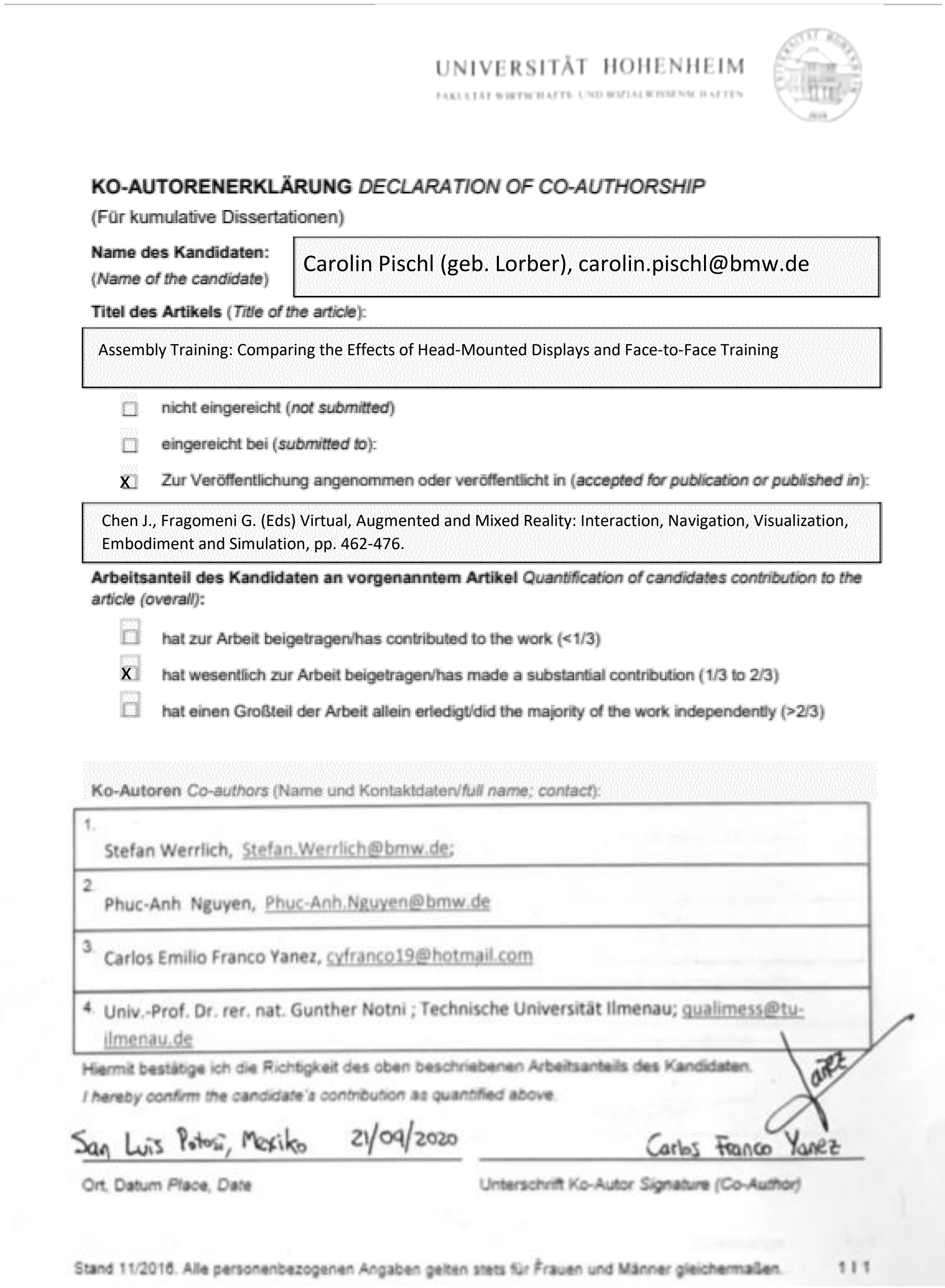
Stand 11/2016. Alle personenbezogenen Angaben gelten stets für Frauen und Männer gleichermaßen. 1 | 1

Carlos Emilio Franco Yanez



UNIVERSITÄT HOHENHEIM
FAKULTÄT WIRTSCHAFTS- UND SOZIALWISSENSCHAFTEN

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San Luis Potosí, Mexiko 21/09/2020

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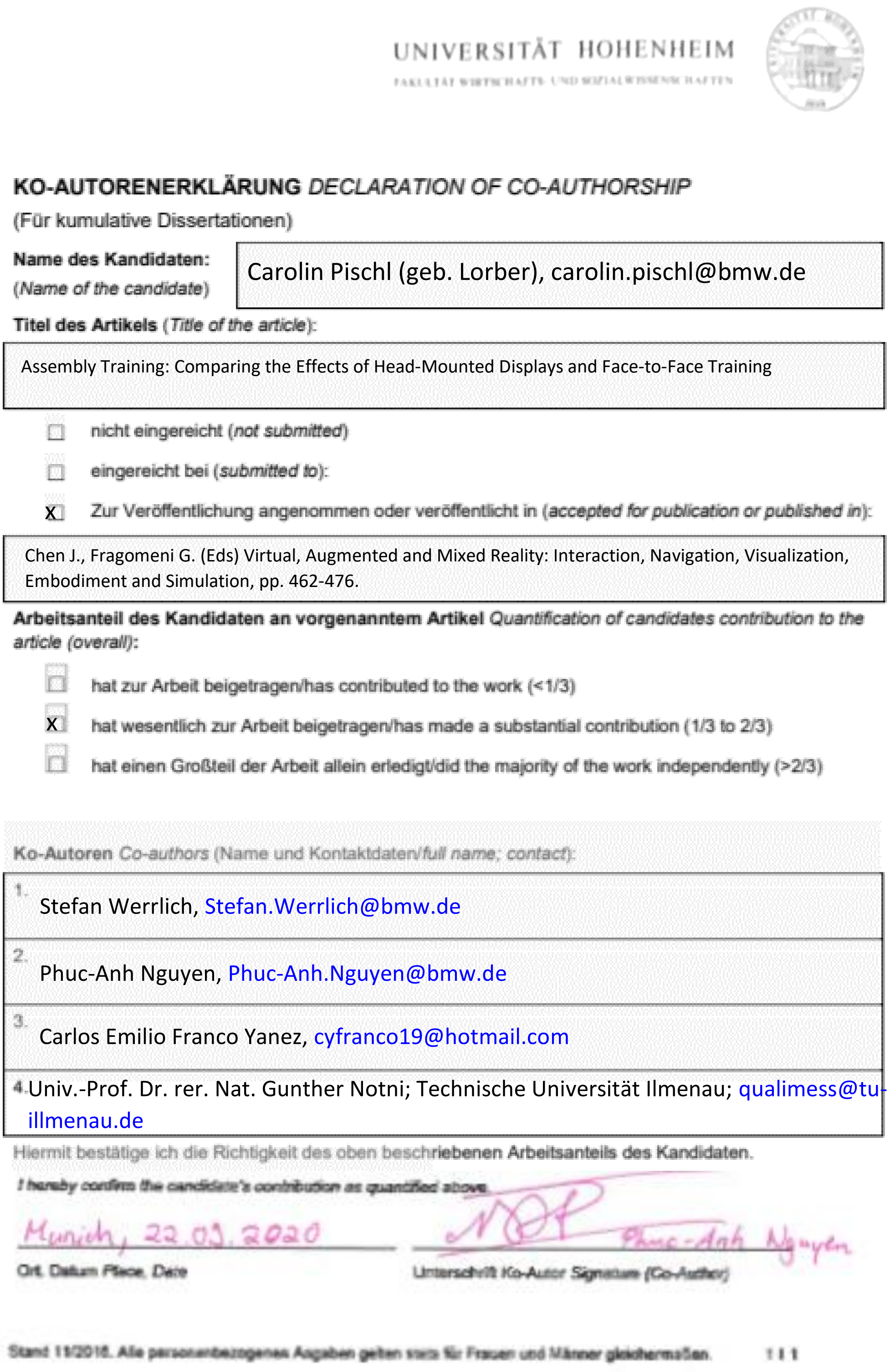

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Hiermit bestätige ich die Richtigkeit des oben beschriebenen Arbeitsanteils des Kandidaten.

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Munich, 22.03.2020 Phuc-Anh Nguyen

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Stand 11/2016. Alle personenbezogenen Angaben gelten stets für Frauen und Männer gleichermaßen. 1 1 1

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Titel des Artikels (*Title of the article*):

VPS Center

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Lorber C. & Stäudel T. (2019) VPS Center. In: Abele, E., Metternich, J., Tisch, M. (Eds) *Learning Factories.* Concepts, Guidelines, Best-Practice Examples (Berlin: Springer), pp. 458-459.

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I hereby confirm the candidate's contribution as quantified above.

Darmstadt, 20.11.12

Ort, Datum Place, Date

Unterschrift Ko-Autor Signature (Co-Author)

Stand 11/2018. Alle personenbezogenen Angaben gelten stets für Frauen und Männer gleichermaßen. 1 | 1

Burggräf, P., Lorber, C., Pyka, A., Wagner, J. & Weisser, T. (2020) Kaizen 4.0 towards an Integrated Framework for the Lean-Industry 4.0 Transformation. *Proceedings of the Future Technologies Conference (FTC)*, pp. 692-709.

Deutsch: Konkrete Konzepte, Methoden und Technologieprojekte auf operativer Ebene können nicht mehr mit etablierten Methoden aus den Feldern Lean und Industrie 4.0 umgesetzt werden um den steigenden Kundenansprüchen, wachsendem Wettbewerbsdruck, und streben nach Individualität im Produktdesign gerecht zu werden. Eine zielgerichtete Auswahl und Bewertung von Projekten ist nötig, um gesteckte Ziele zu erreichen und wettbewerbsfähig zu bleiben. Als Basis dient die Arbeit von Spath et al. 2017 und Schuh et al. 2017, um in einem modellbasierten Ansatz die Komplexitätsreduktion bei anspruchsvollen Entscheidungsfindungen bei der Transformationen von Lean zu Digitalisierung und Industrie 4.0 zu erörtern und anhand eines Reifegrad- und Verfahrensmodell darzustellen, wie Projekte ausgewählt und beurteilt werden können, die der Zielkonfiguration den Unternehmens entsprechen.

English: Concrete concepts, methods and technology projects at the operational level can no longer be implemented with established methods from the fields of Lean and Industry 4.0 in order to meet increasing customer demands, growing competitive pressure and strive for individuality in product design. A targeted selection and evaluation of projects is necessary in order to achieve and maintain set goals. The work by Spath et al. 2017 and Schuh et al. 2017 is the basis, in order to establish a model-based approach to discuss the reduction of complexity in demanding decision-making in the transformation from lean to digitization and Industry 4.0 and to use a maturity and process model to illustrate how projects can be selected and evaluated that correspond to the company's target configuration.

Lorber C. & Stäudel T. (2019) VPS Learing Factory. In: **Abele**, E., **Metternich**, J., **Tisch**, M. (eds) *Learning Factories. Concepts, Guidelines, Best-Practice Examples.* (Berlin: Springer), pp. 335-459.

Deutsch: Die Motivation, der Hintergrund und die didaktischen Grundlagen der Lernfabrik zum Thema WPS werden erörtert. Das VPS Center dient als Best-Practice-Beispiele einer Lernfabrik und wird detailliert und strukturiert vorgestellt. Es werden der aktuelle Stand der Lehrplangestaltung sowie deren Einsatz zur Förderung von Lernen und Forschung sowie Potenziale und Grenzen aufgezeigt. Anhand praktischer Beispiel wird aufgezeigt wie die Lernfabrik im Trainingsalltag eingesetzt wird um unterschiedliche Zielgruppen im Produktionsprozess zu schulen. Zusätzlich wird anhand von Beispielen wie Augmented Reality erörtert, welchen nutzen die Lernfabrik für Forschungsthemen darstellt.

English: The motivation, the background and the didactic basics of the learning factory on the subject of VPS are discussed. The VPS Center of the BMW Group serves as best practice examples of a learning factory and is presented in a detailed and structured manner. The current status of curriculum design and its use to promote learning and research as well as potential and limits are shown. Using practical examples, it is shown how the learning factory is used in everyday training to train different target groups in the production process. In addition, examples such as augmented reality are used to discuss the benefits the learning factory provides for research topics.

Werrlich, S., Lorber, C., Nguyen, P. A., Yanez, C. E. & Notni, G. (2018) Assembly Training: Comparing the Effects of Head-Mounted Displays and Face-toFace Training. In: Chen J., Fragomeni G. (eds) *Virtual, Augmented and Mixed Reality: Interaction, Navigation, Visualization, Embodiment, and Simulation*, pp. 462–476.

Deutsch: Interaktive Assistenzsysteme (z. B. Head Mounted Displays) dienen in heutigen Trainingssituationen dazu Mitarbeiter möglichst Realitätsnah zu schulen. In dieser Arbeit wird mittels einer empirischen Studie in der BMW internen Lernfabrik der Unterschied zwischen konventionellem Anlernen mit einem Trainer versus Anlernen durch Augemented Reality Brillen untersucht. Die Ergebnisse zeigen, dass es keinen Unterschied zwischen den beiden Anlernmethoden gibt, und sogar durch HMD-Unterstützung 10 % weniger Kommissionierfehler, 5 % weniger Montage Fehler und 60% weniger Nacharbeit verursacht wurden. Die HMD-Anlernmethode stellte sich allerdings als deutlich langsamer im Vergleich zu einem Trainer heraus.

English: Interactive assistance systems (e.g. Head Mounted Displays) are used in today's training situations to train employees as realistically as possible. This work uses an empirical study in the BMW internal learning factory to investigate the difference between conventional learning with a trainer versus learning with augmented reality glasses. The results show that there is no difference between the two training methods and that even with HMD support, 10% fewer picking errors, 5% fewer assembly errors and 60% less rework were caused. However, the HMD learning method turned out to be significantly slower compared to a trainer.