DOCTORAL (PhD) DISSERTATION

LENNART HAMMERSTRÖM

HUNGARIAN UNIVERSITY OF

AGRICULTURE AND LIFE SCIENCES

DOCTORAL (PhD) SCHOOL FOR MANAGEMENT

AND ORGANIZATIONAL SCIENCE

KAPOSVÁR CAMPUS

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HUNGARIAN UNIVERSITY OF
AGRICULTURE AND LIFE SCIENCES

DEVELOPMENT OF A RESOURCE-BASED INVESTMENT METHODOLOGY FOR DIGITALIZATION

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The head of the Doctoral (PhD) School

Imre Fertő, DSc

Hungarian University of Agriculture and Life Sciences, Kaposvár
Member of the Hungarian Academy of Sciences

Supervisor

Ferenc Csima, PhD

Hungarian University of Agriculture and Life Sciences, Kaposvár
Associate Professor

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Approval of the Head of Doctoral School Approval of the Supervisor

1 TABLE OF CONTENTS

1.1 Abbreviations

Abbreviation	***Explanation***
AGV	*Automated guided vehicle*
AI	*Artificial Intelligence*
AR	*Augmented reality*
BEV	*Batterie electric vehicles*
BMWi	*Federal Ministry of Economics and Energy (Bundesministerium für Wirtschaft und Energie)*
CASE	*Connected, autonomous, shared, electric*
DC	*Dynamic capabilities*
DCAI	*Dynamic capabilities and Architectural Innovation*
DMAIC	*Define, Measure, Analyze, Improve and Control.* *The acronym's letters represent the five phases that make up the process, which is a data-driven strategy used to improve processes.*
EREV	*Extended range electric vehicle*
ERP	*Enterprise resource planning*
FCEV	*Fuel cell electric vehicle*
HEV	*Hybrid electric vehicles*
I4.0	*4th Industrial Revolution, digitalization and artificial intelligence.*
IGV	*Intelligent guided vehicle*
IIC	*Industrial Internet Consortium*
IoT	*Internet of Things*
JIT	*Just in time. Synchronized production/material supply according to demand*

JIS	*Just in sequence*
KPI	*Key performance indicator*
M2H	*Machine to human*
M2M	*Machine to machine*
MbO	*Management by objectives*
MES	*Manufacturing execution system*
MIT	*Massachusetts Institute of Technology*
MRO	*Maintenance, repair and operations*
MVP	*Minimum viable product*
OEE	*Overall equipment effectiveness*
OEM	*Original Equipment Manufacturer*
OKR	*Objectives and key results*
OR	*Operations research*
PCA	*Principal Component Analysis. Is used in exploratory data analysis for dimensional reduction and for making predictive models*
PCB	*Printed circuit board*
PHEV	*Plug-in hybrid electric vehicles*
ROI	*Return on investment*
S.M.A.R.T.	*Specific, measurable, achievable, realistic. Criteria to define explicit targets*
TPS	*Toyota Production System*
USP	*Unique selling proposition*
VR	*Virtual reality*
VUCA	*Volatility, uncertainty, complexity and ambiguity*

1.2 Figures

1.3 Tables

2 INTRODUCTION

The Era of Industrialization was driven by the hope and enthusiasm of inventors, scientists, engineers and audacious investors who possessed the radical idea of enhancing permanently established technologies and contending with competitors. Hope and enthusiasm have been changing the economic environment since the beginning of the modern age, but the speed of change has never been so fast.

The economic environment in which organizations operate today is becoming more volatile, uncertain, complex and ambiguous (VUCA; Bennis & Nanus, 1985) than ever before. Today, this perception is much more significant. Companies need to develop strategies to cope with these challenges if they want to remain contenders. Besides VUCA, industry changes are accelerating, driven by the 4th Industrial Revolution[1] - *digitalization and artificial intelligence*. The 4th Industrial Revolution is creating an environment of disruption and conversion in which companies are required to react appropriately in order to ensure their economic success. Macroeconomic lectures deal with three industrial revolutions, stating that this endeavor started two centuries ago.

The first industrial revolution was driven in its beginnings by the economic utilization of natural forces such as water and hydrodynamic power, and required the knowledge and potential of *mechanization*. This revolution

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[1] Although the phrase *Industrial Revolution* has been used before (Shigenobu, 1900; Cunningham, 1907), it was popularized after its use by Arnold Toynbee in an article on industrial and agrarian revolution (Toynbee, 1908).

peaked when humankind learned how to utilize the energy produced by a steam-engine. Alongside our growing knowledge of chemistry, the understanding of electricity produced novel technologies that resulted in the worldwide use of electrical power and is termed as the 2nd industrial revolution – it denoted the rise of mass production. With further progress in science, especially in chemistry, physics and natural science, the foundation of the 3rd industrial revolution, relating to electronics and information technology, was laid. Every industrial revolution changed people's perception of the world, space, and time, and each came with great social upheavals.

It is likely that our successors will refer to our times as the period in which the 4th industrial revolution was reaching its peak. Today's agents for creative destruction are digitalization and artificial intelligence, and we have only begun to fathom where this path is leading the human race.

2.1 Introduction to the research field

Disruption in the context of this dissertation is used in a broader sense than the strict definition for innovations given by Christensen, Raynor, & McDonald (2015). It focuses on the nature of conversion and advancement of technologies, deliberately leaving aside the stepwise, evolutionary development of technologies and focusing on the particular difficulties of planning and making strategic decisions. The conversion of industries and businesses, and being aware that an industrial revolution is likely to happen (the first three industrial revolutions were termed retrospectively), results in the attempt of firms to integrate the upcoming inventions and innovations into current business models to strengthen the corporate stratagem and enable further growth, profitability and the long-term viability of the company. Already today, digitalization is a wide field of applications and technologies, and it is likely that it will keep expanding as it continues to develop.

Nevertheless, changing environments and disruption are not new to management science as will be explicated in the literature review.

The adaptation of innovation, the element of human capital and knowledge, the company's current position, its processes and its future paths that lay within the realms of the firms’ present business model to generate a shrewd strategic planning method is the idea explored in this dissertation. Framing the future digitized business model and carving out the right digitalization strategy today will be an important factor for tomorrow's business success. Even before the age of the internet, it has been recognized that that which is ahead tends to stay ahead; in other words, a 'winner takes it all (or the lion's share)` practice became veritable. The digital area does not reward the penny pincher. But it will reward companies that invest their scarce budgets into a digitalization strategy that fits the company's product portfolio, its corporate strategy, its processes and knowledge, and into a shrewd course of action when it comes to utilizing the new technologies within operations and services.

A company aims to gain the most benefit from the investments it makes; from an abstract point of view, growth, differentiation and profitability are often considered the main goal. On an operational level, conceptional ratios such as economic efficiency, revenue, return on invested capital, productivity, rentability and liquidity are employed. The lowest level of the ratios, such as in- and output parameters, scrap rates, changeover time, occupancy time and so forth, form a wide range of different ratios. Digitalization technologies interfere at this level and influence different ratios, depending on the company's conception. Finding a set of digital technologies that supports the company’s long-term goals and aspirations for the future is an optimization problem that will be examined in this dissertation.

Action is an offshoot of reason; investment into digitalization is made clear through pure ratiocination and is following the company's strategy. Robust competitiveness builds on a complementary mix of low-, medium-, and high-technology with conjoint reinforcing impacts. Therefore, the research question is to investigate whether a framework for a digitalization-model can aggrandize the competitive advantage for individual firms that are not the inventors of groundbreaking technologies but their applicants. The dissertation does not focus on developing digital technologies and their improvement; the dissertation's focus is on the combination of digital technologies that is accessible for all market participants and is not a unique selling proposition on its own.

This dissertation's focal point is to recognize the technologies within digitalization that are of proper use for the company, to seize those adequate technologies and the suitable integration into the companies processes while devising a culture to transform and adjust rapidly. The impact affects the "micro" level (individuals, teams, sectors) of the firm predominantly. Still, due to the character of the industries' digital change, the "meso" level (industries, firms, cross-sectoral cooperation) is directly and indirectly affected. The firm's ability to make strategic decisions is constrained by its current position, paths and current processes. The options of what a firm can do and where it can go are therefore not as comprehensive as may seem in the first place. The factors of position, paths and processes limit possibilities for the firm to a greater extent for the decision-makers. The dynamic capability approach provides a structure and a procedure to cope with that incalculability.

2.2 Intellectual origin of the dissertation

The author's motivation to conduct research in the area of strategies for digitalization (Industry 4.0) is based on his observation that a resource-based system to develop an individual, firm-specific strategy that takes the firm-specific technologies, the internal capabilities of a firm, and its long-term goals into account is not existing.

The scientific basis for this dissertation originates from the ardent work of David John Teece, Gary Pisano & Amy Shuen and the eminently compelling article by Rebecca Marta Henderson & Kim Bryce Clark dedicated to architectural innovation. There is a conceptual connection between both theories, and its joint application can contribute to gaining new insights into the strategy of digitalization. It can pave the way to a new understanding of digitalization in the tactical framework of firms.

Teece is a Professor in Global Business at the University of California, Berkeley's Haas School of Business. Teece pioneered the dynamic capabilities perspective[2], defined as the "ability to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments". Henderson is the John and Natty McArthur University

[2] https://www.davidjteece.com/biography

Professor at Harvard University, she holds a joint appointment at the Harvard Business School in the General Management and Strategy units[3].
The intellectual exchange with the professional council of the Hungarian University of Agriculture and Life Science, the disputes with the student body and the discussions at several research conferences with other scientists about macro- and microeconomy, economic development and stability, sustainability and individual responsibility has strengthened the authors decision to conduct further research in this field.
The author is affiliated with the automotive industry and is accountable for the digitalization strategy of the operations area of his employer. Therefore, there is a high intrinsic motivation to develop and execute an excellent digitalization strategy recognized as such. Due to his closeness to operation, he was able to test his hypotheses within the automotive industry at the same time.
The concept introduced and explained in this dissertation is not limited to the automotive industry from the author's point of view and can be applied to other sectors when developing a digitalization strategy. However, the author cannot demonstrate that the concept is working beyond the automotive industry.

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3 https://www.hbs.edu/faculty/Pages/profile.aspx?facId=12345&facInfo=custom&pageId=903

2.3 Structure of the dissertation

Digitalization is brought into the framework of reinforced/overturned and unchanged/changed innovation concepts while utilizing dynamic capabilities to build and execute the appropriate strategy. The era of digitalization is an increasingly complex one. Products are hardly stand-alone; the interaction and range of processes are ever-increasing, and digitalization innovations tend to have a short-term nature. The long-term survival and the economic success of many companies will be determined by their ability to integrate digitalization and its current disruptive nature into their business model and strategy. There is no single approach to finding the appropriate modality for all companies because there are no two companies of a kind, even when they compete in the same market for the same customers. Therefore, a strategy has to be customized for a single company and must offer the possibility of adaptation according to the company's achievements and changes in the economic environment.

The research project is subdivided into 7 main sections to give it an overall structure, to ensure that nothing is overlooked and to put forward a seamless analysis of the investigated topic (Figure 1).

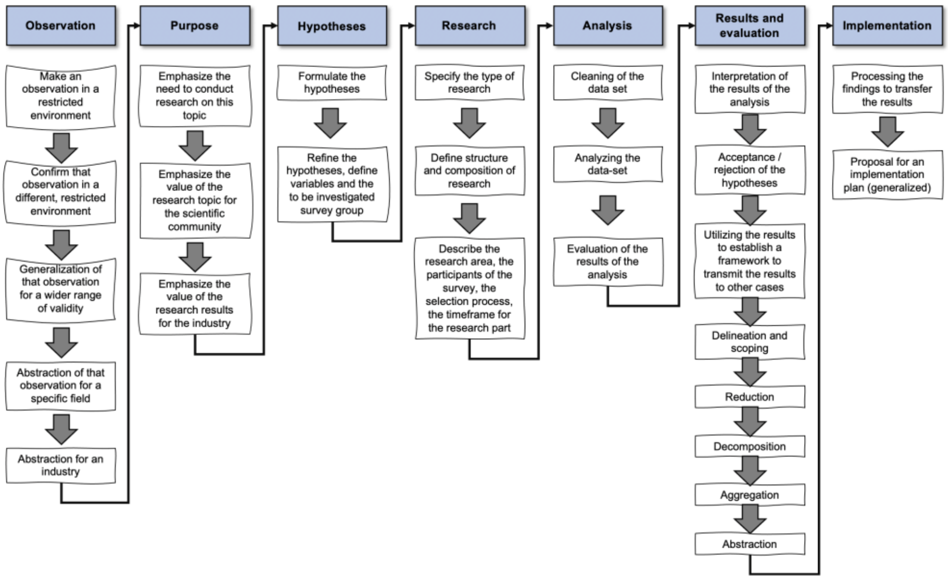

Figure 1: Graphic representation of the chosen procedure to investigate the subject matter and to create a model for the integration of dynamic capabilities and architectural innovation into a common framework (self-edited).

The author conducted research in the automotive supplier industry within a company with more than 33,000 employees at more than 125 locations in 35 countries. The company is vertically integrated to the extent that it runs several dozen production locations to pre-produce its semi-finished products and the final-assembly of its products. The production often highly depends on self-developed production processes with high-value creation; most products are sold directly to the OEMs. The research findings, the recommendations for action and the framework are not bound to the automotive supplier industry, but intended to transfer to other industries.

The research findings that lead to the DCAI-model motivated the author to apply the model at the investigated firm and subject it to a real-life stress-test. I.e., the result of the research was de facto used to enhance the competitiveness of the firm. This real-life application verifies the overall concept, even though it is narrow and limited to a certain field the author chose.

3 LITERATURE REVIEW

The reasons for disruption, renewal and its impact on society attracted and inspired many great minds that built the foundation of this research field. Veblen (1904) described a circuitry of innovation and standardization that, with the enhancement of machines, would issue a revolution of the economy and society. The model advanced by incorporating subjective expectations and speculations within markets by Mitchell (1923). Kondratjew (1925) analyzed and popularized the idea of long cycles, the recurrence of economic ups and downs, and the dynamic conditions that influence the cycles. Nonetheless, Kondratjew was not the originator of cyclical patterns. The theory was previously explored by others such as Pareto, Parvus and van Geldern, but it was Kondratjew who drew attention to long-term cycles (Barr, 1979). Furthermore, Schumpeter (1934, 1939) addressed cycles with elongated intervals of more than 50 years, springing from fundamental technological and organizational innovations. Today's information and communication technology, which can be seen as part of the fourth industrial revolution, is commonly referred to as the fifth Kondratjew-cycle.

A huge amount of knowledge and an extensive library of literature has been accumulated in the field of macro- and micro-economy considering innovation, economic cycles, competitiveness, competitive positions and its obligation to uphold a once attained market position. This wealth of knowledge was taken into consideration but also needed to be restricted to a certain parameter. Hereinafter the most relevant literature, used to describe and demarcate the field of research, is evaluated. To establish a

connection between the origins of the field of research and its newest state, both older literature and the latest, very up-to-date literature was used.
The citations and the reference list strictly follow the *guidelines for the style and content requirements for the Ph.D. thesis and dissertations* of the *Hungarian University of Agriculture and Life Science* (György, 2021), as well as the *Doctoral Regulations*.

3.1 Resource based approach

Knowledge is a recurring theme throughout economists' work, constantly examined from different angles. In his trailblazing article "A Contribution to the Theory of Economic Growth," Solow (1956) proposed his theory that technological progress, not capital accumulation and investments, is the source of long-term growth. His article "Technical Change and the Aggregate Production Function" further supported his theory (Solow, 1957). Linking the concept of competitive advantage with competencies was established by Selznick (1957). Penrose (1959) widened the perspective by integrating the element of internal resources of a company into the scientific discussion. The work of Penrose received relatively little formal attention due to the unpleasant modeling of technological skills that do not obey the law of conservation and do not exhibit declining returns to sale, as in the traditional theory of factor demand (Wernerfelt, 1982). Kuznets considered the essence of modern economic growth to be an increasing stock of knowledge and its proper application to the industry (Kutznets 1966). Porter (1980) combined the traditional strategy concepts (Andrews, 1971) of a firm's strengths and weaknesses with the economic tools of the market and the rivalry among existing firms. Wernerfelt (1982) attempted to look at firms in terms of their resources rather than their products. He emphasized the balance between the exploitation of existing resources and the development of new ones. With his contribution, he is often considered to be the founding father of the modern resource-based perspective. Wernerfelt proposed an analytical tool to evaluate a firm's position from the resource side rather than from the product side to derive strategic options and visualize what he called a resource-product matrix. Solow's growth model was further enhanced by Mankiw, Romer and Weil (1992) by introducing the element of human capital. In the Romer model, growth is driven by technological change induced by investments that are made intentionally and that the stock of human capital determines the rate of growth. Knowledge leads to new technologies; new technologies foster technological progress, and this leads to economic growth. Thus, knowledge and new ideas are the keys to growth. The economic models before Romer considered technological progress as something outside of their models. Romer is regarded therefore as the originator of the endogenous theory of growth, since he incorporated it into the economic growth model. Hitt and Ireland (1986) explored the specific relationships between corporate-level distinctive competencies, performance and their normative character. They were able to show that the strategic business units that applied distinctive competencies gained a competitive advantage over other strategic business units that had the same assignment. Prahalad and Hamel (1990) presented the distinction of portfolio competencies versus a portfolio of businesses and the need to identify, cultivate and exploit the core competencies as a strategic advantage of firms to make growth possible. The specificity in a firm's skills and resources as an enabler to raise barriers to imitation was contributed to the discussion by Reed and DeFillippi (1990). Still, the types of competencies are not further specified in their article. The important fact that an employee's firm-specific know-how has a different value for different firms has been outlined by Mahoney and Pandian (1990). Langlois (1992) made a link between the firm's capabilities view, the cost that the building of competencies necessitates long-term and the cost that occurs with the transformation of knowledge. Under 'dynamic' governance cost, he cited cost for persuading, negotiating, coordinating with and teaching others. Langlois (1992) understood the dynamic costs as "the cost of not having the capabilities you need when you need them" (p. 99). The connecting elements of the theories in industrial-organizational theory, the transaction-cost theory and the evolutionary theory have been realized, and a resource-based approach was developed upon those theories (Figure 2).

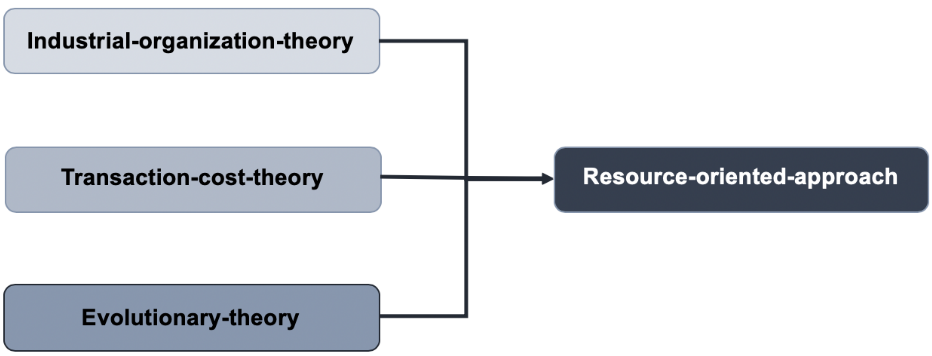

Figure 2: The sources of the resource-oriented approach. Adopted from Foss, N. J., Knudsen, C., & Montgomery, C. A. (1995). An exploration of common ground: Integrating evolutionary and strategic theories of the firm. Resource-based and evolutionary theories of the firm: Towards a synthesis. Boston, MA.

In the 90s of the last century, the resource-based approach flourished and gained a lot of attention in many industries. When the resource-based perspective prevailed, a paradigm shift from the outside perspective of a firm (market orientation) to the inner perspective (competence orientation) took place. Scientists specified that the resource-based approach and its practicability improved. Dynamic capabilities were articulated more understandably, and their definitions worked out in detail. Zobolski (2009) and Zahra, Sapienza, and Davidsson (2006) provided summaries of definitions. Common definitions are as follows:

- Leonard-Barton (1992) and Teece, Pisano, and Shuen (1997): Dynamic capabilities are the firm’s ability to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments. Thus, dynamic capabilities reflect an organization’s ability to achieve new and innovative forms of competitive advantage given path dependencies and market positions.
- Teece (2007, 2010): Dynamic capabilities operate on ‘organizational skills, resources, and functional competencies. They are higher-level competencies that determine the firm’s ability to integrate, build, and reconfigure internal and external resources/competencies to address and possibly shape rapidly changing business environments. They determine the speed and degree to which the firm’s particular resources can be aligned and realigned to match the business environment's requirements and opportunities to generate sustained abnormal (positive) returns.

- Eisenhardt & Martin (2000): Dynamic capabilities are a set of specific and identifiable processes such as product development, strategic decision making, and alliancing. […] dynamic capabilities are idiosyncratic in their details and path-dependent in their emergence. They have significant commonalities across firms […] in high-velocity markets; they are simple, highly experiential, and fragile processes with unpredictable outcomes. […] well-known learning mechanisms guide the evolution of dynamic capabilities. Thus, dynamic capabilities are the organizational and strategic routines by which firms achieve new resource configuration as market emerge, collide, split, evolve, and die.

- Zollo & Winter (2002): A dynamic capability is a learned and stable pattern of collective activity through which the organization systematically generates and modifies its operating routines to pursue improved effectiveness.

- Winter (2003): A dynamic capability is a learned and stable pattern of collective activity through which the organization systematically generates and modifies its operating routines to pursue improved effectiveness.

- Helfat et al. (2007): A dynamic capability is ‘the capacity of an organization to purposefully create, extend, and modify its resource base’. The ‘resource base’ includes the ‘tangible, intangible, and human assets (or resources) and capabilities that

> the organization owns controls, or has access to on a preferential basis’.

The approach developed further, and different fields of application emerged such as dynamic relational capabilities (Weissenberger-Eibl & Schwenk, 2010), capability lifecycles (Helfat & Peteraf, 2003), human resource management based on dynamic capabilities (Easterby-Smith & Prieto, 2008), the interactive use of management control systems and dynamic capabilities (Henri, 2006), and product development (Prieto, Revilla, & Rodríguez-Prado, 2009). The approach can also be used to execute growth strategies (Tartaglione, Sanguigni, Cavacece, & Fedele, 2019). According to recent research, building the proper capabilities is essential to integrate digitalization technologies into a firm (Machado, Winroth, Carlsson, Almström, Centerholt, Hallin, 2019). The Dynamic Capabilities approach is exerted to build competitive advantages in combination with other theories, such as the knowledge-based-view. By doing so, faster learning, which enables a firm to constantly renew the stock of ordinary organizational capabilities in contrast to its competitors, can be established. Studies to combine the Dynamic Capabilities approach with the Knowledge Process Capabilities show that the Dynamic Capabilities approach can also be applied in other research areas (Kaur, 2019). Knowledge has become the main driver for developed countries; transforming this knowledge into actionable change throughout the entire organization will be the differentiator and will create an economic advantage for industry players to build superior advantages over their competitors.

3.2 Dynamic Capabilities

Building competitive advantages in an environment of rapid technological change requires dynamic capabilities (Teece, Pisano, & Shuen, 1997; Teece, 1998). Technology and technological change are something that can be designed, influenced, controlled and managed by a company. Therefore, it should be made part of the planning process of a company (endogenous) and consequently become calculable. Technology, therefore, transforms from being an exogenous event into an endogenous one. A company can develop the ability to integrate, build and reconfigure internal and external competencies to address digitalization's disruptive nature (Teece, 1998), as is displayed in Figure 3.

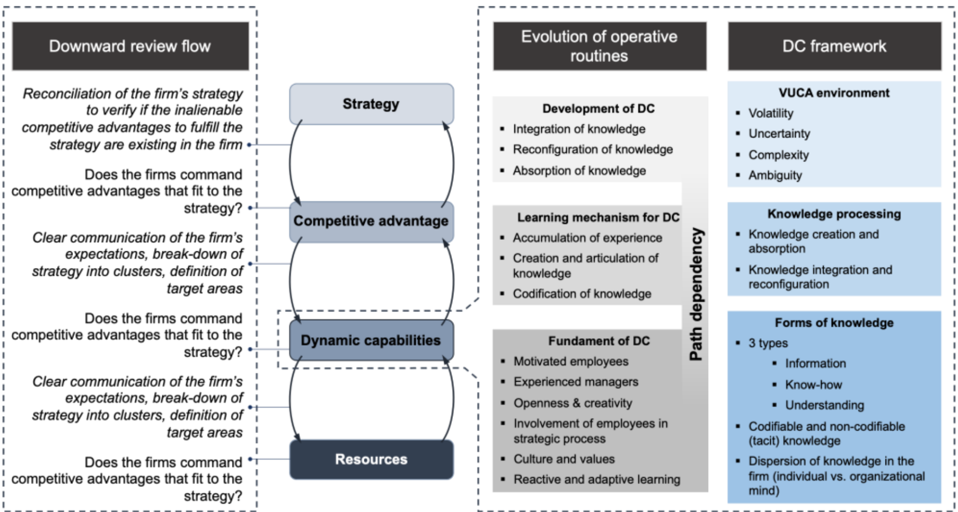

Figure 3: Dynamic capabilities framework. Adapted from: a.) Galunic, C. & Rodan, S. (1998). Resource recombination in the firm: Knowledge structures and the potential for Schumpeterian innovation. Strategic management journal and b.) Verona, G. & Ravasi, D. (2003). Unbundling dynamic capabilities: An exploratory study of continuous product innovation. Industrial and Corporate Change, Vol. 12, Issue 3, pp. 577-606 and c.) Zollo, M. & Winter, S. G. (2002). Deliberate learning and the evolution of dynamic capabilities. Organizational Science, Issue 3, pp. 223-353.

The framework that Teece, Pisano and Shuen (1997) developed suggests that private wealth creation in regimes of rapid technological change depends largely on honing internal technological, organizational and managerial processes inside the firm. If knowledge is assumed to be an asset of a company, it can rarely be bought on the market; it is an asset that is especially difficult to be traded and can be hard to acquire. Furthermore, it is highly tacit when it lacks formalism, and the degree of standardization is humble. An organization needs a deep process of understanding to accomplish codification and replication. Otherwise, it cannot improve. In most application cases, it makes no sense to develop digitalization technology on one's own; the technology can be purchased from companies that are specialized in that particular technology. But the understanding of a digital application, its thorough exploitation and the interrelatedness of digitalization technologies are increasingly salient factors in becoming a differentiator for those companies that are the applicant of digital technologies (Teece, 1996). Buying digital technology to improve internal processes does not create an advantage towards competitors per se because the technologies are available for all market participants. Building an appropriate system of know-how, assets of digitalization technologies and the corresponding processes to make it difficult-to-replicate can shape a competitive advantage (Teece, 1986, 1998). The combination of the dynamic capabilities approach, the incorporation of the precisely needed type of innovation according to the economic cycle, and the understanding of digitalization as the disruptive agent provides the opportunity to develop an approach that is not based on uncertainty anymore, only risk. Unlike uncertainty, risk adheres to probabilities and therefore can be calculated within a strategy (Knight, 1921).

3.2.1 Appropriability regimes

An appropriability regime describes the ease of imitation; it is a function both of the ease of replication and the efficacy of intellectual property rights by legal protection (Teece, 1998, 2000; Teece & Pisano, 2003). The regime is strong when intellectual rights protect the technology, and it is difficult to imitate. The intellectual property system does not provide any legal barriers against imitation with regard to digitalization technologies available for all market players. The ease of replication seems to be low at first. When applying technologies to digitize, the firm has to consider the appropriability regime that it wants (or can) achieve (for graphical display, see Figure 4). To establish a strong regime, a company has to invest (alongside technologies) into capabilities to make the most out of the initial technology investments. On the one hand, those capabilities are directly linked to the use of the technologies. To defend and stay in a strong regime, the firm must have dynamic capabilities to deal with the constantly changing, disruptive nature of the market environment.

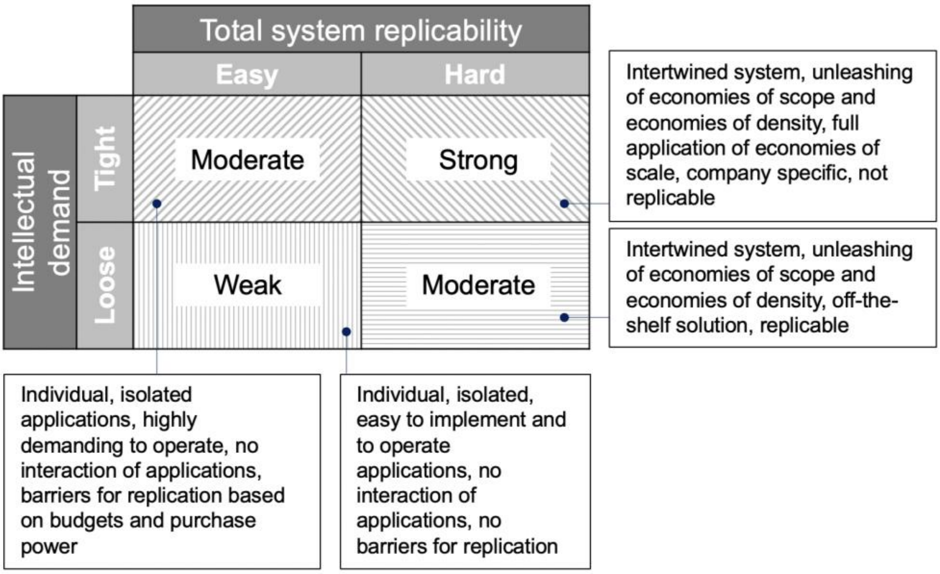

Figure 4: Appropriate regime for digitalization technologies. Adapted from "Knowledge and competence as strategic assets", by Teece, 1998. California Management Review, Vol. 40, No. 3.

A strong regime is non-tradable ("sticky"). It cannot be bought from the outside due to being linked to the company's current position. The transmission of technology is already considered very costly (Teece, 1976), hypothetically others cannot build a similar regime even though the superior know-how is publicized (Szulanski, 2003). A strong regime structure is determined by the path and by such things as the current process-portfolio, global footprint, customer structure, the cultural heritage a company has built up, and so forth. A widely recognized role model for a "sticky" organizational regime that is considered as strong is the production system built by Toyota after the second world war. Toyota never concealed the system, and an extensive number of scientific works have been published with the explicit consent of Toyota. What is more, Toyota is offering in-house-training to understand and to enable others to copy their system. Toyota employees were wanted by other automobile companies and were hired in large amounts from the beginning of the '90s of the last century and are still wanted. Nonetheless, only a few companies came close to the economic efficiency that TPS created at its source.

To structure the firm’s distinctive dynamic capabilities, Teece and Pisano (2013) suggest organizing the dynamic capabilities into three categories: processes, positions and paths. The options of what a firm can do and where it can go are therefore not as comprehensive as may seem at first glance. The factors in the three categories limit the firm’s potential for maneuvering to a greater extent than is apparent for the decision-makers. While working in this research field, it became clear that the suggested structure is appropriate for the grouping of dynamic capabilities within digitalization and can assist in structuring further actions. Hereafter, pursuing substance and reasoning for choosing those categories is outlined.

3.2.2 Process-dependency

Different firms can achieve processes aiming for a similar or even identical outcome by stringing together different activities. The cost for those various processes differs among firms, and to achieve an identical outcome will come at a different cost, influencing a firm's economic efficiency. In his article "The nature of the firm," Coase (1937) compares the cost of transacting with the cost of organizing but fails to investigate why some firms possess lower costs of organizing than others. In 1988, Coase emphasized the need to explain the institutional structure of production and uncovered why the cost of organizing particular activities differs among firms (Coase, 1988).

Teece and Pisano (2003) refer to the way things are done in a firm, to 'routines' or patterns of current practices and learning when outlining managerial and organizational processes, and understand those as a reflection of distinctive organizational or coordinative capabilities. The way production is organized by management inside the firm is the source of differences in firms' competence in various domains (Teece & Pisano, 2003). Performance drivers, such as quality, seem to be less dependent on assets in an accounting sense and are neither directly related to capital investment nor the degree of automation of the production processes, as studies have shown (Garvin, 1988; Johanson, Mårtensson, & Skoog, 2001; Marr, Schiuma, & Neely, 2004). The subfield of process-dependency within the dynamic capabilities approach focuses not only on processes related to production output but also on an integrated vision of all the firms' processes. In the last decade, it became a substantial subfield of research and consulting area aiming for efficient and effective processes to improve the competitiveness of firms - the link to dynamic capabilities is often highlighted by authors (Zairi, 1997; Pritchard, & Armistead, 1999; Trkman 2010; Pradabwong, Braziotis, Tannock, & Pawar, 2017; Paschek, Ivascu, & Draghici, 2018). To further disintegrate the entrepreneurial and orchestration processes, Teece (2007, 2012, 2017) proposes the following three activities:

1. **Sensing**: The identification and the assessment of an opportunity (at home and abroad).
2. **Seizing**: The mobilization of resources to address an opportunity and to capture value from doing so, based on managerial competencies for devising and refining business models.
3. **Transforming**: Continued renewal.

Sensing includes exploring new technologies and estimating the propulsive effect it can have on the current business; it includes scanning of the market environment and punctual assessment of the new opportunities and requires strong capabilities in analysis and diagnosis. The outline of seizing is the phase that is required after opportunities are properly sensed and calibrated (Teece, 2018). It involves identifying and combining the relevant complementary assets needed to support the business (Teece, 1998). Transformation requires leadership to drive change on the path that lay ahead of the firm and act upon the seizing. Seizing and transforming require coordinated actions and interaction between both phases.

3.2.3 Position-dependency

According to scientists that work on the field of evolutionary economics, the current stock of a firm's "assets" at a certain point in time is influenced and determined by decisions made by management in the past (Nelson & Winter, 2002; Helfat & Peteraf, 2003; Nelson 2008; Clark, Feldman, Gertler & Wójcik 2018). It's the legacy of a firm related to its difficult-to-trade knowledge assets, less regarding its fixed assets such as machines, manufactured goods, or production facilities. Therefore, the current stock of capabilities constrains the ability to change the future repertoire of capabilities (Pisano, 2016). Scholars have found that a strong position is supportive of a firm's dynamic capabilities (Danneels 2008; Anand, Oriani & Vassolo 2010; El Akremi, Perrigot & Piot-Lepetit, 2015).

3.2.4 Path-dependency

The dynamic capabilities approach is taking into account the company's history by considering path dependencies. The paths are the strategic alternatives available to the firm and the attractiveness of the opportunities that lie ahead (Teece & Pisano, 2003). Path dependencies are underrepresented when a strategy is worked out and are unintentionally excluded from the strategic decision process. Existing processes, learned behavior, and core capabilities influence the decision processes and, thus, the paths ahead. The result is that the strategic process decisions are biased and do not follow the value maximation criteria. The same is true for technologies that have a similar starting position and compete with each other in a market of adopters. The technologies often have no significant differences in the returns they provide. One experience is that the one technology that is more widely adopted gains more experience, scale effects, and a reduction of cost for implementation and purchasing over time. Insignificant events may, by chance (e.g., the unexpected success of a prototype's performance) give one of them an initial advantage (Arthur, 1989). Based on this slight advantage, technology gains an early lead and develops a dominance in the market. In an advanced state and after many consecutive optimizations of the technologies, it can reach the property of inflexibility and the exclusion of renewal and adaptability; the costs for changes become too high. Hence, technology has reached a 'locked-in' status. The micro-economic assumptions that the most efficient solution will ultimately prevail and that decisions are principally reversible as soon as a superior solution is available is overruled (David, 1985, 1986).

Sydow, Schreyögg, & Koch (2005) characterize path dependency as a dynamic model with three different stages similar to Figure 5 (Sydow, Schreyögg, & Koch, 2005, p. 9).

1. **Preformation phase**, the undirected search process: Choices are still unconstrained, decisions are seen as events that cannot be explained by prior events or initial conditions, and the outcome is of contingent occurrences (Mahoney, 2000). The decisions made can be triggered by various agents of different contexts and backgrounds. These can be superb targets like efficiency advantages in production, a non-holistic perspective, or simply the unknowingness of other options. Or the decisions made have a causal context with the decision-maker, such as her preference for certain technologies, her educational background, or her unwillingness or tendency to avoid certain areas of collaboration. At this point, a dominant design has not emerged yet. Still, a self-reinforcing process may be set into motion. According to Collier and Collier (1991), it can trigger a critical juncture that makes it progressively difficult to return to the initial point when multiple alternatives were still available (Mahoney, 2000). At the beginning of individual motorization, a dominant design for an automobile was not given. Neither was the drive technology. 2- and 3-wheelers were more common in the street scene than today, and electrification within transportation had a higher share than it has today. In this phase, radical innovations make their way into technologies and products.
2. **Path formation phase**, the narrowing process: The reinforcing processes and the causal patterns that track a particular type of behavior are likely to be reproduced over a period of time. They increasingly narrow the options to the point that the agents eventually seem to have no choice anymore (Sydow, Schreyögg, &

Koch, 2005). Within the path formation phase, small events can significantly impact the development, spill-over, diffusion, and further adoption of technologies. The complexity theory is its own field of research with at least three different specializations [algorithmic complexity (mathematical complexity theory and information theory), deterministic complexity (chaos theory and catastrophe theory), and aggregate complexity (individual elements work in concert to create systems with complex behavior)] (Manson, 2001). At this point, most of the competing technologies have been abdicated, and only some technologies are competing for predomination, but choices (even though essentially constrained) are still possible. The dominant types of innovation in this phase are modular and architectural innovations.

3. **Path dependence,** the lock in: A dominant design is apparent and, due to its dominance, is accepted and implemented by new entrants. A dominant design incorporates a range of basic choices about the design that are not revisited in every subsequent design (Henderson & Clark, 1990). The technology is further improved mostly by incremental innovations.

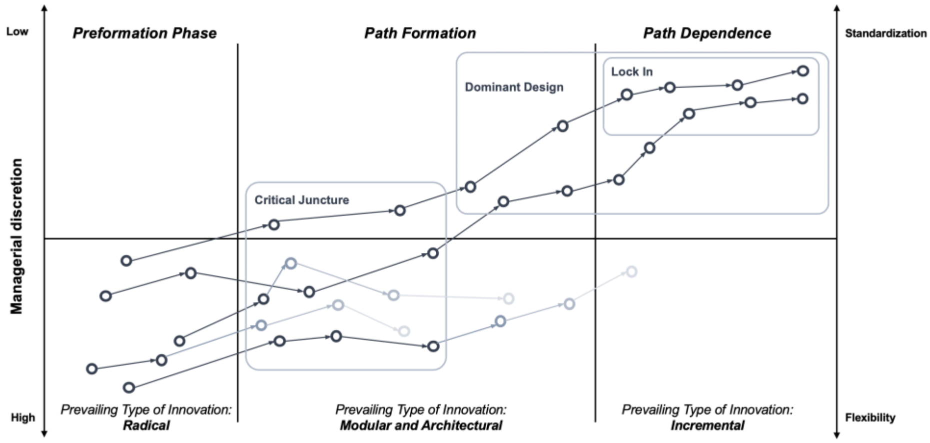

Figure 5: From preformation phase to path dependence – prevailing innovations and the final lock in. Adapted from "Constitution of a technological or institutional path - the classical model", by J. Sydow, G. Schreyögg, and J. Koch, 2005. 21st EGOS Colloquium, June 30 – July 2, Berlin, Germany, p. 9.

When radical technology innovations have been made, and the direction of change is heading towards critical junctures, innovations tend to shift towards modular and architectural innovation. Critical junctures are hypothesized to produce distinct legacies, triggered by their antecedent conditions, the cleavage (or crisis) that emerges from the antecedent conditions, its mechanisms of production, preproduction, and the stability of the legacy's core attributes (Collier & Collier, 1991). It is the phase of the modular and architectural innovations that punt a piece of technology in one direction or the other, predetermining its path to become a dominant design, to be relegated to a niche application, or to perish. After attaining the dominant design, incremental innovations are novated to be the appropriate means to further improve the technology.

3.2.5 Limitations of the resource-based perspective

Even though the dynamic capabilities approach was very well received both by scholarship and when applied within different industries, there are pending issues that justify the request for further research and a response to open questions. There are some fundamental criticisms, such as the assumption that strategic resources are heterogeneously distributed across firms and that these differences are stable over time (Barney, 1991). The dynamic capabilities approach's further downsides are that the resource-based view strives to identify and nurture those capabilities that are relevant mostly for the current business, which can be largely static and unchanging (Chaharbaghi & Lynch, 1999). The paradigm-change from a market perspective (outer perspective) to a competence-based perspective requires a clear differentiation of resources, competencies and capabilities. This is often not done to a sufficient extent; the terms are not expressed precisely and are interfused with each other (Moldaschl, 2006). Galunic and Rodan (1998) criticized the largely singular treatment of resources and emphasized the need to combine resources. While not rejecting that firms differ, some scholars justify their rejection of the resource-based perspective, arguing that its theoretical assumptions are inconsistent and that its construction is poorly defined. It lacks causal arguments and testable empirical implications (Bromiley & Fleming, 2002). Other critics refers to details of the concept, such as the 'lock-in,' which should not be seen as a permanent, but a temporary stabilization of paths in-the-making (Garud, Kumaraswamy, and Karnøe, 2010). Other scholars, such as Schilke, Hu and Helfat (2018) emphasize that in the early years of research on dynamic capabilities, the work was mainly conceptual. But empirical studies (see also Cunningham, Loane, and Ibbotson 2012) and theoretical elaborations have shed substantial light on various, measurable factors connected to dynamic capabilities. Research has shown that the field of dynamic capabilities is rich, and a cohesive, overarching model can be developed (Ibid.). Another finding is that the approach might be more important in one industry than in others (Dries, Pascucci, Török, and Tóth, 2013).

3.2.6 Evaluation of dynamic capabilities

The scope of evaluating and developing dynamic capabilities and integrating those in a business model is to use the fundamental drivers of the current disruption of the industry - digitalization. Building and controlling dynamic capabilities represents a competitive advantage over other market participants in an increasingly demanding environment. As a resource-based approach, the dynamic capabilities approach incorporates distinctive competencies and capabilities that are heterogeneously distributed within a firm. Furthermore, it allows for the inclusion of industrial-organizational research. High accuracy in point and time is necessary to build an efficacious impulse with dynamic capabilities; it is especially relevant in markets with strong innovation-rivalry, price- and performance competition, and a market that indicates disruptive behavior. The dynamic capabilities approach has been chosen due to the following reasons:

- It is an efficiency-based concept that considers how a firm can develop capabilities to develop competitive advantages. It explains the combination of competencies and resources, its development and deployment, and how to protect the advantages.

- It takes into consideration both external and internal factors to address disruption.

It is said that the resource-based approach is less suitable to formulate concrete strategies (McGuinness & Morgan, 2000; Witt, 2008), and further research in the field of application has to be done. Nevertheless, in this dissertation, the approach that is proposed by Grant (1991) to build a competitive strategy based upon dynamic capabilities is turned around. The approach here is to build up the necessary dynamic capabilities in specific fields to achieve the strategy's long-term objectives. The strategy is the leading framework, not dynamic capabilities. The dynamic capabilities approach does not work with the classical hierarchical organization because it promotes and depends on a learning organization's concept.

3.3 Architectural Innovation

Architectural innovations derive from the research on technical innovations and conclude that an exclusive distinction between radical and incremental innovations is incomplete. The article about the then unnoticed architectural innovation from Henderson and Clark (Henderson, & Clark, 1990), that is based on an earlier working paper from Henderson (1990) when she was an assistant professor at the MIT Sloan School of Management, lead to a new thinking about technological innovations.

3.3.1 What is architectural innovation?

This dissertation follows the definition of architectural innovation introduced by Henderson and Clark (1990) since it provides a soundly defined and transferable model to different industries and products.

Henderson and Clark define architectural innovation in the following manner:

> We define innovations that change how product components are linked together while leaving the core design concepts (and thus the basic knowledge underlying the components) untouched. … It destroys the usefulness of a firm's architectural knowledge but preserves the usefulness of its knowledge about the product's components (Henderson & Clark, 1990).

The architecture of a product determines the interaction of the product's single components and the architectural knowledge, the knowledge about how components are linked together, creating completely new interfaces, into a coherent whole, define its performance. With this differentiation, it is possible to distinguish between radical, incremental, modular, and architectural innovation.

3.3.2 Four types of innovation and their distinction

To illustrate the four different types of innovation, every single type of innovation is displayed in Figure 6 based on an electronic component, a capacitor.

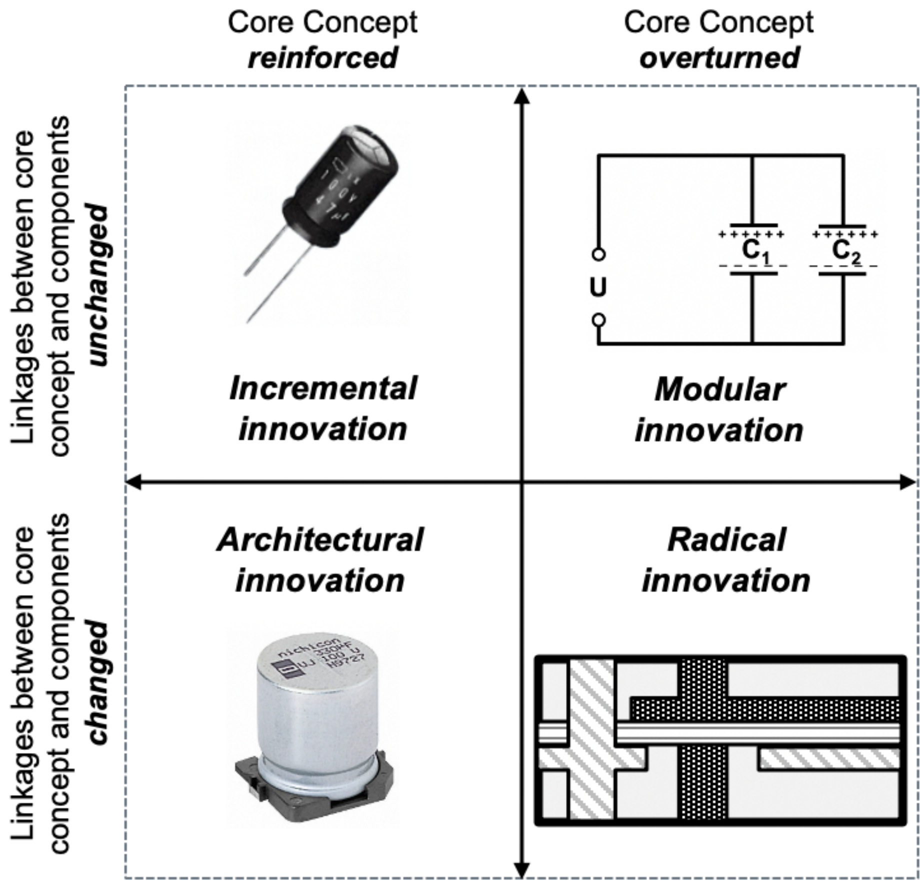

Figure 6: Four types of innovation in the automotive supplier industry, displayed on a capacitor. Inspired by Henderson, R. M. & Clark, K. B. (1990). Architectural innovation: The reconfiguration of existing. Administrative Science Quarterly.

This electronic component stores electrical energy in order to provide fundamental functions within electronic applications. It is widely used within the electronics industry and can be found in many different structural shapes to fit into the product's system.

1. **Incremental innovation:** The through-hole-technology for capacitors (formerly called condensers) with a liquid dielectric is more than 100 years old. It was patented by Elihu Thomson, who was working at the time for General Electric (United States Patent Office, 1921). It requires a hole within the PCB to be assembled and soldered, in order to establish an electrical connection with the other components. The original design underwent a great number of incremental improvements, such as improvements in the weight of the case (which today is mainly made from aluminum), the characteristics of the paper spacer, or the capacitors' cover, nowadays often built from tantalum. Incremental innovations typically result in an increasingly specialized system in which the productive unit loses its flexibility and economies of scale are extremely important (Abernathy & Utterback, 1978). If incremental innovation is the most dominant type of innovation in a firm, it likely fails to maintain leadership when technologies change.
2. **Radical innovation:** Radical innovation is to forgo some parts of the capacitor and to integrate it completely into the PCB. By doing so, it becomes a fixed component of the PCB and must be integrated into the PCBs manufacturing process. This approach economizes the PCB's surface and leaves more freedom for the design of the PCB, and saves space within the final product. Under normal conditions, radical innovation attempts to produce more failures than successes and is highly time-dependent (Leifer, McDermott, O'Connor, Peters, Rice, & Veryzer, 2000).
3. **Modular innovation:** The example of modular innovation focuses on the extension of the use case; the capacitor is used in a different

way to create a new type of utilization. Capacitors are used as devices to create a low-resistance path for electric currents (shunts) to pass around other points in the circuit in high-frequency applications. Modular innovation calls for specialization and co-ordination over organizational boundaries as a managerial response (Magnusson, Lindström, & Berggren, 2003).

4. **Architectural innovation:** A significant architectural innovation was the advancement of the through-hole-technology to the surface-mounted-technology. It required very little change in the mechanical construction of the capacitor. Still, the ‘capacitor-PCB-system’ architecture was dramatically changed. The interface is completely different (soldering on the surface instead by means of a soldering hole), and the components are linked together in a new way. The cost for the assembling process dropped significantly, the design options for the PCB and the available space for designers improved, and further incremental innovations of the production process were made possible. Architectural innovations challenge the whole engineering organization and require a focus on the development efforts of technological interfaces (Magnusson, Lindström, & Berggren, 2003).

Henderson and Clark (1990) emphasize that the distinctions between radical, incremental, modular, and architectural innovations are matters of degree and that innovations cannot always be divided clearly into four quadrants.

3.3.3 Transposition problems within architectural innovation

There are three eminent challenges within architectural innovation that a firm must be both aware of and prepared to apply certain patterns of behavior in order to respond appropriately:

1. Architectural innovation initially can be accommodated within old frameworks, which makes it hard to identify it as architectural (Magnusson, Lindström, & Berggren, 2003).
2. Architectural innovation destroys the usefulness of existing communication channels, information filters and problem-solving strategies within engineering organizations (Henderson & Clark, 1990). Established organizational structures, which previously have constituted parts of the firm's core capabilities, turn into core rigidities that inhibit innovation (Leonard-Barton, 1992).
3. There is evidence that a firm's organization reflects the architecture of the product ("form follows function") and also the structure of the underlying knowledge base and the way competencies are acquired (Brusconi & Prencipe, 2001).

Some firms made a virtue out of necessity and reacted to the three challenges on architectural innovation. Their business model is customized and demonstrates specialized organizational units of labor along with the product level, specialized organizational units to particular components or subsystems to consider the requirements of architectural innovation (Brusconi & Prencipe, 2001). Such firms are considered as system-integrators.

3.4 Economic environment and the research object

Several trends are shaping the industry, and each sector is influenced by means of its trends or megatrends. Digitalization is one of the trends that will fundamentally change the industry and the way of working within. Therefore, a scientific investigation in the form of a dissertation has to focus and shed light on a certain, selected area of interest. The dissertation's objective is not to compile a list of macro-economic insights into the effect of digitalization on the automotive industry collectively. Its objective is to investigate a well-defined, specific area where digitalization will certainly have an impact and how this impact can be steered in the most beneficent direction for a firm (see chapter 4).

The driver behind digitalization is the technological progress in the electronics industry, especially the performance of electronic components, the transfer rate of networks and the ability to store and process data. There are several 'laws' that deal with these improvements and attempt to explain them, with Gordon Moore's law of doubling the number of components per microcontroller (Moore, 1965) being the best-known. Less known but of tantamount importance is Jakob Nielsen's law of the doubling of the internet’s bandwidth. Whereas the components' size is shrinking, and the performance is improving, the components' cost is falling continuously. There are megatrends from which trends derive, e.g., the megatrend of sustainability triggered the trend of electrification. The DAIMLER AG coined one summary of the automotive trends in 2016; it sums up the four megatrends connectivity, autonomous driving, shared vehicles and electrification (CASE) (Eisele, Kauth, Steffens & Glusk, 2019). The trends then lead to various responses within the industry, e.g., becoming apparent within vehicles' electrification in a wide range of propulsion principles.

For the supply of an electric vehicle with energy, three fundamentally disparate options are feasible: storing energy in accumulators, producing the energy aboard (e.g., by converting hydrogen in a fuel cell), or by means of direct supply (e.g., sliding contacts). Combinations of the three are possible and do exist. These combinations result in a wide range of different types of propulsion concepts, such as hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), battery electric vehicles (BEV), extended-range electric vehicles (EREV) and fuel cell electric vehicles (FCEV). This context of a megatrend, trend, and its implementation for the customer requires faster and more efficient product- and process-development than ever before. Digitalization can be the key solution to meeting those challenges within the examined area of operations.

In many parts of Europe, the term I4.0 is widely used and linked to a self-organized value chain between man, machine, product, logistics and customer to deliver individual products at a lower cost (BMWi, 2019). Achieving this and participating in the reduction of expenses is a common driver in the automotive industry, with the OEMs on the forefront, followed closely by their suppliers. Consequently, an environment that demands but also rewards digitalization emerges. This environment is characterized by a high degree of uncertainty. Each firm is well-advised to establish appropriate safety measures to avoid sinking funds which would have been invested more effectively in other areas. This paper provides an answer to this considerable challenge.

To expose an application-case, the research project was narrowed down to the automotive supplier industry, and within this, to the sector of manufacturing of electronic components.

The firm under consideration is a multi-national company committed to digitalization in its self-promotion.

4 OBJECTIVES OF THE DISSERTATION

We are transitioning to the 4th industrial revolution, the area of digitalization and interconnectedness (often considered as Industry 4.0 or I4.0). Like the industrial revolutions that came before, this 4th industrial revolution will dramatically impact the way we work, the way we cooperate, and in the end, the way we live. Today's industrial champions' preeminence will be challenged by competitors that are very small today or might not yet exist. In some years, obituaries for companies that are healthy and wealthy today and prevail in today's industry with their business model will be held. Most companies are aware that a change is happening, and that this change is likely going to sweep away many of today's companies by its disruptive nature. Companies that adhere to their business models, ignore the change, and are suspicious about the 4th industrial revolution are likely to find themselves on the losers' side in the race for productivity. The applications of digitalization and interconnectedness will have a disruptive impact on the automotive supplier industry, too. Even those who are fully aware of the risks and have decided not to dally and actively participate in the change process are at risk. Due to ill-conceived concepts and/or maladjustments or a poorly managed execution of the process of adaptation, it is most likely that wrong investment decisions will be made. Audacious decisions and proceedings are necessary, but not at any cost and, of course, not without a well-considered strategy, execution, and alignment of actions. The nature of digitalization and interconnectedness is that the technologies are interrelated, built on similar basic technologies, are mutually supportive in some cases, and mutually exclusive in others.

There is no clear subjugation of the technologies, there is not the one technology a firm has to start working with and build upon its path and digital structure. The expected payback into those applications is uncertain, and therefore it is hard to create a convincing business case and legitimate high investment into this area. The applications' performance will very likely follow a sigmoid function ('S-curve'); i.e., it is likely that the I4.0 technologies are underrated in their performance today, and investing in them is not convincing. But superior technology alone is rarely enough to build a competitive advantage and shape the firm's paths.

Especially when radical innovations are available for all market-participants, their architectural integration is of paramount importance.

The aim of the dissertation, therefore, is to develop a structural concept that enables companies to work out recommendations and strategies for the implementation of I4.0 technologies that are provided by third parties and are available for all market participants. The number of digitalization technologies that are widely spread and that are purchasable for everyone is very high; the following are some of the most common examples: VR/AR glasses, cloud computing, deep learning algorithms, smart gloves, smart robotics, robot process automation, artificial intelligence, intelligent guided vehicles and so on.

Therefore, the I4.0 technologies have to be selected, combined, integrated, and used according to the need of the firm and can be used to create a unique selling proposition (USP). The structural concept in this dissertation is based upon the dynamic capabilities approach and the integration of technologies in a framework of architectural innovations. The structural concept developed here focuses on the value-adding-process of production industries and emphasizes the course of action necessary to execute the concept.

A dedicated, company-specific strategic framework for the assortment and implementation of the new technologies must affiliate company-specific conditions, such as the current product portfolio, the technologies, and processes utilized to produce the products and services the company provides to its customers. A company's current position and the processes it practices predetermine the (strategic) paths a company can choose to break new ground and develop a robust competitive advantage. The substantial question must be asked and answered; it is not sufficient to just commit to digitalization, invest in a wide field of applications, and then hope for the best. Questions must run deeper than *'What is our digitalization strategy?'* or 'H*ow much will digitalization cost the company?*' They have to be asked not only from a technology perspective but also from the capability's perspective. Some companies do not pose the obvious questions, "*What digital technologies help us best to achieve our strategic aims?*", "*How do we need to incorporate those digital technologies to support our tactic decisions?*", and "*In which of those technologies shall we invest at what point in time?*".

And if they do, they often forget to ask, “*What know-how is necessary to implement the technology, and do we have enough of it?*”, “*Do we have to re-structure our organization to create the most value from the technology?*”, “*Do we have the right people and sufficient capabilities to cooperate with the supplier of the digitalization technology?*”. Those questions are, in fact, two sides of the same coin. Figure 7 demonstrates that two-way relationship; on the left side is the technology perspective, driven by the question of what technology is necessary for the company;

the right side represents the dynamic capabilities or how to integrate the technology. Working in the same industry, possibly as being competitors, two companies have to choose from a different set of technologies to fulfill their strategic digitalization roadmap. Beyond that, they have to develop and apply a different set of dynamic capabilities to get the best out of each technology.

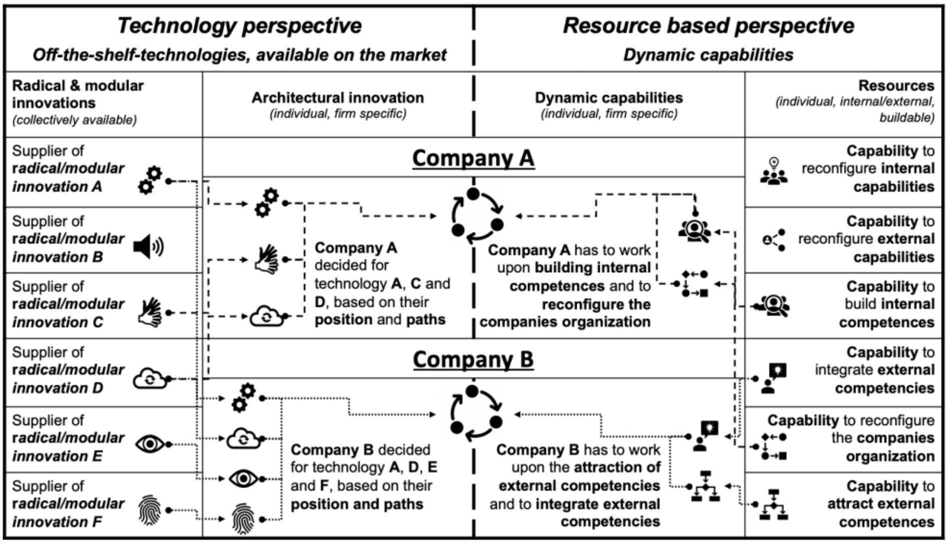

Figure 7: Junction of digitalization technologies and dynamic capabilities with the effect of an architectural framework. The selection of technologies must be brought into accordance with capabilities to create the most possible contribution to the company's strategic aims (self-edited).

This dissertation's focal point is to retrieve the approach from its theoretical treatment and develop a system to implement the digital technologies into the strategy of a firm allowing for the building up or integrating of necessary dynamic capabilities.

4.1 Concatenation of the 2 theories

The ties between the dynamic capabilities approach and architectural innovations have been underlined in various scholarly works (Henderson, 1990; Henderson, & Cockburn, 1994; Teece, 2003; Cockburn, Henderson, & Stern, 2000; Pil, & Cohen, 2006), 'architectural competence' is equated by some to 'capabilities' (Henderson, & Cockburn, 1994) or is even recognized by some as a dynamic capability in its own right (Zollo, & Winter, 2002).

Henderson and Clark (1990) have shown that incumbents in the photolithographic equipment industry were devastated by innovations that had major impacts on the systems' configuration. They saw these devastations as related to the fact that in most cases, architectural innovations require new routines to integrate and coordinate engineering tasks. Figure 8 displays the exigencies to work with the four types of innovation. It is based upon the framework for defining innovation from Henderson & Clark (1990), but is enhanced by examples of capabilities needed to work successfully with each type of innovation (architectural innovation elevated).

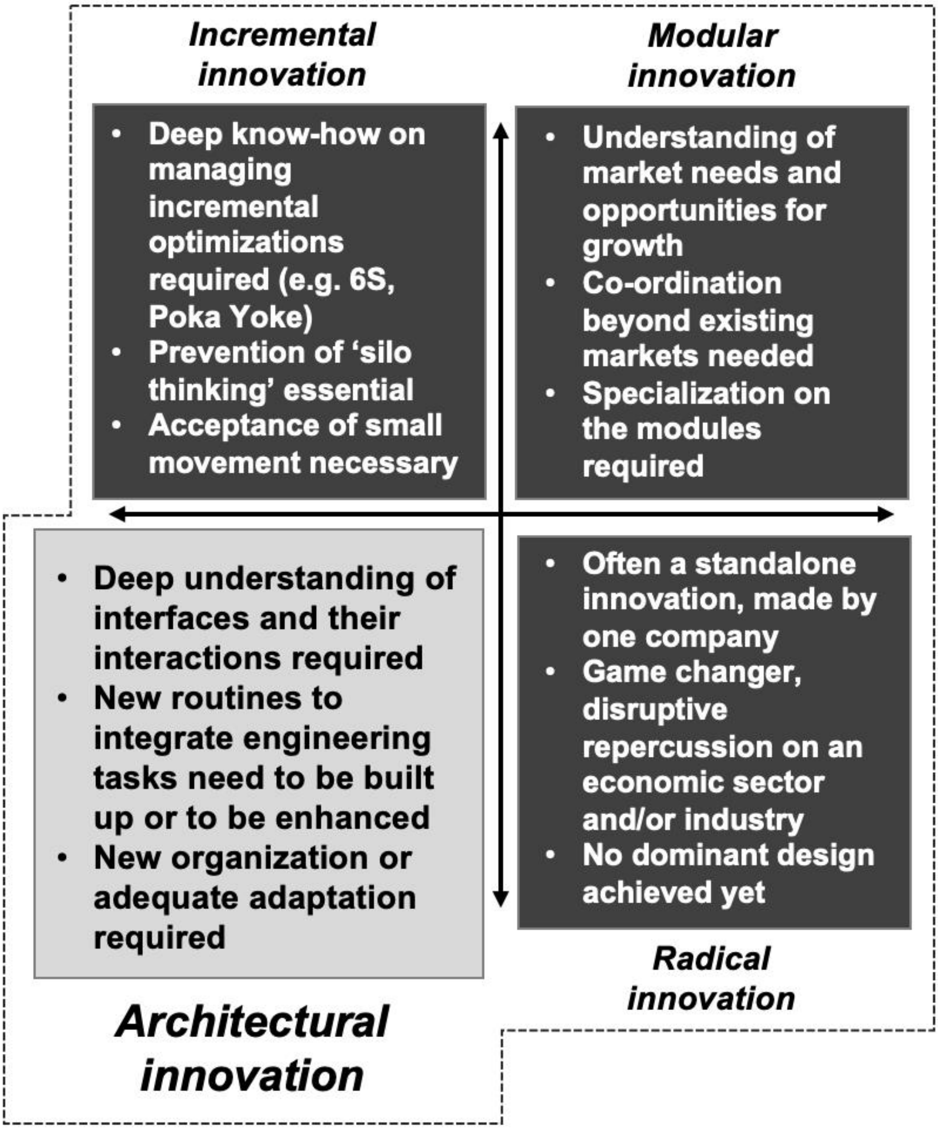

Figure 8: Specific capabilities to deal with the 4 types of innovation in accordance with to the framework for defining innovation. Inspired by Henderson, R. M. & Clark, K. B. (1990). Architectural innovation: The reconfiguration of existing. Administrative Science Quarterly.

Winter (2006) remarks that Teece sought to illuminate business strategy and economic organization's practical issues at a more abstract theoretical level that had been viewed as less understandable and less satisfactory before. Both theories' interrelationship is mentioned both by Teece, Pisano, and Shuen and Henderson and Clark. This also explains several references in each other's scientific work and the subsequent use of each other's findings. Nonetheless, they do not leave the level of theoretical consideration, combine both theories and constitute a new hypothesis, or set up a scientific study to acquire a new theoretical framework or enlarge the existing one.

The resource-based approach asks the question needed to understand the company's capabilities, its current position, the strategic direction, and the effort necessary to achieve the strategic goals. The overall objective that informs the resource-based perspective is to account for the creation, maintenance, and renewal of competitive advantage in terms of firms' resource side (Foss, 1997). The architectural perspective is vital because most market participants are not innovators of groundbreaking technologies that originate from digitalization. The greatest portion of market participants are applicants of digital innovations, and most innovators come up with a single innovation. A single company does not drive the digital revolution. The challenge for all of the applicants is to apply the digital technologies in their firms architecture in the most meaningful way.

Therefore, the overall goal of the dissertation is to develop a structural concept that enables companies to work out recommendations and strategies for the implementation of IIoT technologies, finding the most cost-effective investment strategy in respect of IIoT technologies for that individual firm. The approach is to achieve a genuinely unique position regarding digitalization that has a favourable impact on the future financial situation of the firm (e. g. its balance sheet, income- and cash-flow-statement).

Such a concept cannot be of a collective nature; it works on an individual basis and has to consider the different characteristics of a company and the differences of each industry in which such a company is operating. The dissertation is likely to help the engineering and the finance departments come to a common agreement for investments, evaluate those spending, and measure the long-term success of the investments.

4.2 Research question

Two important considerations that are often overseen by firms when digitizing is a) the mutual reinforcement between the digital technologies and b) the need for people-know-how to implement and to run those new technologies. The integration of several digital technologies might create an advantage for a firm. Still, the real benefit comes from understanding a firm-specific architecture of the relevant technologies and not investing in many digital technologies, but the right ones. The same is true for the necessary capabilities to integrate the technologies and to exploit them to their maximum. Digital technologies often come with more features and functions than initially intended for a certain purpose. The exploitation of digital technologies cannot be left alone to machine and machine algorithms. By way of illustration David Autor (Autor, 2014) highlighted that computer science is trying to overcome Polanyi’s paradox. Still, that tacit know-how such as flexibility, judgment and common sense cannot be easily computerized because we often do not know “the rules”. The fact that a task cannot be computerized does not imply that computerization does not affect that task. On the contrary: tasks that cannot be substituted by computerization are generally complemented by it.

This point is as fundamental as it is overlooked. Most work processes draw upon a multifaceted set of inputs: labor and capital; brains and brawn; creativity and rote repetition; technical mastery and intuitive judgment; perspiration and inspiration. This is also true for Dynamic Capabilities as there is no set of "rules" and no tutorial on the best set of those capabilities; they are firm-specific.

Those two factors described are part of the here present scientific analysis. The research question, therefore, is to investigate how the two theories can be brought into one edifice of ideas, how a firm specific analysis can look, and how the findings can be brought to life by means of a real-life application. The author will investigate the creation of competitive advantages by developing an individual, firm-specific architecture of its digitalization technologies while taking its dynamic capabilities to operate those technologies into account. The enhancement of the theoretical model to establish an empirical model must be examined, i.e., operationalizing the theoretical concept into measurable objects. Furthermore, the underlying mechanisms, processes, and tools necessary to realize such a digitalization strategy will be explained.

4.3 Hypotheses

Based upon constant observations of the industry, specialist lectures, presentations at specialized conferences, and a profound literature review, the following three hypotheses were developed and tested to predict the relationship of digitalization in the framework of Dynamic Capabilities and

Architectural Innovation. In order to accept or to reject the hypotheses, each hypothesis must state an expected relationship between variables, must be testable and falsifiable, and also enable other researchers to re-enact the steps that have been taken to obtain the result presented. Furthermore, it should be stated as simply and concisely as possible. Due to a lack of quantifiable knowledge about its impact on a firm, the decision to invest in digitalization today is subjected to Knightian uncertainty. Firms are accustomed to making decisions involving risk and uncertainty, but seldom Knightian Uncertainty. According to Knight, risk applies to situations where we do not know the outcome of a given situation but can accurately measure the odds. Knightian Uncertainty, on the other hand, applies to situations where we cannot know all the information and where the distribution is unknowable. We need an order to set accurate odds in the first place (Dizikes, 2010). The problem facing someone who is making an investment decision is therefore that fundamental data is missing. To improve the outcome of decisions taken under Knightian Uncertainty requires a structure, a process, a method (or a set of rules) to guide the decision process. The outcome of decisions must be predictable and calculable for the firm. Conclusions have to be drawn on a rational basis that is plausible for all parties involved in the decision process.

The day-to-day procedures to calculate investments and make a recommendation for or against an investment do not work for digital technologies. The data to make a simple calculation for the ROI of an investment, for example, is not available. The decision on hand must be made based on assumptions; in the end, it remains a decision made with uncertainty. If a model were to exist that reduces the number of different options to invest, the decision would still be one to make with uncertainty, but the number of such investments would be reduced. The reflection on this idea led to the following three hypotheses.

4.3.1 Hypothesis #1

There is no pattern or model for investment into digitalization explicitly based on the combination of dynamic capabilities and architectural innovation concepts. The reason is that the investment strategies and the modelling of the payback of investments are most often worked out from tried and tested models found in well-established textbooks and created based on available numbers, calculable risks, and a foreseeable development. Those models hardly work in the field of disruptive technologies and nor in industrial revolutions anymore.

4.3.2 Hypothesis #2

Firms today do not connect the concepts of dynamic capabilities and architectural innovation to build a superior, conjunct systematology when selecting digitalization technologies. Therefore, firms do not take advantage of this framework and do not make optimal decisions with regard to their investments into digitalization.

4.3.3 Hypothesis #3

The methodical support to decide on investments into digitalization is little, needs to be expanded, and a framework with a model to optimize and to support the decision process is beneficial. A frame-concept that amalgamates the concept of Dynamic Capabilities and Architectural Innovation would be firm specific and an identical transfer to another company would be pointless.

The line of argument to accept or reject the hypotheses rests on the possibility to translate the theoretical construct into single, measurable variables that can be tested. The corresponding research model, which indicates the relationships of the variables, is filed in the appendix section as Appendix 4.

To give the research a credible footing, a survey was conducted within the automotive supplier industry with an extensive questionnaire. Corresponding to the research questions, the survey was structured in such a manner as to provide insights both into the architectural framework as well as the dynamic capabilities, and to then convey recommendations for action within a specific firm. Each scientific research stream is recognized in the survey and has been given its own section (Figure 9).

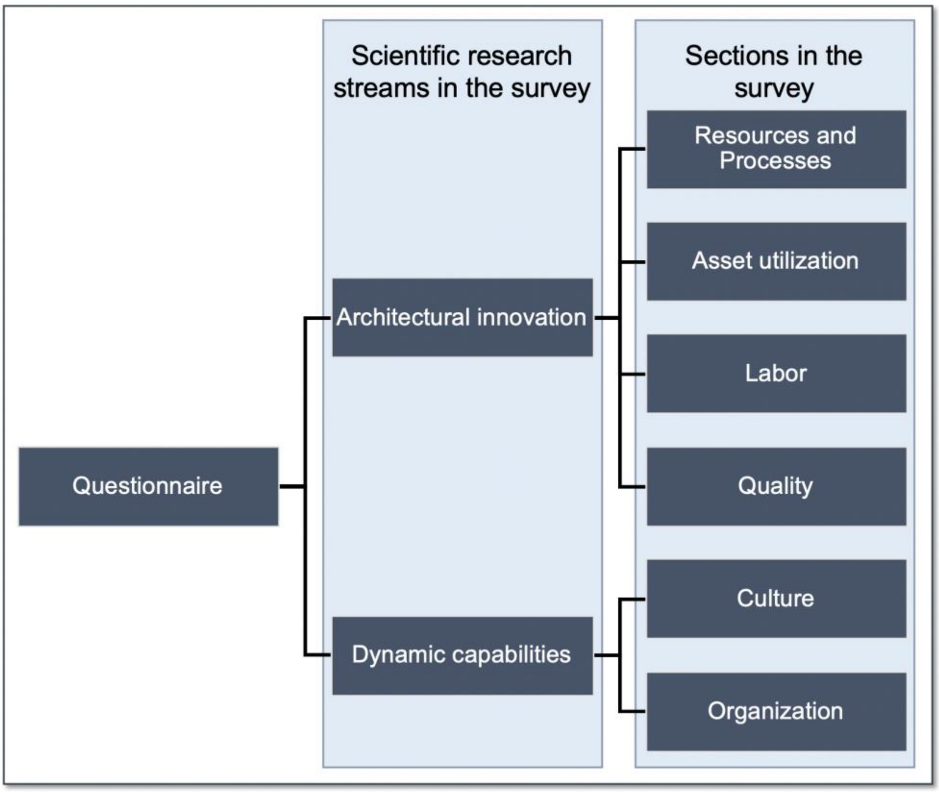

Figure 9: The research streams within the survey: Subdivision between Architectural Innovation and Dynamic Capabilities (self-edited).

The **four sections** (resources and processes, asset utilization, labor and quality) of Architectural Innovation's research stream were further subdivided into technologies that were considered relevant for the inspected company. The **two sections** (culture and organization) for the research stream of Dynamic Capabilities were asked by means of interrogating the company's capabilities with regard to dynamic capabilities.

5.1 The survey

The survey was conducted within the automotive industry in the beginning of 2019 over a period of 6 weeks at a supplier for the OEMs for automobiles. The investigated company employs more than 33,000 staff members and is running more than 125 locations worldwide. The company was chosen because it fits perfectly into the framework conditions of the object of investigation. The firm does not develop or produce digitalization technologies that can be applied in the value creation process by itself. Rather the firm is a user and applicant of the digitalization technologies that are readily accessible and operates those within its value stream.

5.1.1 The participants of the survey

All 142 participants of the survey work within the automotive supplier industry. The larger portion possess higher education qualification, such as a bachelor's or a master's degree. 4 of them have a Ph.D. A small portion of the expert group in Germany underwent vocational training but were considered experts due to their position and accountability. The majority of the participants are male, only a low number of participants are female (< 12%). A basic condition of the survey was strict confidentiality; hence a distinction between the male and female respondents is not possible and cannot be displayed. The participants of the survey come from Asia, Europe and the Americas (Table 1.0). The majority of the participants come from Germany, where the company has its headquarters.

Table 1: Overview of the survey participants

The survey was sent out to 142 participants that were classified into three main groups. Managers with a leadership position, senior experts with extensive technical know-how in a dedicated field and vast experiences in their field, and experts with less long-standing experience. The survey was answered fully by 93 participants, and this produced a participation rate of 65.5%.

	Asia		Europe		North- and South America		
	China	India	Romania	Germany	USA	Mexico	Brazil
Leadership position	3	2	4	9	6	7	2
Senior expert	6	2	6	19	6	7	2
Expert	8	0	7	26	6	14	0
Sum	**17**	**4**	**17**	**54**	**18**	**28**	**4**

After the survey was sent out, the participants that did not send their feedback were reminded twice, with a space of two weeks and an announcement of the closing date. The duration of the survey was eight weeks.

5.1.2 Sections within the questionnaire

The technologies that were considered as relevant are firm-specific and cannot be transferred without further investigation of their relevance to other firms. This always requires an alignment process within each individual firm. The technologies of the four sections considered for the research stream of Architectural Innovation can be looked up in Table 2.0.

Table 2: Considered technologies in the four analyzed sections

Four sections have been analyzed within a total of 32 technologies that can be considered as a stimulus for digitalization in each section. The selection of the technologies is firm-specific and can vary for other firms.

Section	Technologies
Resources and processes	a. Smart energy consumption b. Parameter adjustment on premise c. Intelligent lot sizes d. Automated, real-time feedback to process experts/specialists e. Big data & analytics f. Machine to machine communication g. Data driven design to value
Asset utilization	a. Advanced planning and scheduling b. Real-time analysis of bottlenecks c. Digital documents d. Intelligent replenishment e. Equipment conditioning monitoring for maintenance, repair and operations (MRO) f. Digital support for preventive maintenance g. Predictive maintenance h. Regional and global capacity scheduling i. Virtual reality j. Augmented reality k. 3D printing l. 4D printing m. Automated guided vehicles (AGV) n. Intelligent guided vehicles (IGV) o. Machine to human (M2H) communication p. Digitized simulations, kaizen workshops and value stream planning q. Application of operations research (OR)

Labor	a. Smart wearables b. Human-robot-collaboration c. Digital performance management d. Digital safeguarding of production processes and equipment e. Automation of knowledge-work
Quality	a. Accessibility to data for DMAIC b. Algorithms to steer the upper and the lower specification limits c. Automated feedback of quality relevant data into the design processes

The research stream of Dynamic Capabilities was not broken down into technologies but into the employees' readiness on the shop-floor, the middle management, and the necessary support functions. If the management is willing to press ahead with digitalization in the production area, those functions need to be prepared and able to integrate the new technologies. The following functions were investigated:

1. IIoT readiness of the line operators
2. IIoT readiness of the manufacturing engineer
3. IIoT readiness of the middle management
4. IIoT readiness of the technical experts

5.1.3 Structure of the questions

Each technology queried in the questionnaire is introduced with a short description (‘infobox’) to introduce the technology, its capability for the firm, and to avoid a misinterpretation of its impact on the firm. This is done to ensure that the participant of the survey is familiarized with the meaning of the technology to the firm. An excerpt of the questionnaire can be found in chapter 7.1.1, Figure 33, for a graphic representation. The questions for every technology are identical, and the participant is asked to rate the following dimensions:

1. How do you rate the **strategic relevance** of this IIoT measure with regards to the **economic success** of the firm? Possible answers:
    a. Low
    b. Medium
    c. High
2. How do you rate the **current priority** of this measure for Operations? Possible answers:
    a. Low
    b. Medium
    c. High
3. How do you rate the **current maturity** of this measure within Operations? Possible answers:
    a. Inexperienced
    b. Tentative
    c. Advanced
    d. Dynamic
    e. Outstanding
4. Would you recommend to further **invest** into this measure or to **disinvest** resp. **not invest**? Possible answers:
    a. Further invest
    b. Disinvest/no invest
5. On a scale from 0 (very simple) to 10 (very complex), how **complex** do you rate the worldwide implementation of this IIoT measure?

6. On a scale from 0 (very low) to 10 (mature), how well **prepared** is the Operations **organization** from a **cultural** point of view to implement this IIoT measure?

The 6th question establishes a link to the dynamic capabilities and is later used to verify the answers with regards to dynamic capabilities.
The four functions investigated in the second part of the survey aim for dynamic capabilities and follow an identical structure. For each function, the questions are:

1. Do you agree or disagree that further training and education is necessary to meet the IIoT challenges? Possible answers:
    a. Agree
    b. Disagree
2. How do you rate the current priority of trainings and education within operations? Possible answers:
    a. Low
    b. Medium
    c. High
3. How do you rate the current training level for IIoT within operations?
    a. Inexperienced
    b. Tentative
    c. Advanced
    d. Dynamic
    e. Outstanding

To conduct the survey, the web-based survey system that is provided by the company *Objectplanet* was used. The name of the tools is *Opinio*, a full-featured web-based application that enables the researcher to create, manage and publish online surveys and to collect data from respondents (Objectplanet, 2020).

5.2 The data-set

After cleaning the survey, a multidimensional data-set with a number of 3,000 lines, comprising of the sections, the technologies, and the individual ratings remained. To analyze the data-set, the statistics software Minitab® (version 18) was used.

5.2.1 Principal component analysis

Principal component analysis (PCA) refers to the problem of fitting a low-dimensional affine subspace S of dimension $d \ll D$ to a set of points $\{x_1, x_2, \ldots, x_n\}$ in a high-dimensional space $\mathbb{R}^D$ (Vidal, Ma & Sastry, 2016) and is likely to be introduced at first by Pearson (1901) as a new approach to statistics:

> In many physical, statistical, and biological investigations it is desirable to represent a system of points in plane, three, or higher dimensional space by the "best fitting" straight line or plane. Analytically this consists in taking
>
> $$y = a_0 + a_{1x}, \ \ or \ \ z = a_0 + a_1 x + b_1$$
> $$or \ z = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + \ldots + a_n x_n$$

> where $y, x, z, x_1, x_2, \ldots, x_n$ are variables, and determining the "best" value for the constants $a_0, a_1, b_1, a_0, a_1, a_2, a_3, \ldots a_n$ in relation to the observed corresponding values of the variables. In nearly all the cases dealt with in the text-books of least squares, the variables on the right of our equations are treated as the independent, those on the left as the dependent variables. The result of this treatment is that we get one straight line or plane if we treat some one variable as independent, and a quite different one if we treat another variable as the independent variable. There is no paradox about this; it is, in fact, an easily understood and most important feature of the theory of a system of correlated variables. … In many cases of physics and biology, however, the "independent" variable is subject to just as much deviation or error as the "dependent" variable. We do not, for example, know x accurately and then proceed to find y, but both x and y are found by experiment or observation. We observe x and y and seek for a unique functional relation between them. (pp.559)

Independent from Pearson, Hotelling (1933) developed a similar approach to the standard algebraic derivation and a solution for the same problem, discussing a different geometric interpretation from that given by Pearson (Jolliffe, 1986).

If not the most, PCA today is a popular, multivariate statistic technique used by almost all scientific disciplines. It is a multivariate statistic technique used to structure, simplify and exemplify extensive datasets.

Many variables are approximated by a smaller number of ideally descriptive and meaningful linear combinations (the principal components). The PCA has four goals when applied to a dataset (Abdi & Williams, 2010):

1. Extract the most important information from the data-set
2. Compress the size of the data-set by keeping only the important information
3. Simplify the description of the data-set
4. Analyze the structure of the observations and the variables

New variables, the principal components, are computed and are obtained as linear combinations of the original variables. The first principal component is required to have the largest possible variance and this component will explain the largest part of the data-set's inertia. The second component is computed under the constraint of being orthogonal to the first component and having the largest possible inertia. The other components are computed likewise. The values of these new variables for the observations are called factor scores; these factor scores can be interpreted geometrically as the projection of the observation on the principal component (Abdi & Williams, 2010).

Figure 10, inspired by Vidal, Ma, and Sastry's work, is a graphical representation of a mathematical investigation and leads to the same solution.

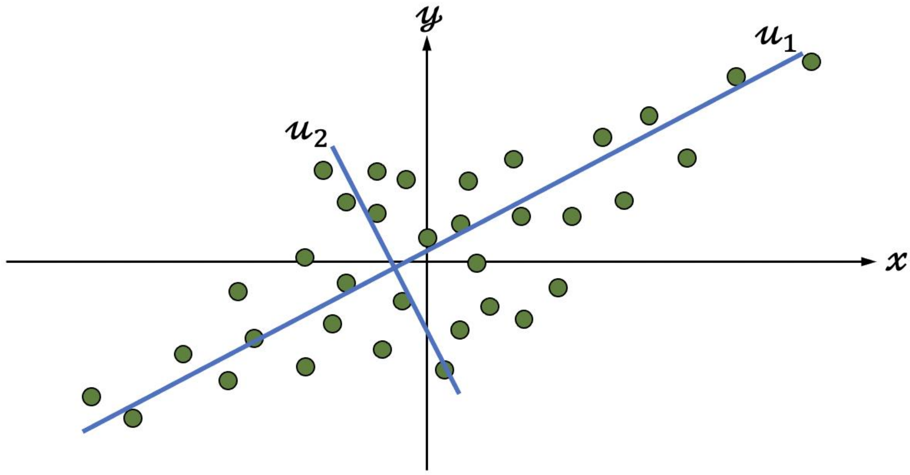

Figure 10: Example of a two-dimensional data-set and its two principal components. Inspired by "Generalized Principal Component Analysis" by Vidal, Ma and Sastry, 2016, p. 33, Copyright by Springer.

The term ‘Principal Component Analysis’ is commonly used, but other terminologies exist. ‘Factor analysis’ being the second most common one, with others being ‘singular value decomposition’, ‘eigenvector analysis’ or ‘axis transformation and midpoint calculation’.

The first part of the dataset's structure and size require its simplification it and working out areas of focus to determine the next steps. The dataset has several effective degrees of freedom within the analyzed ambient space and contains a moderate amount of noise. Therefore, it has been decided to apply the Principal Component Analysis (PCA) to examine the dataset.

The interested reader will find complementary explanations of the PCA, its mathematical principles, and its mathematical description in *Appendix 3 – Explanatory notes referring to PCA.*

5.2.2 Methodology to investigate the data-set for dynamic capabilities

The second part of the data-set was also cleaned and analyzed with the same software (Minitab®). The second part of the questionnaire explores the capacities of dynamic capabilities within the firm. In the investigated framework, dynamic capabilities are essential to effectively build, integrate, coordinate, reconfigure, and redeploy the digital technologies customized for a single firm. To digitize is a strategic decision (based on sensing, the first type of dynamic capabilities); the selection of the appropriate technologies is a downstream decision (seizing, the second type of dynamic capabilities) that must also involve also middle management. Using digital technologies at the best possible rate, nevertheless, is directly linked to the user's capabilities. It requires making the digital technology useful rapidly (transforming, the third type of dynamic capabilities). If the company sensed the need for digital technology and decided to seize it, it is all about transforming to a new state and implementing the technology rapidly. Figure 11 shows that the technology has been sensed, the decision to seize was made, and now the transformation process requires a certain set of the 3rd form of dynamic capabilities.

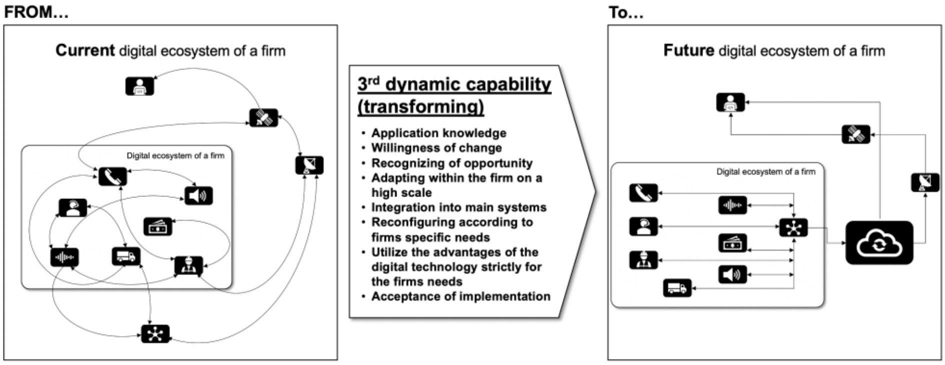

Figure 11: Example of the need of dynamic capability (here: transforming, 3rd dynamic capability) to integrate a new digital technology (here: cloud computing). The structure on how the digital technologies cooperate within the firm can be streamlined and optimized with cloud computing, but requires the capabilities to integrate this new approach within many different fields of applications and users (self-edited).

The aim of the research is to develop a framework that enables a firm to digitize and to gain the most advantages out of it. Therefore, the questionnaire's focus was on the 3rd dynamic capability, the ability to transform rapidly. The prerequisites to do so are (a) the ability and capacity of the applicants/users to apply and work with digital technologies, (b) their current level of know-how about digitalization, (c) the need for training and education in the field of digitalization. The questionnaire has been structured in a way to compare the three different levels for four groups of applicants/users:

1. Middle Management within the production area
2. Engineers that work closes or within the production area
3. The technical experts that apply and maintain technologies
4. The line operators that execute the technologies

For all four groups of applicants/users, the survey participants were asked (a) if they agree or disagree that further training and education is necessary to meet the IIoT challenges within the operations, (b) how they rate the current priority of training and education within operations and (c) how they rate the current training level within operations. The results are then displayed in histograms.

6 RESULTS AND THEIR EVALUATION

The results of the analysis in this chapter are categorized according to the analysis of the data into Architectural Innovation and Dynamic Capabilities. For the analysis of the Architectural Innovation, a reduction of the dimensionality had to be performed, using the principal component analysis (PCA). The second part for the Dynamic Capabilities was analyzed by sorting the data and displayed by means of histograms. Later, the results of both parts were re-combined.

6.1 Analyzing the data-set for Architectural Innovation

The principal component analysis was selected to simplify the first part of the dataset, which is looking into architectural innovations. This practice was done to expose the significant variables and to deduce the key activities.

Table 3: Eigenanalysis of correlation matrix

The first principal component accounts for 43.9% of the total variance.						
Eigenvalue	2.6352	1.1885	0.8440	0.5454	0.4500	0.3370
Proportion	0.439	0.198	0.141	0.091	0.075	0.056
Cumulative	0.439	0.637	0.778	0.869	0.944	1.000

Table 3.0 presents the PCA's result of the variables strategic relevance, current priority, current maturity, invest/disinvest, complexity, and readiness (of the firm). Table 3.1 shows the principal components, which are linear combinations of the original variables that account for the data

variance. The eigenvectors (which are comprised of coefficients corresponding to each variable) are used to calculate the principal component. The coefficients indicate the relative weight of each variable in the component. In these results, the first principal component has large positive associations with current priority (0.487), strategic relevance (0.473), current maturity (0.436), and readiness (of the firm) (0.402). The first principal component in this analysis is interpreted as being primarily a measurement of the firm's (current and future) competitiveness and expresses the concern of the participants of the survey to guarantee the firm's sustained viability. On the other hand, the second principal component can be interpreted as the negligence of the current maturity and financial impact due to the blatant need to invest in digitalization.

Table 4: Eigenvectors

The variables that correlate the most with the first principal component (PC1) are current priority (0.487).

	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Strategic relevance	0.473	0.378	-0.222	-0.068	-0.062	0.758
Current priority	0.487	0.065	0.181	-0.516	0.619	-0.278
Current maturity	0.436	-0.342	0.318	-0.308	-0.699	-0.093
Invest/ disinvest	-0.428	-0.324	0.495	-0.341	0.193	0.559

Complexity	-0.068	0.697	0.675	0.158	-0.133	-0.104
Readiness	0.402	-0.380	0.340	0.702	0.265	0.123

The scree plot in Figure 12 displays the number of the principal components versus its corresponding eigenvalue. It is reasonable to select the number of components based on the eigenvalues. The first two components form a steep curve, followed by a bend, and are therefore relevant for further analysis.

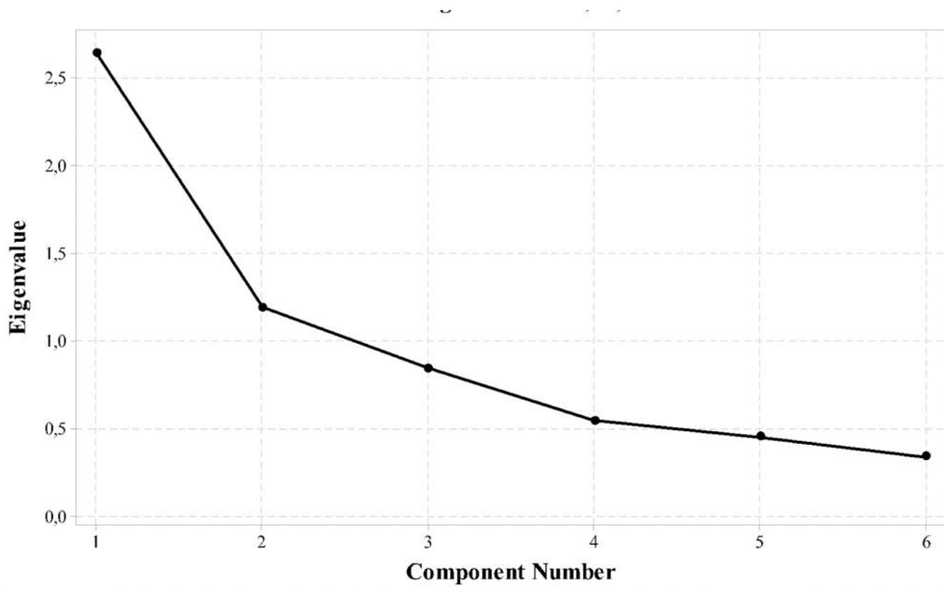

Figure 12: Scree plot of strategic relevance, current priority, current maturity, invest/disinvest, complexity and readiness (of the firm) (self-edited).

The loading plot displays each variable's coefficients for the first component versus the coefficient for the second component. The loading plot is used to identify which variables have the largest effect on each component. Loadings close to 0 indicate that the variable has a weak influence on the component.

The PCA loading plot (Figure 13) shows that current priority, strategic relevance, current maturity, and readiness (of the firm) have large positive loadings on component 1. Invest/disinvest, readiness (of the firm), and current maturity have large negative loadings on component 2 and confirm the statement made earlier.

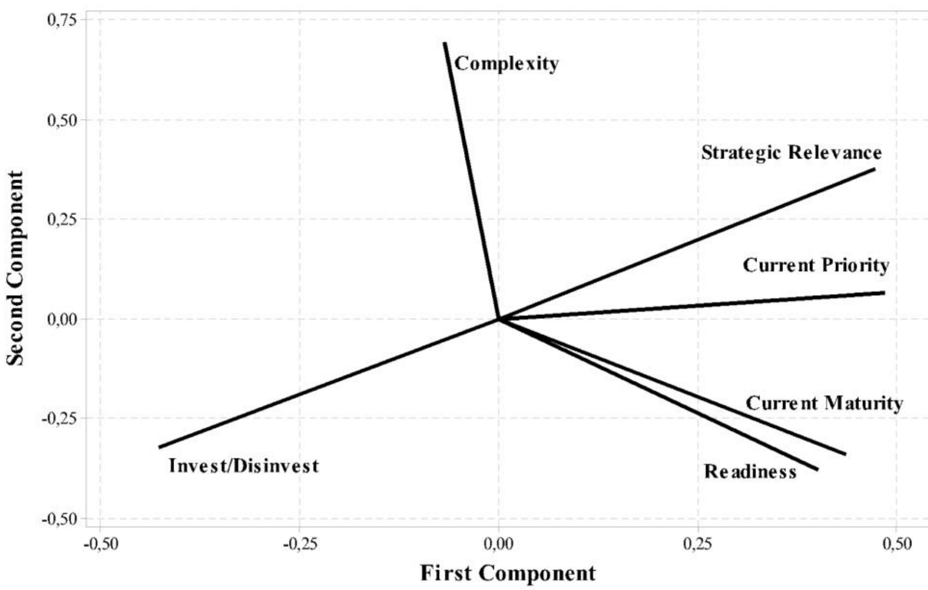

Figure 13: Loading plot of strategic relevance, current priority, current maturity, invest/disinvest, complexity and readiness (of the firm) (self-edited).

The score plot graphs the scores of the second principal component versus the scores of the first principal component and is used to detect outliers, clusters and trends (Figure 14). In the survey's PCA, very few outliers stand out; groupings can be assumed for resources and quality even though the overlap is obvious.

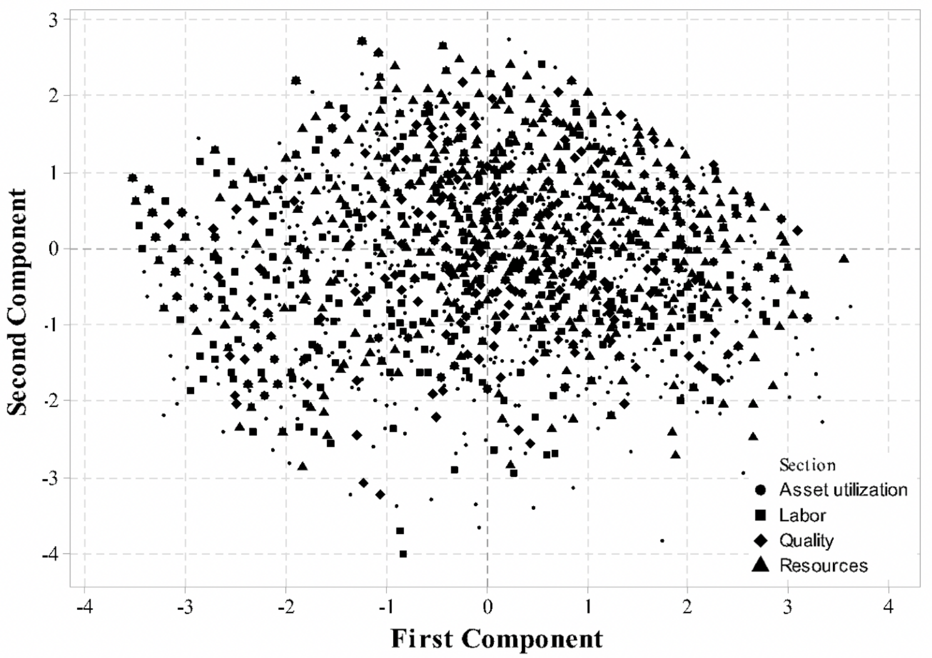

Figure 14: Score plot of the 4 sections showing the scores of the second principal component versus the scores of the first principal component (self-edited).

The results of the score plot (Figure 14) are not as easy to interpret, the groupings of the data are not apparent, and therefore separate distributions in the data are unlikely. The points are randomly distributed around zero; therefore, the data is highly likely to follow a normal distribution.

6.1.1 Designation of the relevant technologies

Once the most important variables have been detected, the data-set is used to determine which technologies are most important from the participants' perspective. To enlarge the distance of the technologies from one another, the values for the rating low, medium, and high are multiplied by the factor 1, 5 and 10.

Table 5: Technology rating matrix

To enlarge the distance of the technologies from one another, the values for the rating low, medium and high are multiplied by the factor 1, 5 and 10.

Technology	**Strat. relevance**	**Current priority**	**Current maturity**	**Complexity of implement.**	**Cultural readiness**
Smart energy consumption	262	204	257	694	567
Parameter adjustment on premise	279	229	246	806	550
Intelligent lot sizes	272	229	255	756	526
Automated, real-time feedback to process experts/specialists	281	236	274	649	605
Big Data & Analytics	277	219	243	776	502
Machine to machine communication	243	197	225	721	494
Data driven design to value	227	168	184	771	378
Advanced planning and scheduling	275	230	252	723	517
Real time analysis of bottlenecks	251	213	283	565	627
Digital documents	236	192	253	499	575
Intelligent replenishment	254	211	247	652	558

Equipment conditioning and monitoring for MRO	251	200	230	665	537
Digital support for prev. maint.	246	190	219	629	528
Predictive maintenance	246	188	204	704	481
Regional and global capacity scheduling	216	167	215	645	459
Virtual reality (VR)	180	149	160	650	392
Augmented reality (AR)	163	130	143	675	351
3D printing	212	178	219	540	508
4D printing	212	127	136	709	313
Automated guided vehicle	234	185	177	622	486
Intelligent guided vehicle	205	160	141	717	405
Machine to human (M2H) communication	218	170	178	676	443
Digital simulations, kaizen workshops and value stream planning	222	190	234	552	542
Application of Operations Research (OR)	183	138	144	676	343
Smart wearables	182	143	154	591	402
Human robot collaboration	216	178	193	672	449

Digital performance management	178	139	167	608	346
Digital safeguarding of production processes and equipment	211	178	220	512	510
Automation of knowledge work	224	180	213	567	491
Accessibility to data for DMAIC	200	170	236	520	533
Algorithms to steer the upper and lower specification limit	210	161	179	689	440
Automated feedback of quality relevant data into the design process	230	171	193	620	449

This data was then processed with the same software (Minitab®) and transferred into a matrix plot (Figure 15).

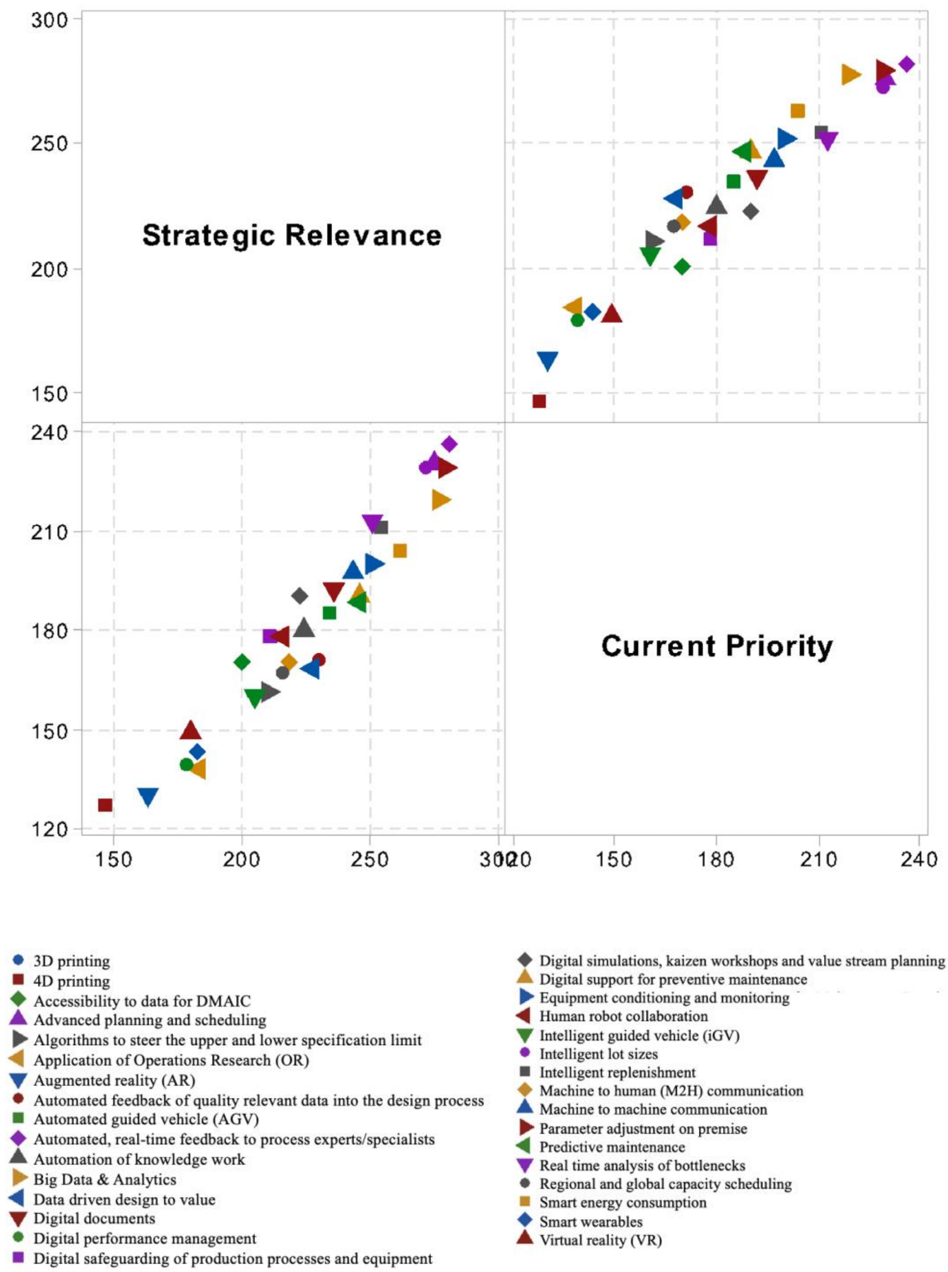

Figure 15: Matrix-plot of current priority (abscissa) and strategic relevance (ordinate) to arrange the technologies in a sequence according to the findings of the PCA (self-edited).

The matrix plot in Figure 15 graphically displays the top-5-technologies with the highest rating. Those are:

1. Automated, real-time feedback to process experts/specialists
2. Parameter adjustment on premise
3. Advanced planning (and scheduling)
4. Intelligent lot sizes
5. Big Data & Analytics

The ulterior motives behind the survey participants' ratings of the technologies are that they thought about the main problems on the shop-floor. Those are mainly downtimes (which would explain the ratings for number 1 and number 2), problems with the supply chain (which would explain the ratings for number 3 and number 4) or sustainability (which would explain the rating for number 5). Sustainability is increasingly important; as well as avoiding a cost driver (reduction of scrap cost), or as a precondition by customers who ask for less and less CO_2 emissions in production processes.

To further improve the transparency of Figure 15, the same criteria for the abscissa and the ordinate were applied in Figure 16 and all other technologies were deleted from the data-set. Figure 16 shows these results, and it is helpful to better recognize the subtle differences between each technology.

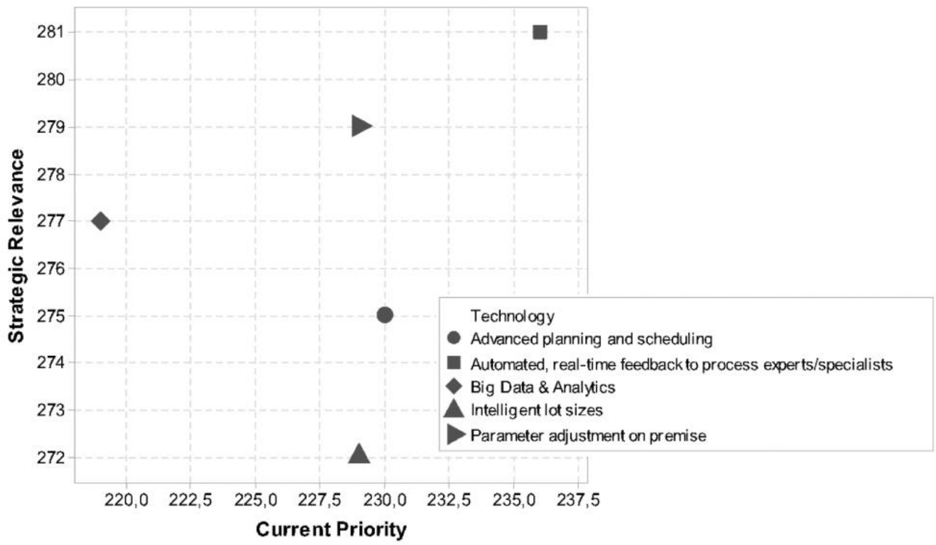

Figure 16: Matrix plot of strategic relevance vs. current priority (self-edited).

It is indisputable that *strategic relevance* and *current priority* are the leading factors for decisions. But it is far from impossible that during the development of the firm-strategy, a target-conflict between the two factors arises due to internal or external causal links. It is then helpful to have the option to consult a third factor and consider it, too. An exemplary comparison of two technologies that could be disputable is *advanced planning and scheduling* and *intelligent lot sizes*. In quadrant 2 (top third, middle square), both technologies have a very similar *current priority*. The *strategic relevance* of advanced planning and scheduling, though, is rated as higher. If a target conflict occurs for whatever reason, and the firm calls for an extension of the argumentation either factor, the firm can broaden the reasoning. The PCA loading plot (Figure 12) reveals that *current maturity* has the third-highest positive loading. This is why it makes sense to extend the plot by this variable and look into the results (Figure 17). In this plot, both of the technologies can be compared separately against a third factor by the firm. The first comparison of strategic relevance and current maturity (quadrant 3, top third, right square) reveals that intelligent lot sizes have a slightly higher current maturity than advanced planning and scheduling. A final check could also validate the results in quadrant 6 (middle row, right square). Both technologies are close to each other, but intelligent lot sizes have a slightly higher current maturity. This comparison further supports a decision to prioritize intelligent lot sizes over advanced planning and scheduling.

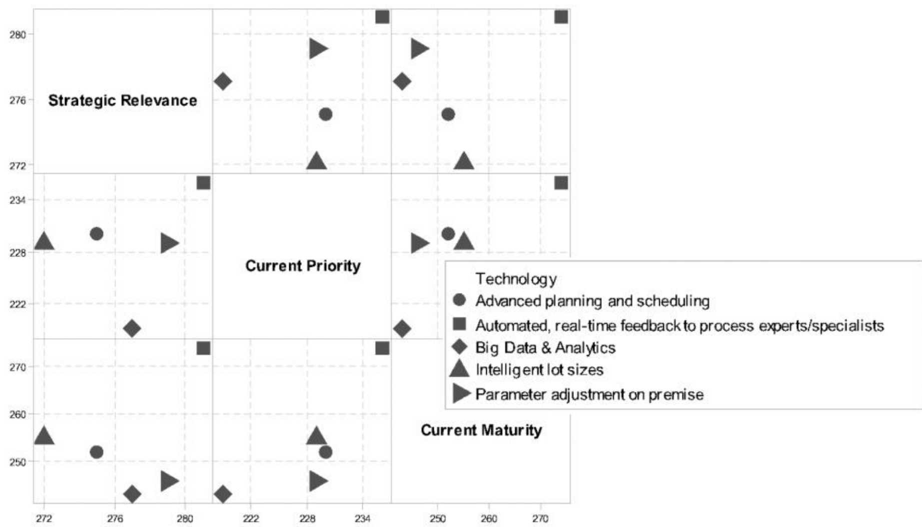

Figure 17: Matrix plot of strategic relevance vs. current priority vs. current maturity (self-edited).

6.1.2 Analysis of the sections of architectural innovation

After a further transformation of the data, the data-set also analyzed the 4 sections *asset utilization*, *labor*, *quality*, and *resources* (see chapter 5 and especially Table 2.0). The range of the evaluation by the survey participants is determined, i.e., the total amount for each section is compared with each other. By doing so a statement of the importance that the participants of the survey admit to every single section is possible. It is a helpful additional decision criterion for the company to define its priorities and to allocate resources. The analysis can be done for all directions; in the present paper, the two main directions, *strategic relevance* and *current priority* were chosen because they are the most important factors for the investigated firm. In Figure 18, *strategic relevance* is the ordinate, and the 4 sections are on the abscissa.

The highest-rated section for *strategic relevance* is the *resources and processes*, followed by a noticeable gap to *quality*.

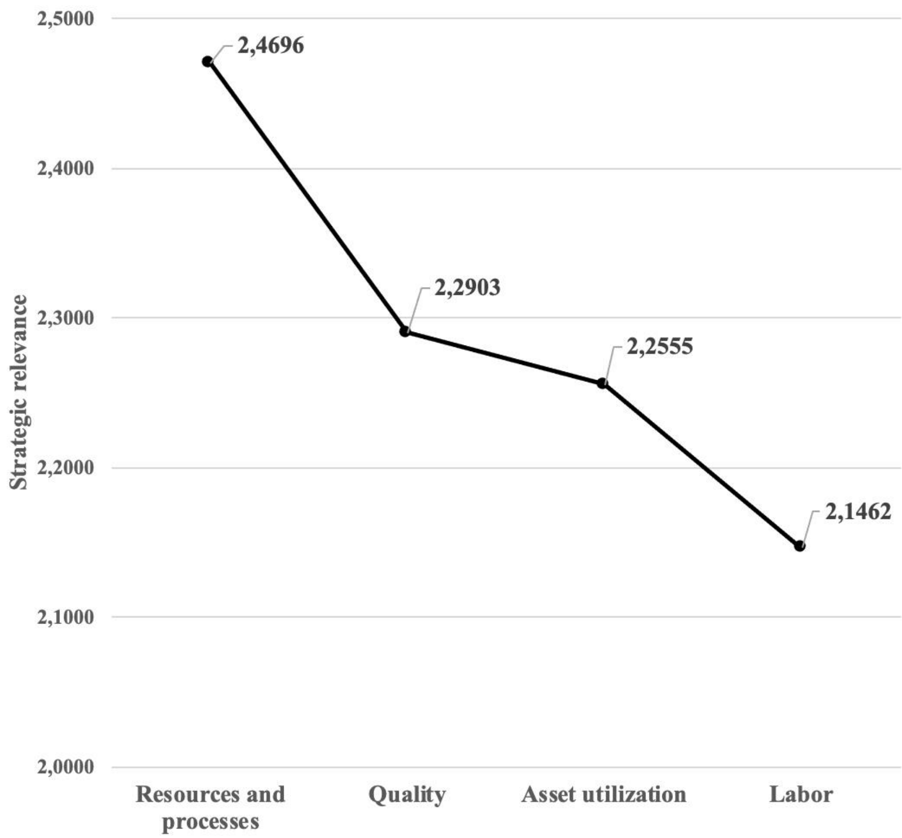

Figure 18: Survey participants rating for the sections from the perspective of strategic relevance (self-edited).

In Figure 19, the *current priority* is the ordinate, and the four sections are also on the abscissa.

The highest-rated section for *current priority* is also *resources and processes*; also, here, a gap to the next section, *quality*, is noticeable.

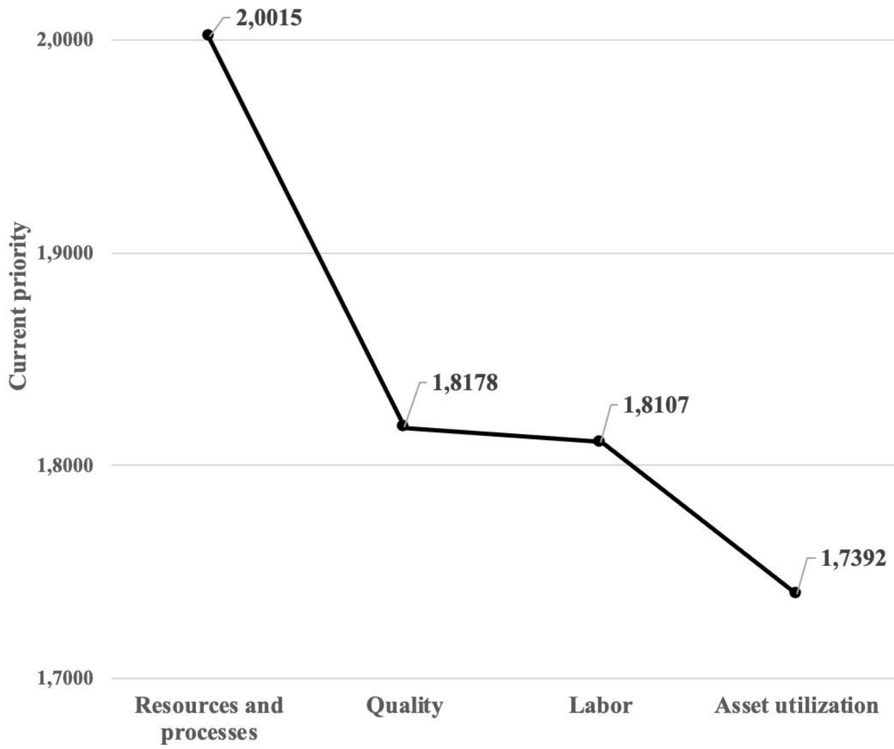

Figure 19: Survey participants rating for the sections from the perspective of current priority (self-edited).

The results which Figure 18 and Figure 19 display show very interesting findings because most of the technologies mentioned in this section (Table 2.0) are technologies that enable the whole system to perform more efficiently and effectively and requires a holistic approach, i.e., the 'health' of the complete system is taken into consideration, and the general context is considered. The machine to machine communication and the intelligent lot sizes are the most apparent technologies which highlight such a holistic understanding. The automated, real-time feedback to process experts/specialists is not obvious but distinct when looked at it in detail. Herein lies why:

1. **Machine to machine communication (M2M):** M2M is a systematology to establish a self-monitoring production and to reduce or even avoid human intervention. The machines monitor the results of their processes and communicate those to other machines that can gain an advantage from those results (i.e., tolerance deviations that trigger a reaction/adjustment of a machine in the downstream processes to improve the outcome of the production processes)
2. **Intelligent lot sizes:** There are several models to define the right order quantities that take a wide range of parameters into account (such as logistic conditions, product-specific requirements, legal conditions (i.e., taxes and customs duties), equipment specific conditions (i.g., setting up and ramping up production equipment). An intelligent lot size enables the firm to react on changes in this complex environment, to give weight to each parameter and to avoid the building up of stock or special cargo.
3. **Automated, real-time feedback to process experts/specialists:** The process parameters are essential for the outcome of the firms' production and have a direct impact on the firms' KPIs. With a direct link to the experts/specialists, a dramatic shortening of the reaction time is possible. This does not only have a positive impact on the production and the operative KPIs, but it also improves the top KPIs of the firm and its competitive position.

To fully understand the firms' digitalization strategy, Figure 18 and Figure 19 play an important role in building our general understanding. The results also underpin the digitalization strategy and put more emphasis on a certain technology portfolio.

6.1.3 Analysis of additional feedback for architectural innovation

The questionnaire was built in a way that allows the survey participants to extend their feedback regarding technologies, capabilities, and applications in the form of free-text. This feedback is necessary to counteract negligence in the questionnaire, and it is helpful to complement the survey and answer the research question. The survey participants were asked what technologies are missing from their perspective and where the company should develop greater insights. The participants were asked to rank their feedback to see how each technology would impact the firm. The data-set was also cleaned for this particular section of the survey and prepared for visualization.

39 survey participants gave a written statement, and out of those, 37 statements came up with an extension of the technologies mentioned in the survey. The two statements omitted can be explained by a misinterpretation of the question in the survey.

The 37 statements were classified to fall into one of the following domains:

1. **Visualization & reporting:** Devices such as tablets for the operators, digital performance management, OEE capture and reporting by the machine, a link of andon-systems with the MES.

2. **Data security:** Several feedbacks regarding the process of protecting the data (authorization access and data corruption) generated for or within the production processes.
3. **Smart logistics:** The feedback focused most on the internal logistics processes within production (intralogistics) and extended the technologies presented in the questionnaire.
4. **Interconnection**: (e.g., ERP with MES): Technological aspects of the two systems and missing preconditions were given as feedback (such as a too low data transmission rate in some locations).

The evaluation of the feedback highlighted that no major technology was forgotten when the questionnaire was set up. Some preconditions need to be fulfilled, and that might not be in place yet. The comments regarding the cross-functional use of technologies point directly to an interrelation of technologies that are part of this research (such as the connectivity of MES and ERP). The feedback is valuable for any firm heading towards digitalization, as this part highlights weak points necessary to execute a digitalization strategy.

6.1.4 Conclusion on the analysis of the data-set for architectural innovation

The PCA, together with the designation of the digital technologies, is a strong tool to ascertain what digital technologies are of most interest and need for a firm; it is a methodology to showcase the direction a company needs to invest within digitalization to establish a decent architecture of digital technologies customized for the needs of the individual firm. It is the part of the analysis that determines what technologies will create the architecture of technologies within the firm to support its business model and ensure that it is prepared for digitalization from an architectural point of view.

The firm that has been investigated is now clear about the investments it has to make and more importantly, which investments to avoid. These are the main findings:

1. Main focus: The firm has to look for technologies with a high strategic relevance (becoming relevant in the future) and those that are rated to have a high priority on the current business. The participants of the survey focused less on technologies that have a high degree of technological readiness, and interestingly, did not hesitate to defer technological complexity as a hindrance for the implementation of digital technology.
2. The firm is able to point out the 5 technologies to focus on (advanced planning and scheduling, automated feedback to process experts/specialists, big data & analytics, intelligent lot sizes and parameter adjustment on premise).
3. The firm is able to clearly distinguish between the necessary technologies and its relevancy (Figure 15 and Table 5.0).
4. If necessary, the firm can further extend its argumentation for the technologies to invest in. It has a system from which to draw a further argument if there are split decision or target conflicts (Figure 17).
5. The firm has created awareness about the sections that are of highest interest for the firm. This knowledge was available but hidden in the firm, now it is apparent (Figure 18 and Figure 19).

By doing so, the firm has all remedies at its disposal to create an unprecedented, individual digitalization strategy. This digitalization strategy will be different from all other firms' digitalization strategies and, correctly applied and implemented, produces a competitive advantage to the firms' competitors.

6.2 Analyzing the data-set for Dynamic Capabilities

The second part of the data-set refers to the dimension of dynamic capabilities. It is a detailed examination of the working levels that have to integrate digital technologies; in other words, make the digital technologies run on the shop-floor, disseminate good practice examples, advocate the achievements and captivate the users for their benefits. The working levels that were recognized as being decisive for the survey (middle management, engineers, technical experts, and line operators) are consequently the subject of the survey.

6.2.1 Dynamic capabilities of middle management

The middle management has a limited influence on the strategic direction of a firm. But middle managers are essential for the rapid implementation of technology-related decisions on the shop-floor and prevent resistance against those technologies. If this management level neither understands the strategic direction (and the decisions that lead to choosing a certain type of digital technology) nor the impact it has on the shop-floor, the transformation process will be unsatisfactory at best and is likely to fail.

The evaluation of the participants of the survey for the middle management regarding its need for training and education for digitalization therefore is essential.

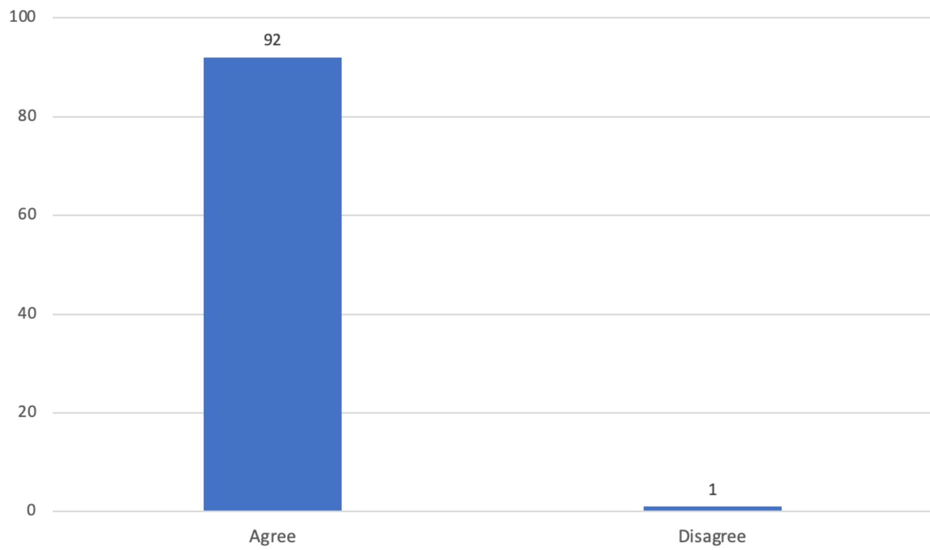

Figure 20: Histogram for necessity for further training and education; IIoT readiness of middle managers. "Do you agree or disagree that further training and education is necessary to meet the IIoT challenges?" (self-edited).

The participants of the survey see a huge need for training and education. 92 out of 93 participants believe the middle management ought to be trained, as is graphically displayed in Figure 20.

Nevertheless, the current priority of training and education reveals a varied picture. 22 participants rate the need as low, the majority (47) rate it as medium, and 24 rate the priority as high (Figure 21).

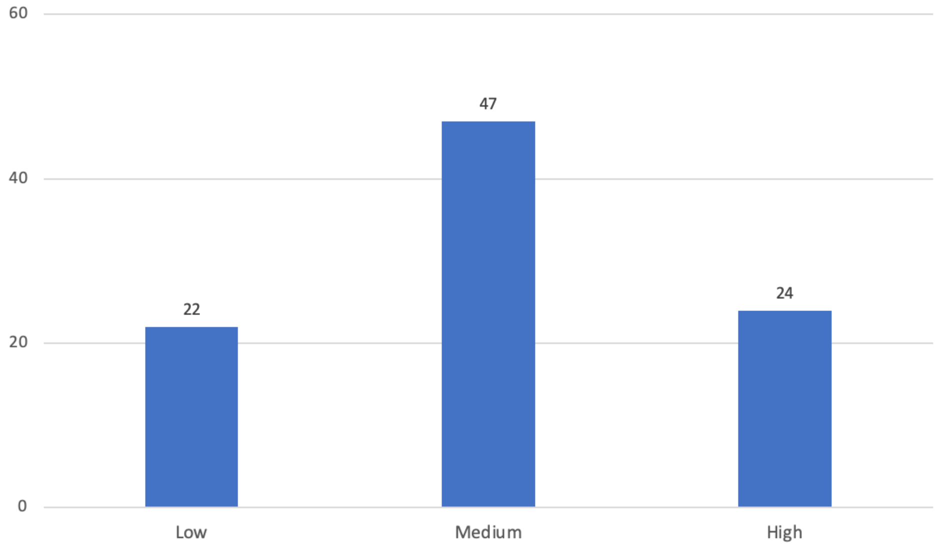

Figure 21: Histogram of current priority; IIoT readiness of middle managers. "How do you rate the current priority of training and education within operations?" (self-edited).

The participants' answers regarding their assessment of the current training level provides no obvious indication of why the need for training and education is not rated higher. The answers to the third question clearly show that 66 participants rate the current training level as inexperienced (18) or tentative (48). A minority rate the current training as advanced (18) or dynamic (9). No one rated the training level on the highest level, outstanding (Figure 22).

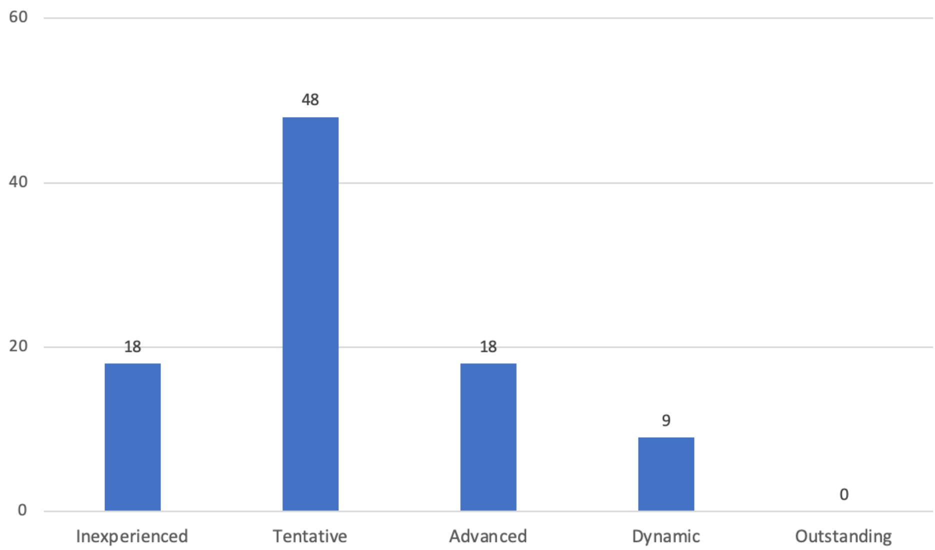

Figure 22: Histogram for current training level; IIoT readiness of middle managers. "How do you rate the current training level for IIoT within operations?" (self-edited).

6.2.2 Dynamic capabilities of engineers

Engineers have to integrate the digital technologies within operations and the shop-floor, maintain the technologies, keep them running, and help other entities to work effectively with the technologies. If the availability of technology is not given or restricted, its acceptance will decrease swiftly. Consequently, it is not surprising that the rating for the need for training and education is identical to the one for middle management (Figure 23). The feedback on the current priority of training is also a mixed one. The rating differs from the one for the middle management; the priority is rated as low by 18 participants, the majority (55) rate it as medium, and 20 participants rate the need as high (Figure 24).

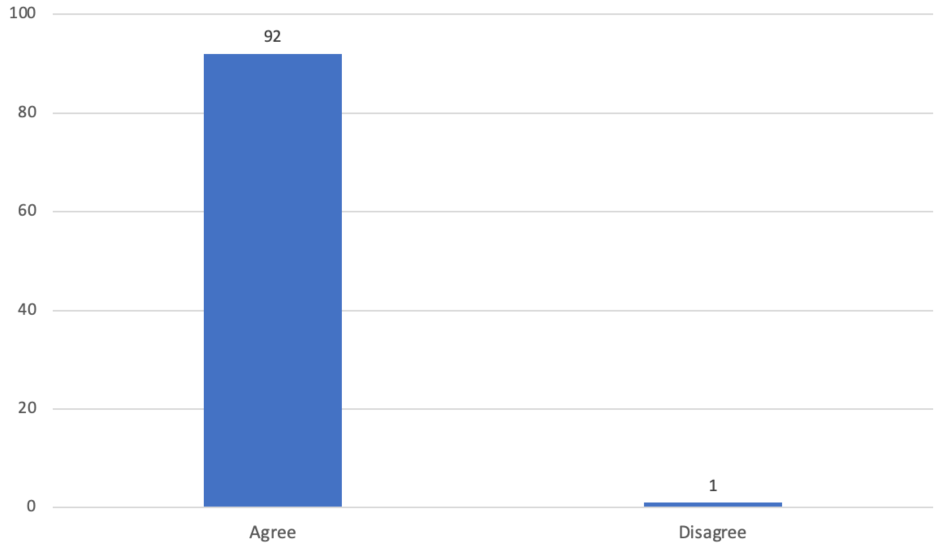

Figure 23: Histogram for necessity for further training and education; IIoT readiness of engineers. "Do you agree or disagree that further training and education is necessary to meet the IIoT challenges?" (self-edited).

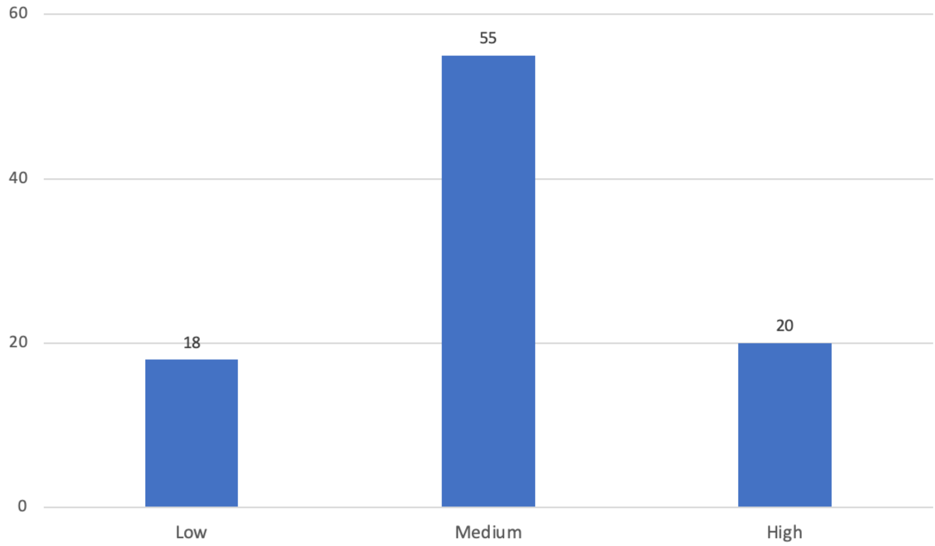

Figure 24: Histogram of current priority; IIoT readiness of engineers. "How do you rate the current priority of training and education within operations?" (self-edited).

The engineers' current training level with regards to digitalization is rated by the majority of the survey participants as inexperienced and tentative (64) and by 29 as advanced and dynamic. No one rated the training level of the engineers as outstanding (Figure 25).

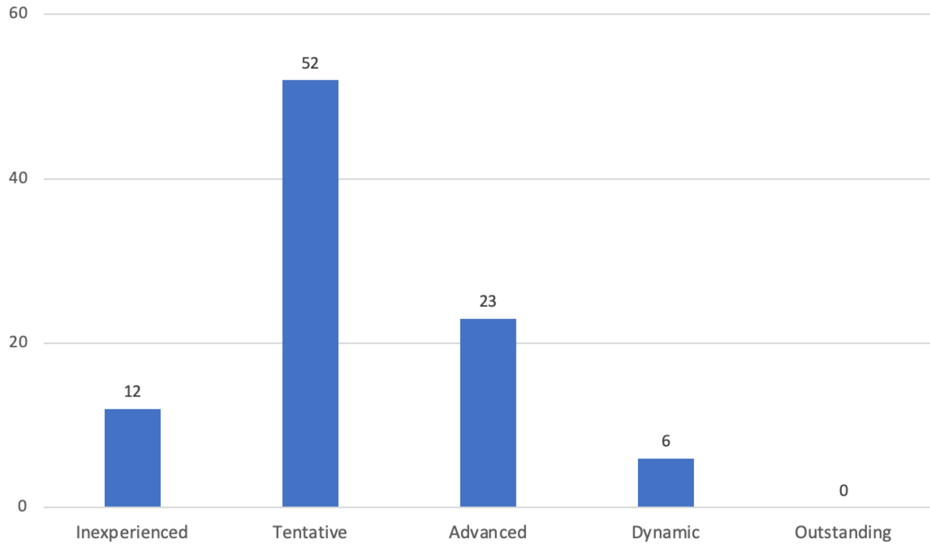

Figure 25: Histogram for current training level; IIoT readiness of engineers. "How do you rate the current training level for IIoT within operations?" (self-edited).

6.2.3 Dynamic capabilities of technical experts

Most firms employ digital technologies to enhance technical experts' effectiveness and efficiency because those employees are often rare in the labor market, need several years of experience, and have reduced availability.

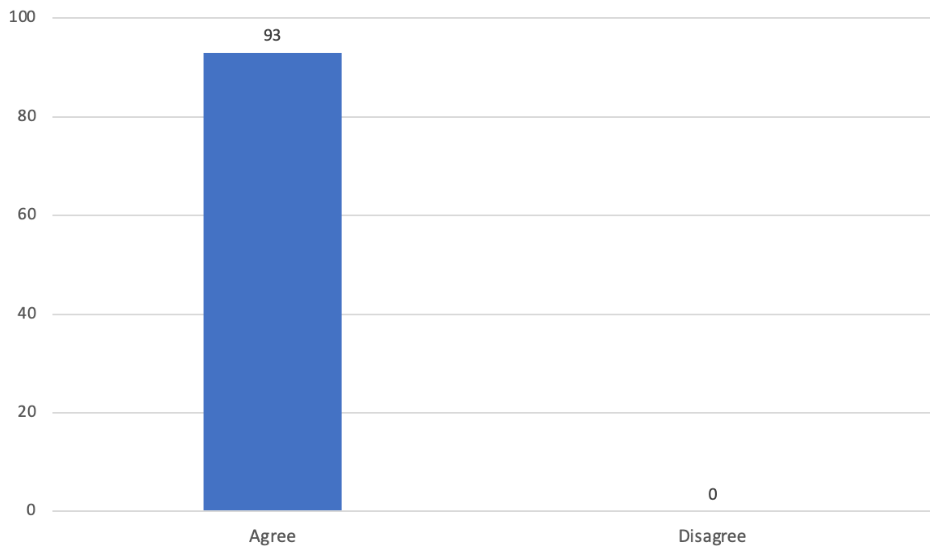

Figure 26: Histogram for necessity for further training and education; IIoT readiness of technical experts. "Do you agree or disagree that further training and education is necessary to meet the IIoT challenges?" (self-edited).

Nevertheless, those experts need to be able to work with digital technologies to improve their cost/benefit ratio. The survey participants agreed unanimously that the necessity for training and education for technical experts exist (Figure 26).

As a consequence, a minority of the participants of the survey rated the current priority for training and education for technical experts as low (14); but most rated it as medium (46) or even high (33) (Figure 27).

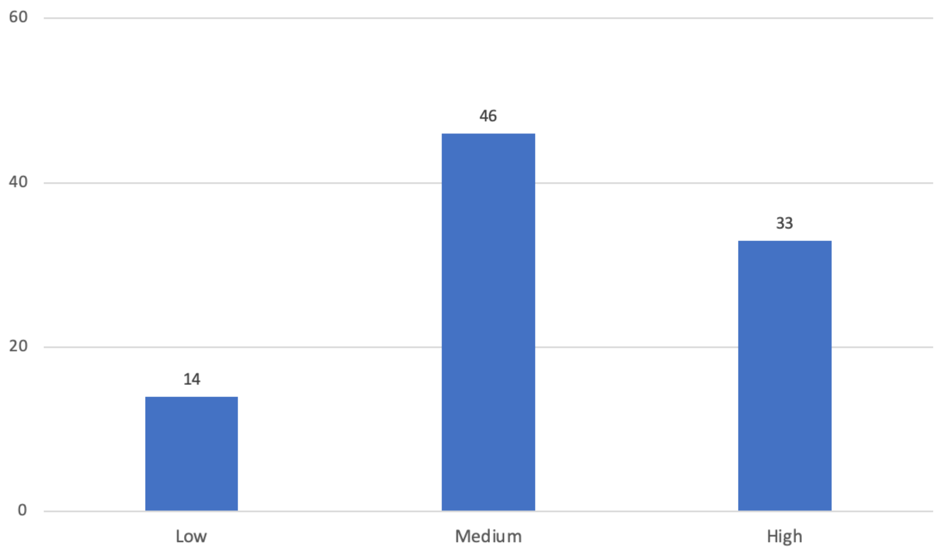

Figure 27: Histogram of current priority; IIoT readiness of technical experts. "How do you rate the current priority of training and education within operations?" (self-edited).

The technical experts' current training level was rated as inexperienced by 11 participants. The majority (74) rated the training level as tentative or advanced, and 8 participants rated the training level as dynamic and outstanding (Figure 28).

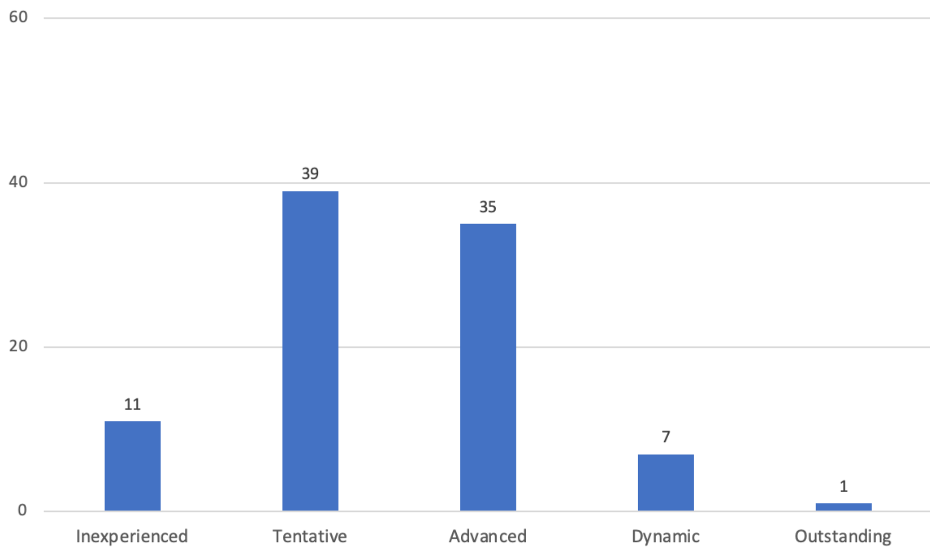

Figure 28: Histogram for current training level; IIoT readiness of technical experts. "How do you rate the current training level for IIoT within operations?" (self-edited).

6.2.4 Dynamic capabilities of line operators

The line operators must be able to operate the digital technologies just like the technical experts, albeit at a lower level. They are also faced with new challenges, and therefore need to be trained and educated. The question of the necessity for training and education was answered by 90 participants of the survey with a positive response. Only three claimed that there is no need to further educate and train the line operators at this point in time (Figure 29).

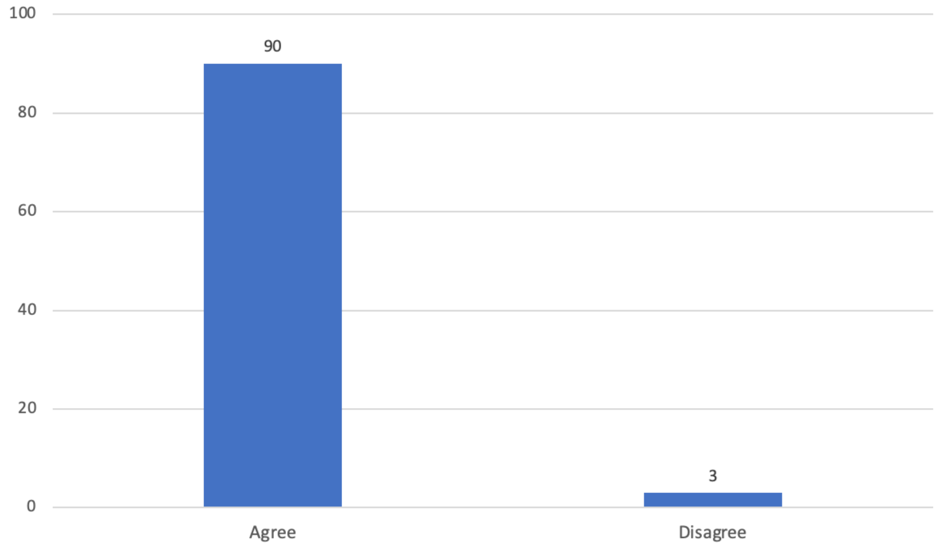

Figure 29: Histogram for necessity for further training and education; IIoT readiness of line operators. "Do you agree or disagree that further training and education is necessary to meet the IIoT challenges?" (self-edited).

The question regarding training and education as a current priority for line operators was rated as low by 18 participants, medium by 49 participants, and 26 participants stated that the priority is high (Figure 30).

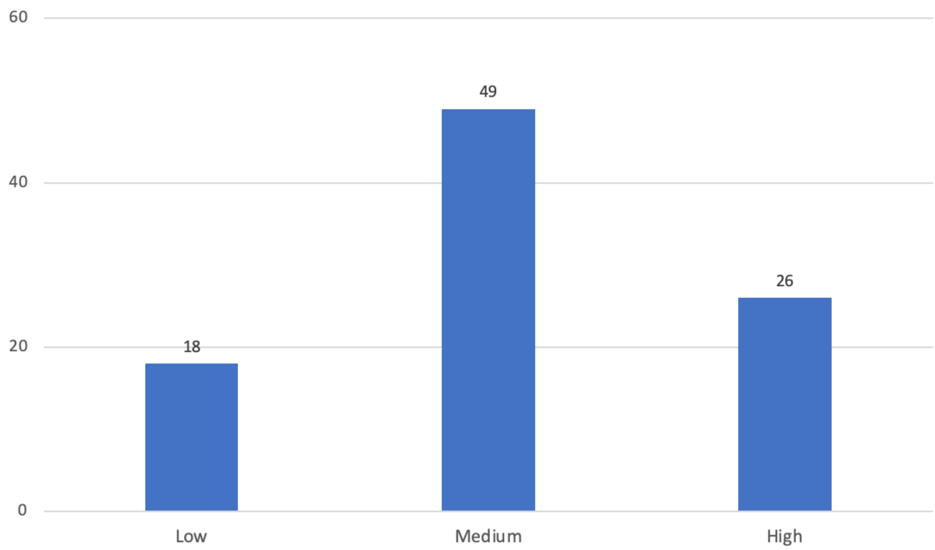

Figure 30: Histogram of current priority; IIoT readiness of line operators. "How do you rate the current priority of training and education within operations?" (self-edited).

The third question regarding the current training level of the line operators was evaluated as inexperienced and tentative by 78 participants of the survey, 25 evaluated the training level as advanced or dynamic, and no one evaluated the current training level as outstanding (Figure 31).

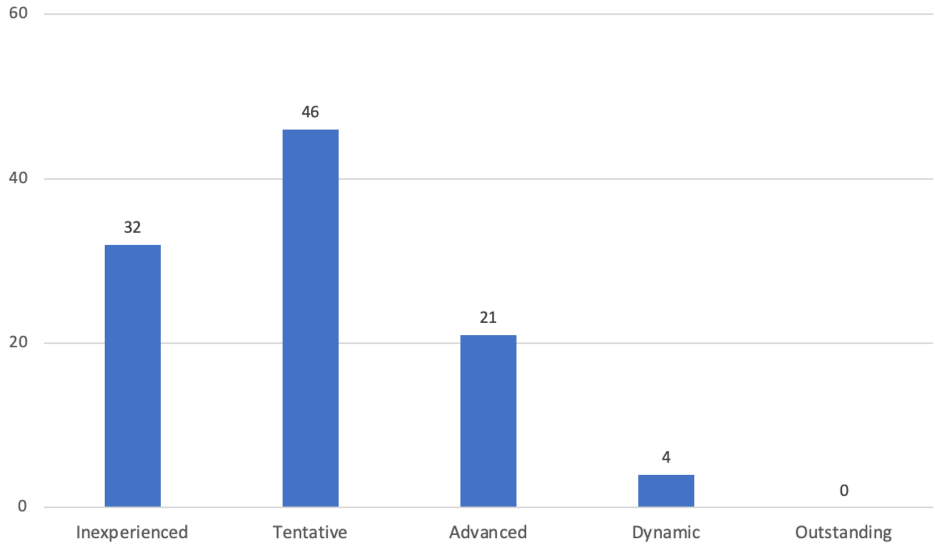

Figure 31: Histogram for current training level; IIoT readiness of line operators. "How do you rate the current training level for IIoT within operations?" (self-edited).

6.2.5 Results of the analysis of dynamic capabilities

The survey participants almost entirely agreed to the questions addressing training and education as necessary to cope with digitalization and the new technologies. The question regarding the current priority of training and education notwithstanding is rated as medium by most participants of the survey. The enquiry about the current training level of the four groups received the most mixed views, with the main emphasis on a low training level. The survey results for the dynamic capabilities would be utilized in the framework to highlight to the firm that the need for the development of dynamic capabilities exists and that the company is aware of that need. The firm is also aware that the four investigated groups' training and education levels are mainly inexperienced to tentative - action to take countermeasures are necessary to be prepared for the digitalization.

Nevertheless, the participants of the survey rated the current priority for training and education mainly as ‘medium’. For the framework, this is a finding of the highest interest due to the fact that a blocking point for the implementation of digital technologies is becoming obvious.

6.3 Repercussions for the framework

The competitive landscape is transforming, and the classical view on gaining a competitive advantage has lost its validity. In this milieu, the awareness that knowledge and its application within the firm are a crucial advantage for competitiveness is growing. To cope with this considerable challenge, a combination of the Dynamic Capability approach, together with the systematic of Architectural Innovation, enhances the opportunities of a firm to compete successfully.

After conducting the analysis of the data-set for architectural innovation, it is now clear what type of technologies the company shall focus on. The result of the PCA indicates which variables apply to the participants of the survey; this allows for the selection of technologies that are most important for the firm. The results of the analysis of the dynamic capabilities are less obvious. The need for the development of capabilities is emphasized, but the priority to act upon this need is not spelled out clearly.

The strengths of both of the concepts were mapped out and amalgamated to develop a new concept that can be applied in areas that are subject to rapid change, such as the fast-changing field of digitalization. The subsequent, firm-specific recommendation for this company is discussed in the following chapter.

7 IMPLEMENTATION OF A FIRM-SPECIFIC DIGITALIZATION FRAMEWORK

Understanding the interrelation and close connection of Dynamic Capabilities and Architectural Innovation was the impetus behind establishing a concept to model the connections and build a common framework which can be used for other cases. The model must consider both theories and present each theory's subfields, which is essential for a combined framework. In the following section, this framework is worked out, outlined and thus made more general to make it applicable for cases outside of the current study.

7.1 Outlining the DCAI concept

The two theories of Dynamic Capabilities (DC) and Architectural Innovation (AI) are drawn together into the DCAI concept for further reading. The DCAI concept refers to the findings and explanations from the related chapters of Dynamic Capabilities and Architectural Innovation mentioned earlier in this thesis.

7.1.1 Architectural innovation within the DCAI concept

The DCAI concept addresses the architectural setup of technologies from Figure 7, the junction of digitalization technologies and dynamic capabilities with the effect of an architectural framework. In the example, company B (which is the applicant of radical/modular innovations that other companies provide) has decided to establish a technology-architecture that requires the application of technology A, D, E and F. Company B also already identified that it needs to work upon the attraction of external competencies and their ability to integrate external competencies.

Buying technologies (that are considered as radical innovations) is not sufficient. To make the architecture of new technologies reach its full potential, the company must prepare itself to handle the technologies. The company must learn how to work with each technology; therefore, it requires dynamic capabilities or it will not be able to harvest the advantages of new technologies to the full. To do so, the firm must follow a certain integration process. Figure 32 displays a process in which the integration of technologies bought is explained.

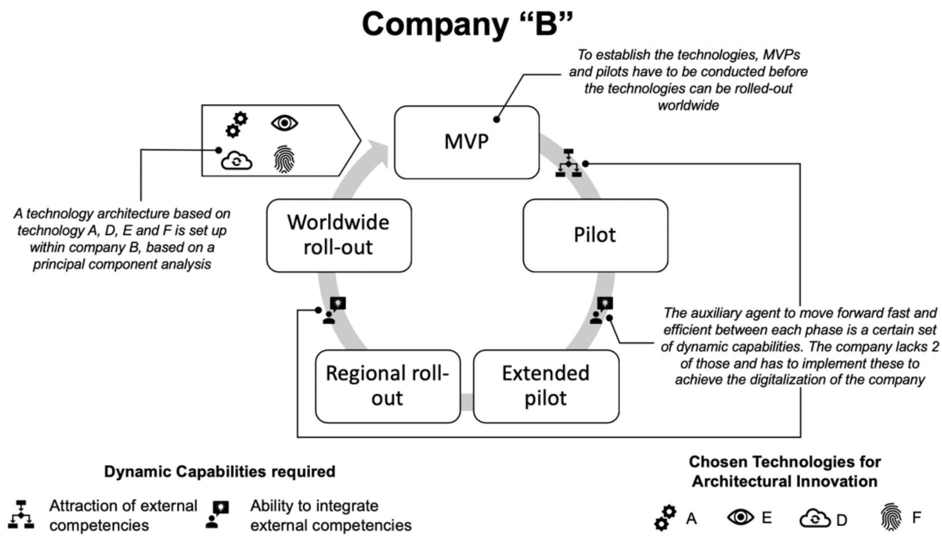

Figure 32: Company "B" worked out a firm-specific digitalization strategy that is based on Architectural Innovation the radical/modular technologies A, D, E and F are a prerequisite and need to be brought into the firm. The missing Dynamic Capabilities which enable the firm to integrate the technologies are the attraction of external competencies and the ability to integrate those competencies (self-edited).

The company starts with an MVP (minimum viable product) to obtain a first insight into each technology's capabilities and understand how they interrelate. This phase can be followed by one or several pilots. When the pilots have been executed successfully, and the company has learnt from their findings, a regional roll-out can be arranged. If this regional roll-out has been achieved successfully, a global roll-out is the next and final step.

The DCAI concept requires the survey and the PCA analysis that has been conducted for the case study. The survey has to have depth and requires adaptation to the company that shall be investigated but without leaving out core digitalization technologies. An example of one technology is illustrated in Figure 33.

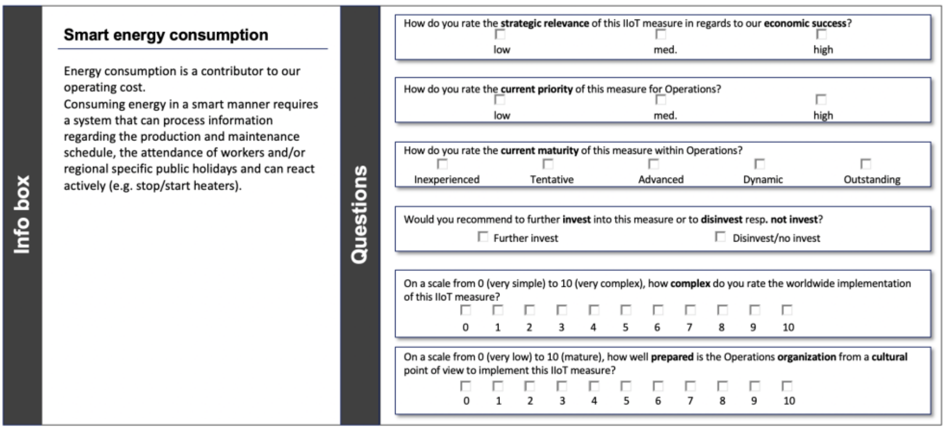

Figure 33: Excerpt from the questionnaire that had been sent out to the participants of the survey (self-edited).

7.1.2 Dynamic capabilities within the DCAI concept

Furthermore, the company is asked to prepare a comprehensive set of dynamic capabilities, and the participants of a than to be conducted survey must be selected cautious. Table 6.0 summarizes a certain range of dynamic capabilities; these must to be specified for each particular company.

Table 6: Example of the selection of dynamic capabilities

Matrix for the selection of dynamic capabilities a company requires before it is capable to harness the full advantages of an architectural set-up of certain digitalization technologies and to move between the different phases (relating to Figure 32).

Dynamic Capabilities *"Rapid and flexible innovation with a timely response"*					
Sensing *"Identify and create business opportunities"*		***Seizing*** *"Mobilize internal resources to address those opportunities and to utilize it for the company"*		***Transforming*** *"Align all resources and activities to address those opportunities"*	
Capability to recognize mega-trends, trends, shifts in the market		Capability to reconfigure internal capabilities		Capability to align the resources and activities to manage the transformation	
YES ✓	**NO**	**YES ✓**	**NO**	**YES ✓**	**NO**
Capability to evaluate trends for the company		Capability to reconfigure external capabilities		Capability to transform the organizational structure	
YES ✓	**NO**	**YES ✓**	**NO**	**YES ✓**	**NO**
Capability to classify trends		Capability to build internal competencies		Capability to enable/support the transformation process	
YES ✓	**NO**	**YES ✓**	**NO**	**YES ✓**	**NO**
Capability to realistically estimate the own position in the market		Capability to integrate external competencies		Capability to build an innovation strategy that leads to commercialization	
YES ✓	**NO**	**YES**	**NO ✓**	**YES ✓**	**NO**
Capability to recognize disruption (in industry, economy, ecology, politics)		Capability to attract external competencies		Capability to proactively shape change	
YES ✓	**NO**	**YES**	**NO ✓**	**YES ✓**	**NO**

The example company fulfills nearly all requirements with regards to dynamic capabilities, with only two lacking. These are the capability to integrate external competencies and the capability to attract external competencies; both marked with “No” in the matrix. Being aware of having a gap within the dynamic capabilities is the baseline to counteract and to close the gap. Based on the identified gaps, actions have to be taken; in Figure 34, this is done based on the missing competency for the integration of external competencies. The form chosen is a polar coordinate system to get an overview of the gaps at one glance. A firm has to fulfill certain preconditions to build a dynamic capability. In this example, the dynamic capability is broken down into tasks/assignments that have to be fulfilled. Those assignments could be broken down further, such as mentoring a new employee, for example. A good mentor must have a certain sensitivity to understand the mentee, listen closely, have a certain range of experience in the area she/he is assigned to support, and be willing to share them with the mentee. Not all persons that are assigned to be a mentor are capable of filling out this role to a sufficient standard.

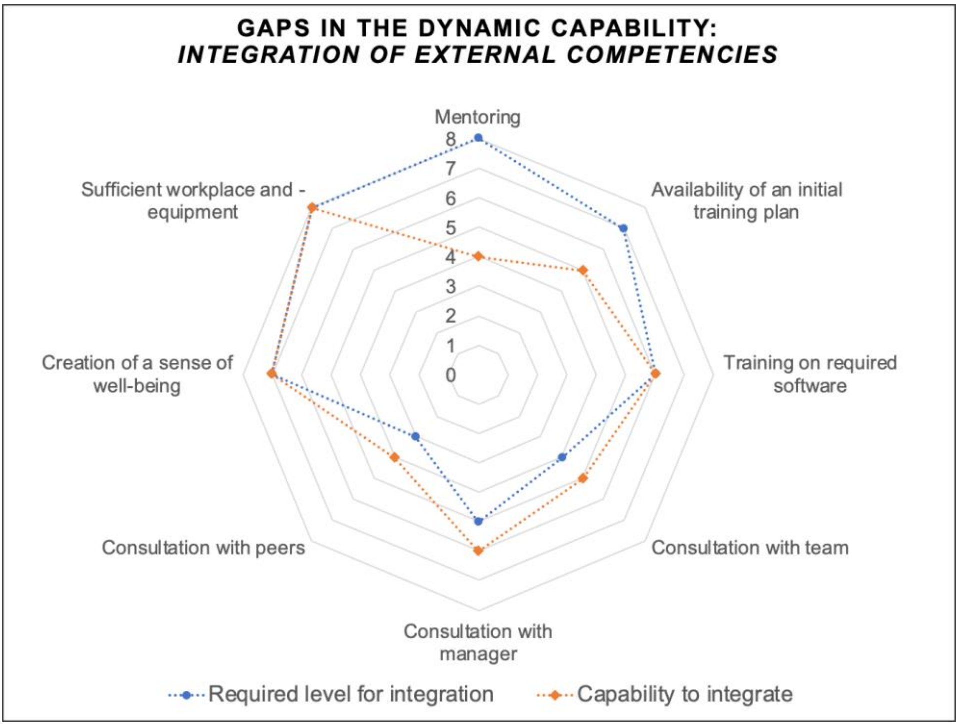

Figure 34: Definition of preconditions and subitems that are necessary to build a Dynamic Capability and to exploit the DCAI approach (self-edited).

In the example of Figure 34, the firm has defined eight tasks/assignments that are necessary to close the gap for the dynamic capability integration of external competencies. Six of those eight tasks are fulfilled or overfulfilled by the firm. Two of the assignments require actions and can be addressed within the company with the competent departments' actions. The human resource department could take the task to find a capable mentor for a new employee, the department where the new employee is going to be deployed could be accountable to work out an initial training plan that consists of the daily routines and instructions on how to work on certain tasks.

7.2 Endorsement for the DCAI concept - Objectives and Key Results (OKR)

To keep track of the fast pace of digitalization, a company needs to be able to adapt to sudden and unforeseen changes within the business environment that it is operating in. The speed of those changes is much higher within digitalization than in entrenched technologies; as a result, a company must implement and adapt a methodology that supports and measures the implementation of the DCAI-concept, both fulfilling the company-specific findings of the architectural innovation and the dynamic capabilities approach. One methodology that complies with the depicted requirements is the OKR methodology. OKR is an abbreviation that stands for Objectives and Key Results and assists the target definition, the implementation of the DCAI strategy, and provides a system to manage the process. OKR supports agility but ensures that continuity is taken into account and bears in mind the overall target. The OKR methodology requires thinking in terms of 'Outcomes' versus 'Activities.'

The originator of OKR is Gróf András István (Andrew Stephen Grove), who was born in Budapest, Hungary, in 1936. He migrated to the United States in 1956 and participated in the founding of Intel ('late founder').

He became Intel's president in 1979 and chief executive officer in 1987 (Grove, 2015). The OKR methodology derives from other methodologies and combines their strengths. The main methodologies which OKR relates to are Management by Objectives (MbO), Hoshin Kanri, S.M.A.R.T., balanced scorecard, and agile management. John Doerr, who was working for Intel in 1974, was trained in OKR by Grove and, in his later position, when working for Kleiner Perkins Caufield & Byer, implemented the concept at Google in 1999. The OKR methodology became very successful there and is still prevalent today (Doerr, 2015). Table 4.0, which rests on a comparison of MbO and OKR by John Doerr, illustrates the differences and the advancement of the methodology.

Table 7: The difference of objectives in the MbO methodology and the OKR methodology. Adopted from "Measure what matters" by J. Doerr, 2018

The OKR methodology operates in shorter cycles, requires more communication, more contemplation in the target-segmentation process, and calls for more active inclusion of the different management levels and the persons responsible.

	MBO	**OKR**
Focus	"What"	"What" and "How"
Frequency	Annual	Quarterly or Monthly
Visibility and recognizability	Private and Siloed	Public and Transparent
Development and introduction	Top-Down	Bottom-up or Sideways
Relation to compensation	Tied to Compensation	Mostly Divorced from Compensation
Risk tolerance	Risk Averse	Aggressive and Aspirational

A form of occupational systematic for working with OKR was established by Grove, such as less is more (with regards to well-chosen objectives), set goals from the bottom up (individuals should be encouraged to contribute to the goal-setting process to foster motivation), stay flexible (the capability and the willingness to change an objective whenever it does no longer seems to be practical or relevant must be in place. This is important for executing the DCAI concept), dare to fail (aspirational OKRs should be uncomfortable and possibly unattainable to push the organization to new heights. Consequently, not all objectives can be reached in full, and this must be clear from the beginning; this is noteworthy when setting objectives in the DCAI concept when digitizing a company).

7.3 Implementation of DCAI with the OKRs methodology

Using OKR to implement the DCAI concept requires breaking down the single technologies that shall be implemented within the firm and to defining concrete actions. By the example of automated, real-time feedback to process experts/specialists (the most important technology for the analyzed firm, see chapter 6.11), the process of defining objectives that follow the OKR systematic is displayed. The most important elements of the OKR methodology regarding the DCAI concept are the focus, the frequency, and the risk tolerance; these three elements will be investigated in the following section.

7.3.1 Defining the “What” and “How” – basis for the implementation of a technology

Having automated, real-time feedback would be a great contributor to many companies. But it is a prerequisite to be clear about the variable that must be feedbacked to the process experts/specialist to achieve the best possible result. There is a wide range of different variables, though most of them are irrelevant to achieve a defined process-result. The variables that have a notable influence on a certain process must be designated, and measurement must be installed (e.g., pressure, humidity, temperature). Within a close-loop diagram (Figure 35), those measurements must be installed, e.g. in the form of sensors.

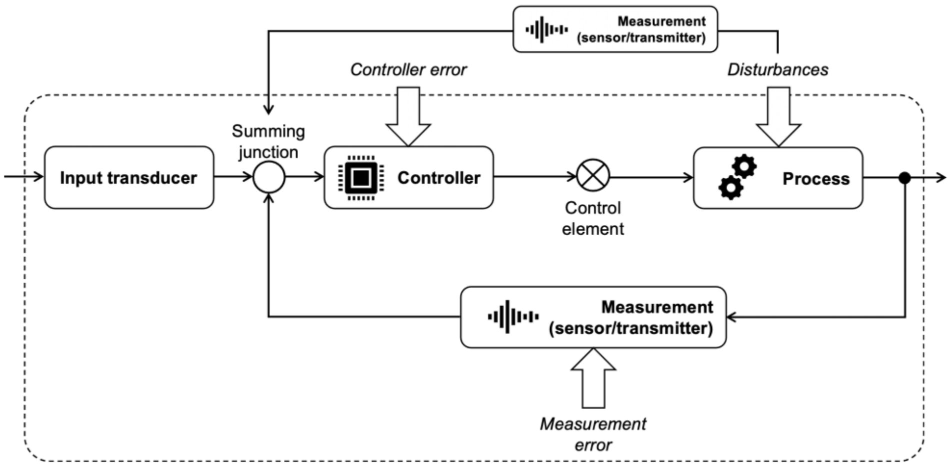

Figure 35: Scheme of a close-loop system. The process experts need to enclose the necessary variables that are required to control the output of a certain process (self-edited).

The matrix for the objectives could look like Table 8.0, according to OKR requirements.

Table 8: Definition of the "What" and "How" according to OKR requirements

The matrix is defining the basis for the implementation of technology. In this case, for the technology with the highest priority of the case study – the automated, real-time feedback to process experts/specialists

Objective	***The relevant sensors to steer a dedicated process to achieve an output with a minimum of scrap/rework are defined and integrated into the close-loop***
Key Result 1	Determine the variables that are necessary to steer the process (e.g. temperature, pressure)
Key Result 2	Determine the sensors that are capable to measure the variables with the necessary accuracy
Key Result 3	Integrate the sensors into the close-loop-system in consideration to avoid measuring errors
Key Result 4	Ensure that the measured variables are available for the process control within the needed period of time to avoid an erroneous feedback control

7.3.2 Setting the right frequency to verify the objectives

The implementation of digitalization technologies is not a task that is done regularly, nor can the implementation team rely on experience garnered from other projects. Therefore, the DCAI concepts call for a close verification of the status of the digitalization technology's implementation to allow a fast response when the process does not develop accordingly. In Figure 36, the distance between each tactic cycle is three months, with two strategic cycles in between.

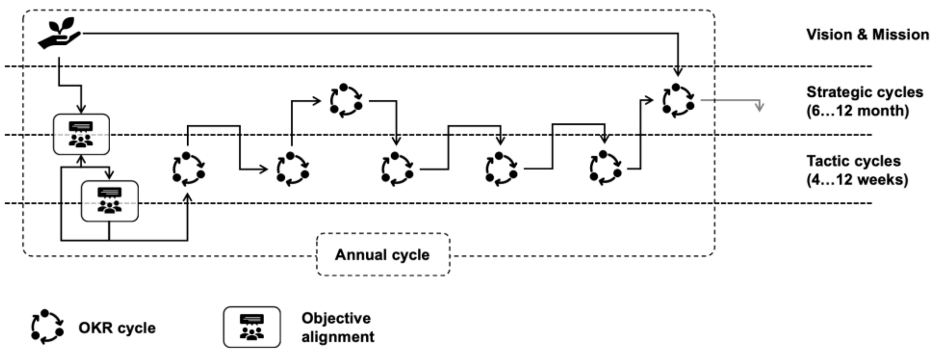

Figure 36: Scheme of the tactic and the strategic cycles in the OKR system. The tactic cycle reviews the achievements of the objectives and enables the team to evaluate the quarterly (or weekly) objectives in line with to the overall aim (self-edited).

The frequency of tracking the objectives must be adapted to the company's experience with the technology. In the case study, the company has very little experience; a higher frequency of reviews makes sense e.g., every four weeks. Once the team evaluates the key results for the technology automated, real-time feedback for the first cycle (e.g., key result #1: Determine the necessary variables to steer the process), it can examine carefully if this key result has been achieved. The team has to execute the same procedure for all other key results and define measures if they have not been achieved.

7.3.3 Endorsement of risk into the DCAI concept

Firms which decide to accept a certain degree of uncertainty and are willing to invest in digitalization (see also chapter 4) are mostly aware that the risk for new technology is higher than for an established one. This risk must be integrated into the DCAI concept, and a “failure culture” must be implemented. Failure culture in this sense shall not be equalized with complacency about failures; it implies a culture where failures are a source of learning, where failures are analyzed and communicated openly to avoid their reoccurrence. This can be achieved by using early failures to learn from and using those as examples of a failure culture, managers leading as an example, and moderating openly through the failure analysis process.

7.3.4 Audit process for the DCAI concept

To audit the implementation of the technologies coming from the DCAI concept, OKR workshops are held and the status is reviewed. The process is highly transparent and enables both the team and the management to react while the project is moving ahead, to readjust the target setting if it is not ambitious enough and/or if the team is not stuffed accordingly. It is very important for digitalization projects to know if the strategic direction is still correct or if it requires adjustment. If adjustments are necessary, this can be done within a short timeframe (mainly within one cycle) and not in the normal, one-year timeframes of business planning processes.

8 CONCLUSIONS AND RECOMMENDATIONS

The thesis statements combine the two suppositions that a firm that is bound for digitalization often oversees a) *the mutual reinforcement between the digital technologies* and b) th*e need for people-know-how to implement and to run those new technologies*. By overseeing the two effects, the firm cannot achieve the best outcome possible. It will lack the right architectural set-up for its technologies and will not be able to build the necessary dynamic capabilities to exploit the new technologies to their full potential. Both the architecture and the dynamic capabilities need to be firm-specific from the authors' point of view and cannot be generalized. Therefore, the research question was to investigate how the two theories can be brought into one edifice of ideas, how a firm specific analysis can look, and how the findings can be brought to life through the employment of a real-life application.

An advantage of the concept of Architectural Innovation is that digital technologies have a mutual interdependence and interact with one another. Ultimately, this results in synergy effects, especially within the economies of scope and the chaining effect. The reasons for this are multifaceted; examples include the complementarity of digital technologies, boosting effects for one technology if another is implemented, and features of digital technology (the technology was intentionally bought for a different reason, but it turns out to be useful in other areas, too).

Dynamic Capabilities become important when it comes to integrating, building, and reconfiguring the capabilities needed to exploit the digital technologies to their maximum. The Dynamic Capabilities are also necessary to recognize the digital technologies' additional capabilities, to make the interaction between them work, to recognize further fields of application, and to apply them within the complete firm.

The strategic architecture is basically a high-level blueprint for the deployment of new functionalities, and the Dynamic Capabilities are the vital spark to create a competitive advantage that cannot be duplicated from competitors.

8.1 General Conclusion and recommendation

The firm that was investigated in this survey is a company within the automotive supplier industry facing the challenges of digitalization. The course of actions has to be based on two directions, both integrating the selected technologies and building dynamic capabilities. The frameworks systematic is to integrate available technologies into a company that is not producing digitalization technologies on its own.

Planning assumes a degree of exactitude, but strategic planning must be more generalistic and must allow a certain degree of freedom and room to maneuver. Nevertheless, planning the digitalization from a strategic perspective requires determination regarding digital technologies. The digital strategy must fit seamlessly into the firms' competitive strategies, and it is not detached from it. The corporate firms' strategies can be more general, but it must be specified that choosing technologies that fit the overall strategy is possible and reasonable.

Therefore, the presented framework's contribution here is to work out the top 3 to 7 technologies that are of the utmost value for a firm and then focus the spare capacities (time to implement and capital expenditures) on those. Alongside, the actions to build and strengthen the necessary dynamic capabilities and ensure that a real competitive advantage can be worked out, based on the outcome of the analysis, must be undertaken. The company must be aware of the need for training and education, and the willingness to invest in this area must be given and must be scrutinized by management. Figure 37 displays the mesh of the buildup of dynamic capabilities and the concurrent integration of digital technologies.

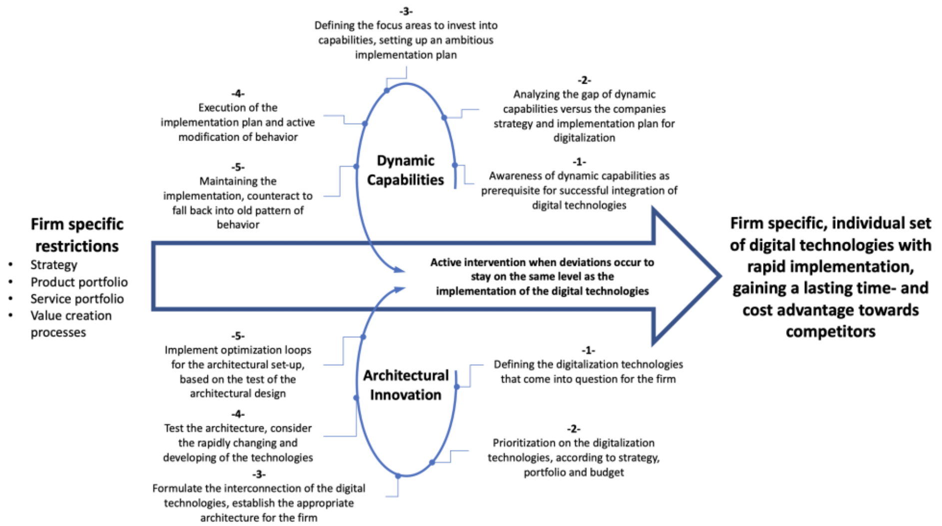

Figure 37: Synchronization between dynamic capabilities and the development of a digital architecture requires a constant and active intervention to assure that the buildup of DC is consistent with the development of the architecture (self-edited).

A firm would have to set up and adapt an implementation plan according to the individual survey findings, their prioritization of the single measures, and the number of optimization loops that the integration will require. With transparency over the dedicated technologies, the firm can set up focused purchasing- and integration plans for each individual technology, appoint implementation teams, organize the necessary implementation support from the individual supplier, and ensure that the equipment is available at the right time. Creating an innovative architectural structure that can make a difference to its competitors, the firm now has the chance to map out in detail the full range of each technology, to establish the optimal interconnection between the different technologies, and fully scale each individual technology. This is only possible with the right dynamic capabilities; these need to be built up in good time to ensure that the use of the digital technologies and their integrational architecture has a higher impact on the firm, rather than just buying the same equipment without utilizing it fully within a unique architecture.

8.2 Firm specific conclusion and recommendation

Due to the research, the examined firm now has a better understanding of where to invest (the five top technologies out of the survey, see Figure 14). It can focus on developing each technology to its full potential. Each technology can have various fields of application and therefore has different impacts on the company. The technology big data & analytics was chosen to explain this statement, and in Figure 38, its (incomplete) field of application is displayed.

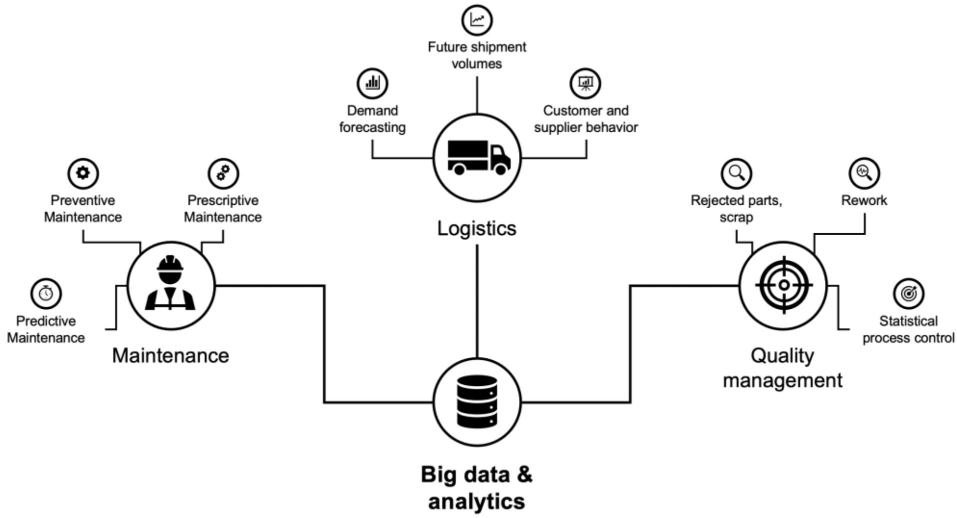

Figure 38: Incomplete graphical presentation of the fields of application of big data & analytics, outline of the possible fields of application and the need to determine a field of the digitalization application (self-edited).

Big data & analytics can be applied within maintenance, logistics, quality management, and other areas. The firm has to decide on where to apply big data & analytics, but the logic of how this technology is applied is very similar in each field of application and therefore must not be detailed for the firm-specific framework. The examined firm's dynamic capabilities need to be established within the handling and employment of the technologies. The awareness of the need for education is there, but the willingness to execute this part of the framework is backwardly developed. Hence, the digitalization strategy is firm-specific. Making general statements that the firm is committed to digitizing, releasing budgets without knowing what technologies shall be enhanced, or not being aware of their own expectations regarding technology's deliverables is a senseless endeavor. A digitalization strategy must be a high-level blueprint for the deployment of new technologies i.e. it must be clear about the technologies that shall be used to digitize the firm.

The data analyzed within this survey demonstrates that a single person cannot assume the necessary direction of the firm specific digitalization strategy and its impact on the firm. Misconceptions are likely to happen when such decisions are made by one person who might be unaware of the latest developments in this fast-changing environment, unaware of local requirements and conditions, or being biased due to their professional career and work history. It appears that giving the data structure and deriving recommendations from its analysis creates a valuable counselor when deciding to invest in a certain field of digitalization. The approach helps avoid certain types of biases i.e. the Dunning-Kruger effect (Dunning, 2011), the mere exposure effect, or the system justification bias, and to draw fact-based decisions (see also Chapter 3.2.4).

A large number of survey participants helps to prevent (or at least minimizes) such effects. The data gathered enables the analyst to disclose hidden patterns within the firm that can be considered part of its collective intelligence. The mass data analysis revealed a pattern of hidden knowledge that would have remained unnoticed.

8.3 Critical review

Alongside many other tasks, the author's field of work includes the preparation of investment-decisions into machines and equipment that can be considered as belonging to the 3rd industrial revolution. Another area of his responsibility is to drive the selection and implementation of technologies that can be considered revolutionary for the area of operations and manufacturing. The author has been looking for a systematic and well-established approach to set up a procedure which selects, integrates, and rolls out I4.0 technologies within the firm he is working for. This company is not producing I4.0 applications; it considers itself a user of such technologies. The models available almost always require data and empirical knowledge from past experiences. A further area he studied to find support for his question involved talking to start-ups and recently founded small companies that provide new solutions in the area of digitalization. These companies often come with a single solution, and the integration is left to the firm. The author was not able to find a comprehensive way of working for the selection of digitalization technologies. In short, the problem is persistent, but he was determined to find a solution. Following the lectures and readings at the Hungarian University of Agriculture and Life Science and intense discussions and consultation with the professorate, the idea was established to investigate models and theories which confront such problems differently and combine these models into a new one. The author decided to focus his research this area, and the present paper is the outcome. The procedure to investigate the subject of the matter is presented in Figure 1. This figure can also be used as an overview of the evaluation of the improvement areas for this research project. The author recognized several of those areas of improvement himself; unfortunately, this recap is inchoate.

The first area for improvement would be the choice and extension of literature. The range of literature for Dynamic Capabilities and also for Innovation is a large one. Finding the right literature, analyzing it, and extracting the relevant information from the complete research field turned out impossible. Even at this point in time, there are new contributions being made to this research; the author tried to take both the early literature and the newest scientific publications into account.

A second major area for discussion opens up regarding the questionnaire and the selection of the participants. The structure and assembly of the questionnaire had to consider the two different objectives that were to be analyzed. The research's complexity required an explanation for the participants of the research (see Appendix 1). The participants' expressed feedback was often that the questionnaire was too long, considered too many technologies, and consumed too much time to give thorough feedback.

Due to the type of research question and the limited time and capacities for conducting the research, only one firm was investigated. The number of participants was already high due to the company's size; the idea to involve further firms in the research was rejected. Expanding the research would have provided deeper insights and would have led to more valid results.

Predicting the crisis that COVID-19 triggered was impossible, and the pandemic turned out to create insurmountable hindrances for the evaluation of the implementation phase. Budgets that had been assigned to digitalization could not be released due to the unforeseeable development of the crisis. A limited number of technologies were implemented and used to validate the hypotheses. For further readings, see chapter 10.

Although the COVID-19 crisis deferred the implementation of digitalization technologies on the shop-floor for the investigated firm, it also shifted the priority and relevance of others. The most explicit example is the prioritization of *augmented reality* (considered as *asset utilization* in the survey, listed as point “*j*” in *Table 2: Considered technologies in the four analyzed sections*). This technology had a low rating in priority and strategic relevance according to *Figure 15: Matrix-plot of current priority (abscissa) and strategic relevance (ordinate) to arrange the technologies in a sequence according to the findings of the PCA (self-edited).* With the strict travel restrictions that the firm had to comply with, it had to search for and find solutions to uphold its communication with its locations worldwide. The COVID-19 crisis facilitated this technology's breakthrough within the investigated firm, all within a short time.

A further criticism is related to the assumptions that have been drawn from the analysis. Others would draw slightly disparate assumptions from the findings. They would come up with a differing framework for the conjunction of Dynamic Capabilities and Architectural Innovation or different recommendations for its implementation.

All things considered, it cannot be neglected that there are areas in the present paper that could have been investigated more closely, or that the data could have allowed different conclusions. The author did his best to adhere to the rules of scientific research overall and to the rules of the Hungarian University of Agriculture and Life Science in particular.

9 NEW SCIENTIFIC RESULTS

A new way of strategizing to gain an edge in the industry took off when Teece, Pisano, and Shuen published their research in 1990, which led to employing Dynamic Capability in various fields of the business economy. Henderson and Clarks' work, released in the same year, gave new insights that enriched the process of innovation by another degree. Joining the Dynamic Capability approach with the Architectural Innovation's concept into a mutual framework, a methodology that can be pivotal for the economic superiority of one firm over another becomes conceivable. The research produced the following new scientific results.

1. **Unification of the strengths of Dynamic Capability and Architectural Innovation**

   The combination of the Dynamic Capability approach, together with the systematic of Architectural Innovation, enhances a firm's opportunities to compete successfully. Combining both concepts creates a robust approach to respond to the fast-changing field of digitalization.
2. **Pointlessness of general digitalization strategies**

   The digital strategy must be customized to fulfill the expectations of the overarching firms' competitive strategy. It must support the other policies, processes, and methods of a firm or replace them with superior ones. It has to support the decision process of not digitizing instead of applying more than the firm needs and applying in practice.

3. **Synergies between Architectural Innovation and Dynamic Capabilities**

   The concepts of Architectural Innovation and Dynamic Capabilities can interact and create synergy effects, especially within the economies of scope and the chaining effect. The reasons for this are broad, such as the complementarity of digital technologies, boosting effects of one technology when implementing another, and features of digital technology that are useful but were not incorporated so far.

4. **Factual basis for a digitalization strategy**

   The core findings of the dissertation are the companies' main directions in digitalization. Hidden in the data-set, this information was disclosed with the principal component analysis (PCA). The company is now making decisions based upon facts and independent of individuals. Unarticulated and concealed knowledge about the context in which digitalization is connected with the firms' products, production processes and logistics is recognized and considered in the digitalization strategy.

5. **Averting cognitive biases**

   A large number of survey participants helps to prevent (or at least minimize) effects such as the Dunning-Kruger effect (Dunning, 2011), the mere exposure effect, or the system justification bias. The data discloses hidden patterns within the firm that can be considered part of its collective intelligence and would have remained undetected.

6. **A concept to structure the digitalization process**

   The hallmark of digitalization is that nearly everyone believes in its capability to create a competitive advantage, but a) the risk to invest into a pointless technology or b) not to gain the full capabilities of a digitalization technology and c) to discount on the advantages of the interaction of the digitalization technologies is preventing firms from investing sufficiently. The proposed DCAI concept is a guideline for a firm to invest in its digitalization. The concept assures that a) the right technologies that are of utmost need for the firm will be chosen and b) that those technologies are applied to their total capacity and become effective to their full potential.

7. **Risk-free knowledge transfer between competitors**

   Another research finding came up late when the firm decided to become involved in the subsidy program *Long-term future investments vehicle manufacturer and supply industry as well as research and development (clause 35c)*. This program was launched by the Federal Ministry of economics and energy (for further details, please read *Chapter 11 Outlook and further exploitation of the research*). A non-transferable, firm-specific framework for digitalization was already recognized at the beginning of the research and formulated as hypothesis number 3. Evidence of this hypothesis was shown in the research process; but the effect became even more evident when the firm started to think about working in the subsidy program. The decision process was simplified, and the anxiety to share information and new findings with other program participants was sharply reduced.

10 SUMMARY

The traditional factors of production are overturned by today's knowledge economy, and a need for formulating new individual approaches that enable firms to withstand today's fierce competition are heavily sought after. This applies to the globalized industry as a whole, but it is particularly true for digitalization. Advantages that multi-national firms could rely on for decades, such as economies of scale and scope, are changing into economies of knowledge. The rapid change of technologies (often referred to as the 4th industrial revolution), cut-throat competition, and market changes create an environment for even fiercer competition. When digitizing a firm, it is often overseen that a) the mutual reinforcement between the digital technologies and b) the need for people-know-how to implement and to run those new technologies is decisive for their success. A wide range of different digital technologies could create an advantage for a firm, but it is potentially a random product. Recognizing the need for certain, firm-specific digital technologies, and the architecture that can be built from them, is the more appropriate goal. The same is true for the necessary capabilities to integrate the technologies and to exploit those to their maximum. Digital technologies often come with a wide range of features and functions that initially were not envisaged. David Autor (Autor, 2014) underlined that computer science is trying to overcome Polanyi's paradox. Still, that tacit know-how such as flexibility, judgment, and common sense cannot be easily computerized because we often do not know "the rules." The fact that a task cannot be computerized does not imply that computerization has no effect on that task.

On the contrary: tasks that cannot be substituted by computerization are generally complemented by it. This point is as fundamental as it is overlooked. Most work processes draw upon a multifaceted set of inputs: labor and capital; brains and brawn; creativity and rote repetition; technical mastery and intuitive judgment; perspiration and inspiration. This is also true for Dynamic Capabilities as there is no set of "rules" and no tutorial on the best set of capabilities; they are firm-specific.

The present paper attempts to investigate the two factors, based on the groundwork in the fields of Dynamic Capabilities (mainly Teece, Pisano & Shuen) and Architectural Innovation (mainly Henderson & Clark). The proposed view integrates the views of an ingenious, firm-specific architecture of digital technologies and the capability to gain more out of that architecture than competitors can, due to the capability to learn faster about the possibilities of digital technologies and, more importantly, their mutual reinforcement.

A clear and concise research question was formulated, and three hypotheses were outlined. The research question was to characterize how the two theories can be brought into one group of ideas, how a firm-specific analysis can look like, and how the findings can be carried over into a course of action. The first hypothesis was that there is no investment model into digitalization based on the concepts of dynamic capabilities and architectural innovation. This is true from a restricted perspective; there is no such model, but others that combine Dynamic Capabilities with other models [i.e. knowledge base as a competitive advantage (Kaur, 2019)] do exist. The data is not sufficient to accept or reject the second hypothesis which indicates that today's firms do not connect digitalization technologies with the concepts of dynamic capabilities and architectural innovation and do not take advantage of this framework. Although extensive literature research, internet research and academic exchange at different conferences regarding this hypothesis was conducted, no evidence could be found that the hypothesis is wrong and must be rejected. The third hypothesis, which states that the methodical support to decide on investments into digitalization is little and that this methodology requires an expansion by an explicit framework, was accepted. No framework combines the two theories explicitly, but initial approaches can be found. Those do not have a clear-cut framework, a course of action, or a scientific study that utilizes the two concepts in a mutual framework. Still, the idea of a combination of both theories existed before and is not entirely new.

The chosen process to test the hypotheses and to accept or reject them was to investigate a multi-national firm and to apply the scientific process with the help of an extensive questionnaire. The survey was addressed to the international management team of that firm; the return rate of the questionnaire was as high as 65.5%. The dataset was investigated with the principal-component analyses (PCA). PCA is a popular multivariate statistic technique and is used to structure, simplify and exemplify extensive datasets. A large number of variables is approximated by a smaller number of ideally descriptive and meaningful linear combinations, the so-called principal components. The analysis revealed the direction of the most urgent need for the firm to move in. The second part of the analysis consists of Dynamic Capabilities that the company requires to focus on.

The research project also involves developing a concept for a framework that is built upon the findings of the preceding analysis. The two theories were combined into one framework (DCAI concept), the course of action outlined, and the methodology described. The DCAI concept is picking up the strengths of both theories and unifies their advantages. In Figure 32, the operation and interaction of both theories are outlined. The complete course of action of how to implement and execute the DCAI concept is circumscribed in the presented paper. The paper is comprised of an operational sequence description that supports firms to develop and implement a firm-specific DCAI concept.

The firm analyzed and presented in this work could not be investigated completely according to the DCAI concept because the concept developed within the work on the present paper. Nevertheless, the concept was transferred as much as possible. Its positive effect on the firm was witnessed, but the implementation of the digital technologies chosen and the building of necessary dynamic capabilities that were previously missing was hampered by the COVID-19 crisis as well as a subsequent crisis in the particular industry which led to fewer working hours for most areas of this firm. For example, the firm could not send its experts back and forth between different locations and solve technical issues that have been solved in this way hitherto. Flights were canceled, and most airlines grounded their fleet. Therefore, the firm decided to invest in a digital technology that allows a near-on-site experience for the technical experts and to make their know-how available wherever needed worldwide - smart glasses. The decision for a certain type of smart glasses was made based on the following consultation a) which smart glass would suit the digital architecture of the company best and b) how this new technology could interact with other (already available and also future investments into digitalization) and c) where the firm would be able to integrate fastest and reconfigure the internal competencies for this device (i.e., considering Dynamic Capabilities and/or building them).

All things considered, the DCAI concept is an effective one, and the findings of the research were verified at the firm investigated.

11 OUTLOOK AND FURTHER EXPLOITATION OF THE RESEARCH

Today, the world is facing a pandemic situation, with more than 100 million COVID-19 cases to the present day. The second wave of the pandemic is in full swing, leading to significant lockdowns worldwide. Thirty-five countries in the European Region begun vaccinations, administering 25 million doses (World Health Organization, 2021). One should not forget that more than 2m people worldwide did not survive the infection so far, with numbers rising.

No branch of industry has remained untouched from the crisis that COVID-19 triggered. Almost all suffer massive negative impacts, with only a tiny number of branches experiencing positive effects (such as media-streaming-providers, the logistics industry, or online-retailers).

The automobile industry is suffering from the crisis, too. With entire workforces in quarantine, closed borders causing long waiting times for deliveries & supply, machine stoppages due to service engineers not allowed to travel and material shortages, resulting in a dysfunctional supply chain, making the negative aspects of JIT/JIS blatant.

Another main driver for change in the automobile industry is the conversion of drive-technology, especially electromobility and alternatives fuels. These drivers are leading to the omission of main parts of the powertrain, such as injection technology, (manual) gearbox, or the need for a tank.

In this critical situation, many measures got off the ground to support and stabilize the industry. The main measure in Germany that has proven its effectiveness already in the past (i.e. in the financial crisis of 2008/09) was to declare short-time work for tens of thousands of blue and white collars to avoid irrevocable lay-offs.

A further step to stabilize the industry is to announce subsidy programs tailored for different industries. For the automotive industry, a subsidy program from the *Federal Ministry of Economics and Energy (BMWi)* was announced at the end of 2020. It is framed as a recovery program with a volume of €2bn. The program has a duration of at least three years (2021 to 2024), but it's likely that the program will be prolonged. The programs focus is on investments in new concepts, methods and procedures, products, qualification, and production-equipment (i.e. autonomous driving, exploitation of data based on GAIA-X or interconnected modular production systems (Bundesministerium für Wirtschaft und Energie, 2020). To delineate the investments from another, three modules were defined within the program.

1. Module **A** – *Modernization of the production as a thrust for productivity and resilience*
    a. Collaborative exploitation of (production-) data
    b. Additive manufacturing
    c. Product- and System-Lifecycle and Management
    d. Digital supply chain
    e. Execution on the concept of the 'digital twin'
    f. Transfer projects

2. Module **B**
    a. New data-driven and cloud-based approaches to accelerate development of autonomous driving functions

   b. Automized and connected driving, development of AI-applications
   c. New car-architectures for CPU vs. many decentralized control units
   d. Connections to GAIA-X
   e. Innovations in ecology and new materials
   f. Novel drive-technologies for commercial vehicles and train-applications

3. Module **C**:
   a. Innovation-cluster as a nucleus as well as a framework for collaborative research and development
   b. Accompanying measures like training, public relations work, research infrastructures, planning for the implementation of new technologies
   c. Tracking of regional approaches with a strong reference to value-added-chain

The subsidy program is structured in a way to ensure that the measures intertwine. The aspect of transferring and exchanging experience is of central interest, and particular clusters are planned to be formed to ensure the transfer between the three modules.

The investigated firm recognizes the subsidy program as a chance to re-start its digitalization activities that have been stopped or delayed due to the crisis. Furthermore, to speed up the process of digitalization for the firm.

The subsidy program requires a consortium of several firms and, which is a fundamental condition, a scientific transfer process. The funded projects have to disclose their findings to the industry; firms that are not willing to do this cannot participate in the program.

The approval process for the program is similar to other programs. When a consortium has been established, it must provide a sketch of the ideas, determine that it can ensure the scientific transfer process, and provide a full proposal that requires to be finally released by the BMWi. This process can take up to several months.

To contribute to the described process, the investigated firm used the research findings to ascertain projects that fulfill all requirements, such as the non-disclosure requirement. Figure 15 provides the overview of the technologies that are of interest for the firm but haven't been worked on so far. Based on that, the firm was able to define the projects that shall be taken into consideration for a potential consortium. Another additional advantage of the DCAI concept unfolds here, the firm-specific digitalization strategy. It enables the firm to share its findings, work openly and transparently in the consortium, and the firm does not need to be afraid to give away an advantage to its competitors while working in the consortium. Due to the architectural design, the firm can fully contribute to the consortium, use all the benefits coming from the subsidies and accelerate its own digitalization activities. The findings can be integrated into the firm, but because of the architectural design, the impact on the firm's profitability and effectiveness will be higher than for all other participants of the consortium. The whole nexus of *economies of …* unfolds its effects, particularly *economies of scope* (spatial, temporal, and functional), *economies of density*, and *economies of learning*.

To prepare for the program, the firm has assigned a project manager to gather the information and promote the activities related to the subsidy program. Several meetings to coordinate the tasks took place, both with universities, potential partners from the industry, and members of the IIC. To the point in time when this dissertation was written, it was not finally decided if the firm is going to participate in a consortium or, if even possible, lead one.

It has been said that the science of one age is the common sense of the next. However, having access to a concept like DCAI and knowing its potential impact can be crucial for the success or failure of a firm's digitalization strategy. The results of this research have become part of the investigated firm and will have a long-term impact on the firm and its effectiveness.

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14 PUBLICATIONS AND PRESENTATIONS RELATED TO THE TOPIC

1. Hammerström, L. (2018). Organizational design of big data and analytics teams. *European Journal of Social Science, Education and Research*. DOI: 10.2478/ejser-2018-0065. ISSN (print): 2411-9563. ISSN (online): 2312-8429
2. Hammerström, L., Zwerenz, D. (2019). Maturity-model for the evaluation of investments into IIoT. *European Journal of Economics and Business Studies*. DOI: 10.26417/ejes.v5i1.p126-140
3. Hammerström, L., Giebe, C. & Zwerenz, D. (2019). Taxonomy of an IIoT device based upon production functions. *European Journal of Economics and Business Studies*. DOI: 10.26417/ejes.v5i2.p6-22
4. Hammerström, L., Giebe, C. & Zwerenz, D. (2019). Influence of big data & analytics on corporate social responsibility. *SocioEconomic Challenges*, Volume 3, Issue 3. ISSN (print): 2520-6621, ISSN (online): 2520-6214. DOI: 10.21272/sec.3(3)47-60.2019
5. Giebe, C., Hammerström, L. & Zwerenz, D. (2020). Big Data & Analytics as a sustainable Customer Loyalty Instrument in Banking and Finance. *Financial Markets, Institutions and Risks*, 3(4), 74-88. http://doi.org/10.21272/fmir.3(4).74-88.2019
6. Hammerström, L. (2021). Supplementation of the Blue Ocean Theory and the 7 Transformations of Leadership. In S. Berke, K. Szabó, B. Szücs & P. Gáborné (Ed.), Organizational Behaviour and Leadership Theory in Practice (pp. 115-121). Hungarian University

of Agriculture and Life Sciences Kaposvár Campus. ISBN 978-615-5599-92-7

7.

8. 1st Joint Research Conference on Economic Science. Presentation: *Evaluation of the impact of big data & analytics on the energy consumption within the automotive industry and its contribution to corporate social responsibility*. 23rd of February 2018. Venue: Hungarian University of Agriculture and Life Science, faculty of economic science, Kaposvar, Hungary. Chairman: Prof. Dr. Sándor Kerekes

9. 16th International Conference on Social Sciences. 23-24 November 2018. Venue: Mercure Paris Centre Eiffel Tower, Paris, France. Chairman: Prof. Dr. Rodica Sirbu

10. 2nd Joint Research Conference on Economic Science. Presentation: *Success-factors in data-driven optimizations.* Venue: Hungarian University of Agriculture and Life Science, faculty of economic science, Kaposvar, Hungary. Chairman: Prof. Dr. Sándor Kerekes

11. 17th International Conference on Social Sciences. 8-9 March 2019. Venue: Campus de la Merced, Universidad Murcia, Spain. Chairman: Prof. Dr. Ahmet Ecirli

12. Making Industry 4.0 real. Fourth international industry 4.0 conference. Presentation: *Steering the transformation process – IIoT applications in the automotive supplier industry*. Park Inn Hotel, Kaunas, Lithuania. Chairman: Florian Schröder, CEO German-Baltic Chamber of Commerce

13. 3rd Joint Research Conference on Economic Science. Presentation: *Measuring the impact of IIoT devices on global networks*. Venue:

Hungarian University of Agriculture and Life Science, faculty of economic science, Kaposvar, Hungary. Chairman: Prof. Dr. Imre Fertö

14. 20th International Conference on Social Sciences. 6-7 September 2019. Venue Zurich University of the Arts, Switzerland. Chairman: Prof. Dr. Rodica Sirbu

15. AutoDigital 2019. Organized by WESER KURIER. Presentation: *Digitalization in the automotive-supplier industry*. December 2019, Bremen, Germany.

16. 4th Joint Research Conference on Economic Science. Presentation: Maturity-model for the evaluation of investments into IIoT. Hungarian University of Agriculture and Life Science, faculty of economic science, Kaposvár, Hungary. Chairman: Prof. Dr. Imre Fertö

17. International Conference on Sustainable Economy and Agriculture. Presentation: Data analytics as a sustainable customer loyalty tool. Hungarian University of Agriculture and Life Science, faculty of economic science, Kaposvár, Hungary. Chairman: Prof. Dr. Imre Fertö

15 RESUME

The author was born in Berlin in September 1976 and went to primary school and secondary school in Bremen, Germany.

After finishing school, he fulfilled basic military service which was then compulsory in Germany, at different units and underwent miscellaneous training concerning different operational purposes. Hereafter, he undertook vocational training at the Lürssen shipyards and specialized in machine- and system-technology. He started his academic studies in 2000 at the Hochschule Bremen – City University of Applied Sciences, Bremen in the faculty of mechanical engineering. In 2003, he won a fellowship from the Fiber-Institute (FIBRE) in Bremen and spent 9 months at the Australian Wool Exchange (AWEX) in Sydney, Australia. After successfully finishing his studies, he applied for a job in the automotive industry and started working in this industry in 2004. Alongside working as an engineer, he started his postgraduate studies in 2005 at the University of Applied Science in Hamburg, in the Faculty of Economic Science and Business Management, which he completed successfully. To prepare for a Ph.D. program, he finished all courses on the masters degree at the University of Applied Science in Hamburg successfully and applied in 2017 to the Doctoral School for Management and Organizational Science at the Hungarian University of Agriculture and Life Science, Faculty of Economic Science, Kaposvár, Hungary.

16 AUTHOR’S STATEMENT

I, Lennart Immo Hammerström, declare that I shall behave in a manner worthy of the doctors of the University, I shall comply with the ethics of sciences, I shall also in the future continue to work on developing my discipline, I shall serve my country with my knowledge and the universal human culture. I endeavor through all this to further the reputation of the Hungarian University of Agriculture and Life Science, which conferred this doctorate upon me. I shall bear with due respect towards the University at all times.

I shall endeavor to gain reputation with my professional attainments to my country, to Hungarian University of Agriculture and Life Science and to myself.

Kaposvár,

Appendix 1 – Enquire to the participants of the survey

Industrial Internet of Things - Questionnaire

By this time the public is well aware that a new age of machines is upon us, based on the computing machine…to replace human judgment on all levels…this new replacement will have a profound influence upon our lives, but it is not clear to the man of the street what this influence will be.

Norbert Wiener, 1949

Dear Colleague!

In this year's SCU I presented to the management board of the business unit Electronics a brief overview of the digitalization strategy of Operations.

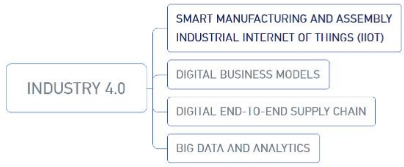
Within the next month my team and I like to *"earn the right to (further) digitize"* and to convince the organization that our endeavors will be an important contributor to the success of HELLA.

We have taken the first steps to prepare the digital future for Operations; for example, the organizational unit E-OD (Operations digitalization) was created and new colleagues were hired in Romania and Germany to work on the realization of our current digitalization strategy.

To improve our strategy and to widen its focus I kindly ask you to invest some of your limited time and to share your feedback with us.

We have chosen to approach you with a questionnaire to collect your feedback and to develop a harmonized and more on the long-run orientated digitalization strategy.

The focus of the questionnaire is on SMART MANUFACTURING AND ASSEMBLY, often summarized as the INDUSTRIAL INTERNET OF THINGS (IIoT).



You won't find smart products in this survey, for example, because this is part of the digital business models.

The questionnaire does not only focus on new technologies, but also on organizational topics, necessary new structures and the need for new skill-sets and trainings.

To reduce the time necessary to fill out the questionnaire each IIoT technology is introduced and an identical set of 6 questions is requested to be answered. Only the questions for the part "Organization" deviate from this structure.

To provide addition information to you regarding IIoT we have worked out a set of "*background information*"; those you can find as an appendix to this document.

Filling out the questionnaire will consume between 25 and 35 minutes of your spare time.

Your feedback is highly appreciated and will help my team and me to better shape the digital roadmap of E-OEN.

Your feedback is kindly requested till the 22nd of February 2019, the survey will be closed that day.

With kind regards

Lennart Hammerström

Operations Engineering Electronics

Figure 39: The cover letter that was sent out to the participants of the survey (self-edited).

Background information

Here you can find additional information regarding the *Industrial Internet of Things* and why it is supposed to shape the future of our production, the way we are going to collaborate in the future and why it is very probably going to change the competition.

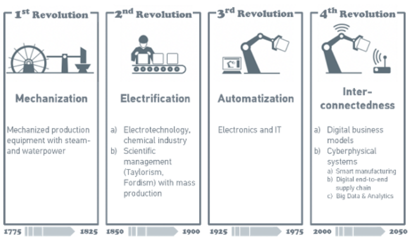
If further information is not necessary for you, feel free to skip the informational pages and go directly to the questionnaire.

The 4th industrial revolution

In school we learned that the development of mankind is classified into several phases and that stepping from one phase to another is triggered by a transformation in human behavior (e.g. social behavior or change from hunters and gatherers to peasants) or has been triggered by inventions (such as the invention of the fist wedge).

The industrial revolution is also classified in this manner, the textbooks show 3 different industrial revolutions, triggered by natural-scientific discoveries and the inventions that are based on those discoveries.

It is most likely that we are already in a phase that will be described in some years as the beginning (or the center point) of the 4th industrial revolution, the area of *digitalization* and *interconnectedness*.



The aftermath of the digitalization and the interconnectedness get a wide range of attention today, but were recognizable for visionary already long ago, such as the following statement, taken from a letter sent to the president of the United States on the 22nd of March 1964, Lyndon B. Johnson:

> *A new era of production has begun. Its principles of organization are as different from those of the industrial era as those of the industrial era were different from the agricultural. The cybernation revolution has been brought about by the combination of the computer and the automated self-regulating machine. This results in a system of almost unlimited productive capacity, which requires progressively less human labor* (Pauling 1964).

Every revolution needed its drivers or enablers; for the digitalization there are several enablers, such as the doubling of components on an IC every 12 to 24 months (Moore's law), the increased bandwidth (Nielsen's law), the reduced cost for hardware, driven by mass production (economies of scale) or the multicore technology that is able to sextupling Moore's law in regards of the speed of calculation.

Restriction of the questionnaire

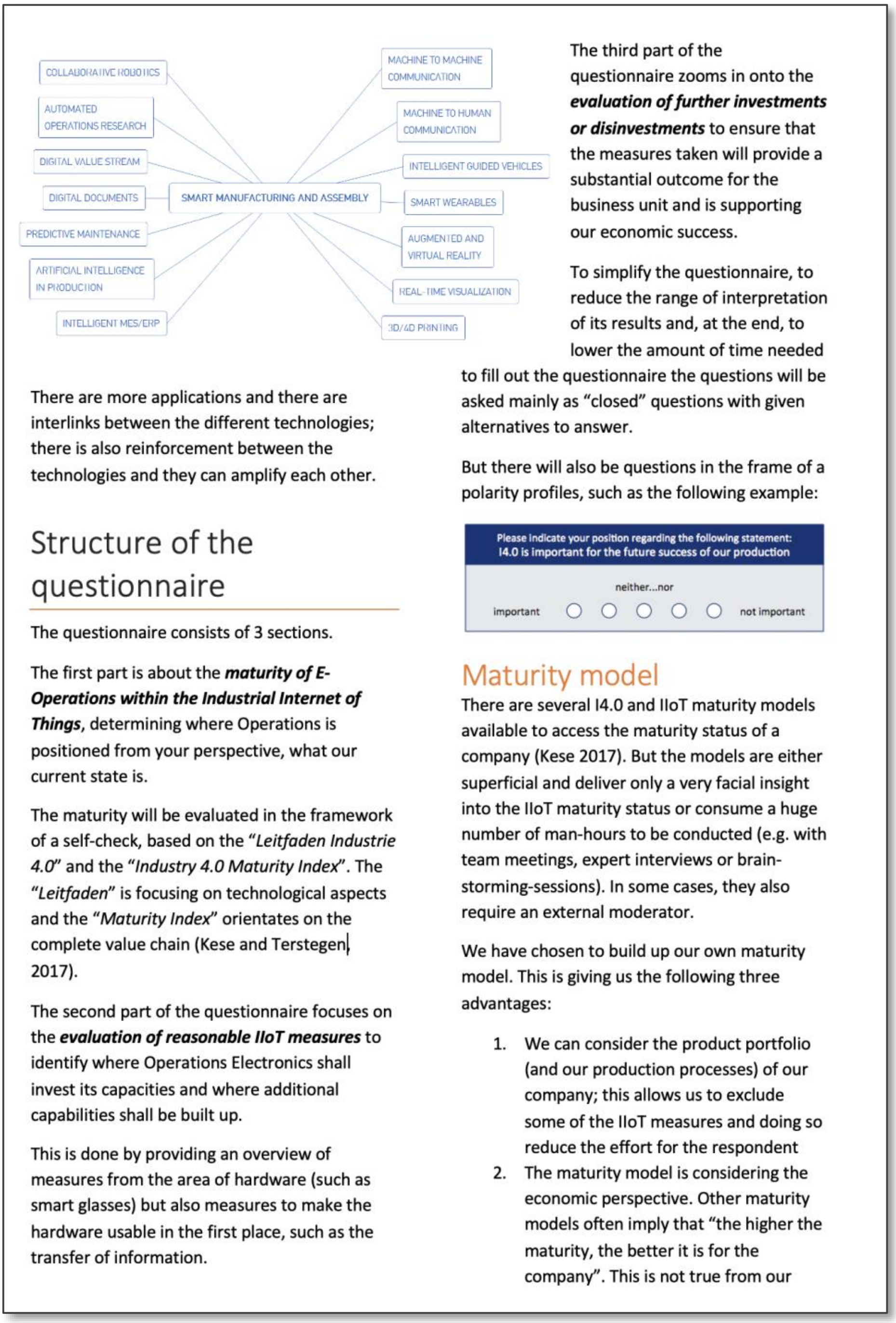
The intention of the questionnaire is not to cover the full technological range of I4.0, the complete process house of HELLA (HPH) or the complete value chain of HELLA (*Market to Contract → Idea to Produce → Order to Fulfill*). The questionnaire zooms in on I4.0 and focuses on:

- Shop floor and office floor at production locations
- Integration of suppliers of means of production

By zooming in the focus of the survey is getting narrower and delimitable, looking at the Industrial Internet of Things in a sense. Doing so it becomes more applicable to work out a strategy resp. a roadmap for Operations.

The following graph is a selection of the most common applications regarding smart manufacturing and assembly.

Figure 40: The background information that was sent via email to the participants of the survey, page 1 of 4 (self-edited).



There are more applications and there are interlinks between the different technologies; there is also reinforcement between the technologies and they can amplify each other.

Structure of the questionnaire

The questionnaire consists of 3 sections.

The first part is about the ***maturity of E-Operations within the Industrial Internet of Things***, determining where Operations is positioned from your perspective, what our current state is.

The maturity will be evaluated in the framework of a self-check, based on the "*Leitfaden Industrie 4.0*" and the "*Industry 4.0 Maturity Index*". The "*Leitfaden*" is focusing on technological aspects and the "*Maturity Index*" orientates on the complete value chain (Kese and Terstegen 2017).

The second part of the questionnaire focuses on the ***evaluation of reasonable IIoT measures*** to identify where Operations Electronics shall invest its capacities and where additional capabilities shall be built up.

This is done by providing an overview of measures from the area of hardware (such as smart glasses) but also measures to make the hardware usable in the first place, such as the transfer of information.

The third part of the questionnaire zooms in onto the ***evaluation of further investments or disinvestments*** to ensure that the measures taken will provide a substantial outcome for the business unit and is supporting our economic success.

To simplify the questionnaire, to reduce the range of interpretation of its results and, at the end, to lower the amount of time needed to fill out the questionnaire the questions will be asked mainly as "closed" questions with given alternatives to answer.

But there will also be questions in the frame of a polarity profiles, such as the following example:

Maturity model

There are several I4.0 and IIoT maturity models available to access the maturity status of a company (Kese 2017). But the models are either superficial and deliver only a very facial insight into the IIoT maturity status or consume a huge number of man-hours to be conducted (e.g. with team meetings, expert interviews or brain-storming-sessions). In some cases, they also require an external moderator.

We have chosen to build up our own maturity model. This is giving us the following three advantages:

1. We can consider the product portfolio (and our production processes) of our company; this allows us to exclude some of the IIoT measures and doing so reduce the effort for the respondent
2. The maturity model is considering the economic perspective. Other maturity models often imply that "the higher the maturity, the better it is for the company". This is not true from our

Figure 41: The background information that was sent to the participants of the survey, page 2 of 4 (self-edited).

point of view and can be avoided with an adapted model
3. An external consultant or moderator is not necessary to conduct the survey; the effort to create and conduct the survey is reduced

Out of sixteen different maturity models an own model was created; the main contribution for the maturity model is coming from the "*Leitfaden Industrie 4.0*" (Anderl 2017) and the "*Industrie 4.0 Maturity Index*" (Schuh 2017).

Leitfaden Industrie 4.0[1]

The VDMA[2] developed a guideline to give SMEs orientation regarding the implementation of I4.0 and IIoT.

The guideline from the VDMA was chosen even though it focuses on SMEs since the Operations locations of the business unit Electronics often have to operate in a manner of speedboats to meet customer demand and expectations. Therefore, the guideline of the VDMA is applicable from my perspective. E-OEN is driving standards and is focused on the worldwide implementation of identical measures and applications to keep our cost down and the speed of transfer on a very high level. Between those two requisitions we must manage the IIoT measures.

The guideline is built upon a chronological structure and provides a toolbox that is subdivided in *products* and *production*.

The guideline is sub-divided into a five-step-process, requires a strong contribution of the employees of the analyzed company and can be installed to generate ideas and to structure the development-process while working out a strategy for I4.0.

[1] Developed by Reiner Anderl (TU Darmstadt) and Jürgen Fleischer (wbk Institut für Produktionstechnik)
[2] Verband Deutscher Maschinen- und Anlagenbau

The Industrie 4.0 Maturity Index (acatech) [3]

The acatech model's approach is based on a succession of maturity stages, i.e. value-based development levels that help navigate through the transformation process, starting with the basic requirements for I4.0 to full implementation.

1. Computerization
2. Connectivity
3. Visibility *("Seeing" – What is happening)*
4. Transparency *("Understanding" – Why is it happening?)*
5. Predictive capacity *("Being prepared" – What will happen?)*
6. Adaptability *("Self-optimizing" – How can an autonomous response be achieved?)*

It is not about reaching always the maximum level. A company's desired target state will depend on its business strategy and about the best balance between costs, capabilities and benefits for its own individual circumstances (Schuh 2017).

The VDMA guideline takes also 4 different structural areas into account, such as:

1. Resources
2. Information systems
3. Culture
4. Organizational structure

Therefore, the acatech model is a more holistic one that is taking also basic requirements and support functions into account.

Distinct maturity model

The model that was created is a three-dimensional one.

It takes into consideration the

The three dimensions of maturity are the following ones:

1. Maturity level

[3] Developed by Deutsche Akademie der Technikwissenschaften (acatech)

Figure 42: The background information that was sent to the participants of the survey, page 3 of 4 (self-edited).

2. Field of application
3. Culture & Organization

Each dimension is subdivided into dignified levels to provide a better understanding and to allow the creation of recommendations that are based on the survey.

The *maturity levels* are arranged as the vertical axis, the ordinate; we have chosen the following denominations (progressive ranking):

1. Inexperienced
2. Tentative
3. Advanced
4. Dynamic
5. Outstanding

The *field of application* will be the horizontal axis, the abscissa. Here we will request your feedback for each single IIoT application (or the value drivers). The main clusters are:

1. Resources/processes
2. Asset utilization
3. Labor
4. Quality

The *Culture & Organization* will be the third dimension and will allow us to ensure that when creating the IIoT strategy to ensure the readiness from a cultural, training and knowledge-based point of view.

Confidentiality statement

All information gathered in the context of this questionnaire will be protected and used only in a direct connection to the ongoing survey.

I understand that, as an executioner of this survey, no information and no conclusion of the participants of the survey shall be made approachable to third parties.

I acknowledge that it is my responsibility to respect the privacy and confidentially of this information. I will not access, use, or disclose any confidential information outside of my observation.

List of references

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Figure 43: The background information that was sent to the participants of the survey, page 4 of 4 (self-edited).

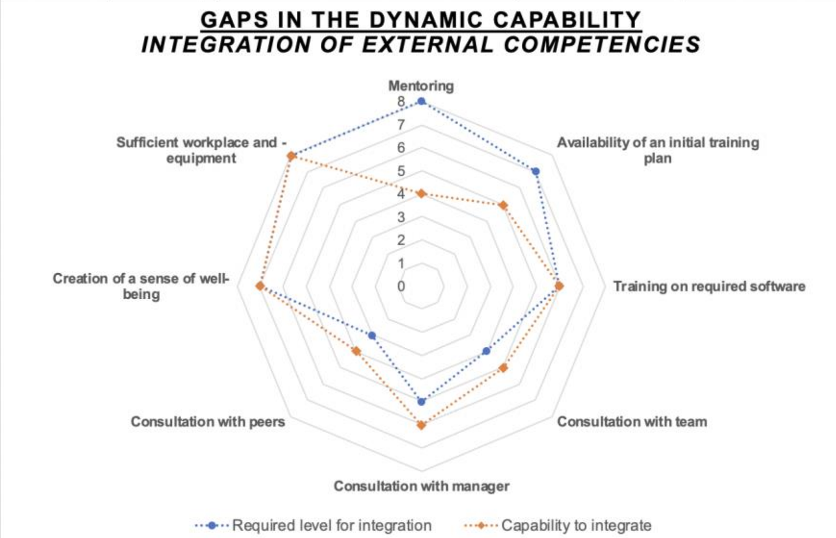
APPENDIX 2 – PERFORMANCE EVALUATION SHEET

Performance evaluation and action plan to ensure a gap closure in regards to dynamic capabilties

Dynamic Capability:* *Integration of external competencies

Name of employee:	
Working area of employee:	
Start date in new position:	
Timeframe for execution of actions:	

Prerequisites for achievement	**Required level for integration**	**Capability to integrate**
Mentoring	8	4
Availability of an initial training plan	7	5
Training on required software	6	6
Consultation with team	4	5
Consultation with manager	5	6
Consultation with peers	3	4
Creation of a sense of well-being	7	7
Sufficient workplace and -equipment	8	8



Actions to be taken:	**Accountable:**	**Due date:**
1. Mentoring for the employee		
1.1 Find a mentor for the employee		
1.2 Install a coaching systematic for mentor and mentee		
1.3 Install optimization loop if required		
1.4 Review the mentoring		
2. Training plan		
2.1 Work out a training plan		
2.1 Prioritize the main skills that are required		
2.2 Set the prioritization in order		
2.3 Organize the trainings for the employee		
2.4 Review the effect of the trainings		

Figure 44: Performance evaluation sheet and action plan for a Dynamic Capability (self-edited).

APPENDIX 3 – EXPLANATORY NOTES REFERRING TO PCA

The purpose of the Principal Component Analysis (PCA) is to replace k metrical, correlating variables with a smaller number of uncorrelated components, which nonetheless contain a large proportion of the information of the original set of variables that allow a meaningful interpretation of the data-set. This reduction facilitates simplifying the interpretation of the data-set because it is easier to interpret a smaller number of components than numerous immediate correlations. The PCA is a descriptive statistical method and does not require basic inferential assumptions (Mayer, 2020).

The following explanations are based upon the scientific work of Jolliffe (1986), Mayer (2020), Partridge & Jabri (2000), Sharma (2020), Vidal, Ma & Sastry, (2016) and Wold, Esbensen & Geladi (1987).

With a PCA the dimensionality of the variable space can be reduced by representing it with a few orthogonal (uncorrelated) variables that capture most of its variability. Principal component analysis (PCA) refers to the problem of fitting a low-dimensional affine subspace S of dimension $d \ll D$ to a set of points $\{x_1, x_2, \ldots, x_n\}$ in a high-dimensional space $\mathbb{R}^D$. Mathematically, this problem can be formulated as either a statistical problem or a geometric one as it is shown in Figure 45 and Figure 46.

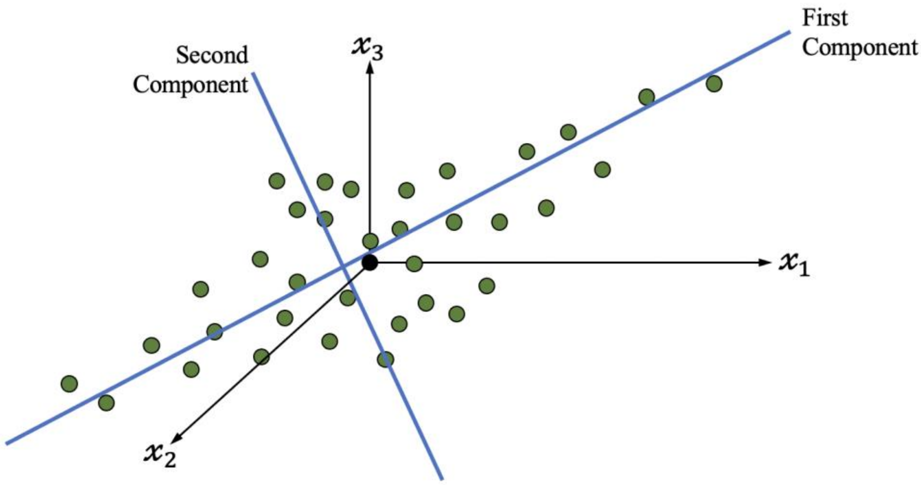


Figure 45: 2 components in a 3-dimensional space. Inspired by "Generalized Principal Component Analysis" by Vidal, Ma and Sastry, 2016, p. 33, Copyright by Springer.

As an equalization calculus the method of the least squares can be applied to determine the components. A very comprehensible visualization of this method is the animation on the webpage "heartbeat.fritz.ai", developed by Sharma (Sharma, 2020).

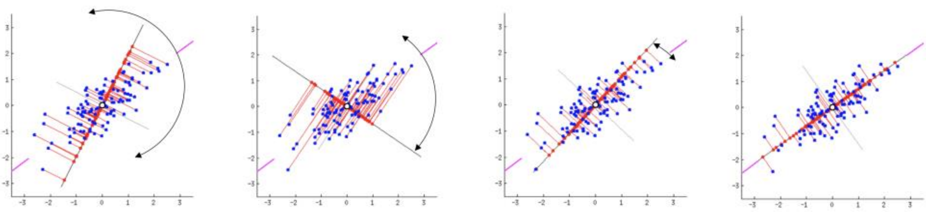


Figure 46: Visualization of the method of least squares. Taken from the animation "PCA Algorithm" in "Understanding the Mathematics behind Principal Component Analysis" by N. Sharma, retrieved from https://heartbeat.fritz.ai/ understanding-the-mathematics-behind-principal-component-analysis-efd7c9ff0bb3.

The technique to reduce the dimensions of the feature space is called dimensionality reduction. Large data-sets make it hard to distinguish between the important features that are relevant to the output and the not-so important ones.

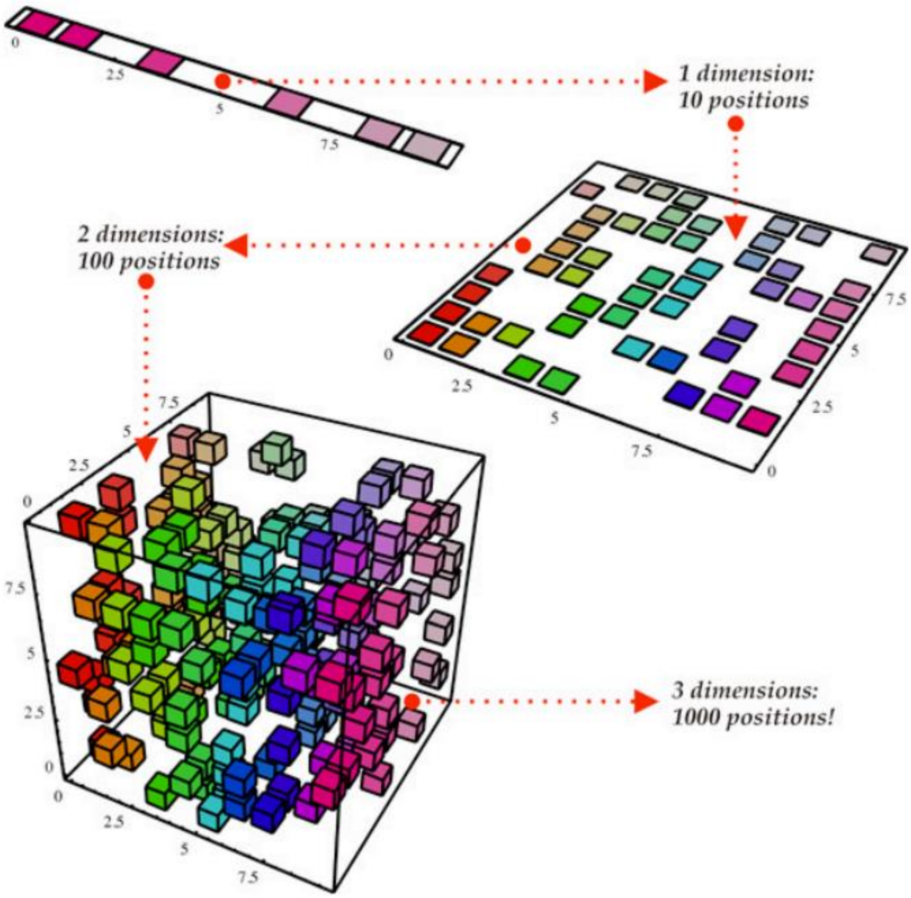


Figure 47: Dimensional reduction. Reprinted from "Understanding the Mathematics behind Principal Component Analysis" by N. Sharma, retrieved from https://heartbeat.fritz.ai/understanding-the-mathematics-behind-principal-component-analysis-efd7c9ff0bb3.

The preceding and the following explanations are based upon the scientific work of Jolliffe (1986), Mayer (2020), Partridge & Jabri (2000), Sharma (2020), Vidal, Ma & Sastry, (2016) and Wold, Esbensen & Geladi (1987).

> The central idea of the method is based upon the overall variance, i.e., the sum of the variances of the primal k correlated variables. The PCA transforms correlated variables {x1, x2, …, xn} into uncorrelated components {y1, y2, …, yn}. This is done according to the principle that the principal components in descending order explain the highest share of the total variance (first principal component y1). The second principal component (y2) explains the highest share of the remaining variance (y3), the third of the then left highest share of variance and so forth.
>
> Also PCA does not ignore covariances and correlations, it concentrates on variances. The first step is to look for a linear function $\alpha'_1 x$ of the elements of x which has maximum variance, where α_1 is a vector of ρ constants, $\alpha_{11}, \alpha_{12}, \ldots, \alpha_{1\rho}$, and ′ denotes transpose, so that
>
> $$\alpha'_1 x = \alpha_{11}x_1 + \alpha_{12}x_2 + \cdots + \alpha_{1p}x_{1p} = \sum_{j=1}^{\rho} \alpha_{1j}x_j$$
>
> The next step is to look for a linear function $\alpha'_2 x$, uncorrelated with $\alpha'_1 x$, which has maximum variance, and so on, so that at the kth stage a linear function $\alpha'_k x$ is found which has maximum variance subject to being uncorrelated with $\alpha'_1 x, \alpha'_2 x, \ldots, \alpha'_{r-1} x$. The kth derived variable, $\alpha'_k x$, is

the k^{th} principal component. Up to p PCs could be found, but it is hoped, in general, that most of the variation in x will be accounted for by m PCs, where $m \ll p$.

If a set of p (>2) variables has substantial correlations among them, then the first few PCs will account for most of the variation in the original variables. Conversely, the last few PCs identify directions in which there is very little variation, i.e. they identify near-constant linear relationships between the original variables. Having defined PCs, we need to know how to find them. Consider, for the moment, the case where the vector of random variables x has a known covariance matrix, $\sum$. This is the matrix whose (i^{th}, j^{th}) element is the (known) covariance between the i^{th} and j^{th} elements of x when $i \neq j$, and the variance of the j^{th} element of x when $i = j$. (The more realistic case, where $\sum$ is unknown, follows by replacing $\sum$ by a sample covariance matrix S. It turns out that, for k = 1, 2, ..., p, the k^{th} PC is given by $z_k = \alpha'_k x$ where α'_k is an eigenvector of $\sum$ corresponding to its k^{th} largest eigenvalue λ_k. Furthermore, if λ_k is chosen to have unit length ($\alpha'_k \alpha_k = 1$), then $\mathrm{var}(z_k) = \lambda_k$ where $\mathrm{var}(z_k)$ denotes the variance of z_k.

To derive the form of the PCs, consider first $\alpha'_1 x$; α_1 maximizes $\mathrm{var}[\alpha'_1 x] = \alpha'_1 \sum \alpha_1$. It is clear that, as it stands, the maximum will not be achieved for finite α_1, so a normalization constraint must be imposed. The most convenient constraint here is $\alpha'_1 \alpha_1 = 1$ (i.e. the sum of squares of elements of α_1 equals 1), but others (e.g. $\text{Max}_j|\alpha_{1j}|$=1, use the technique of Lagrange multipliers and maximize

$$\alpha'_1\sum\alpha_1 - \lambda(\alpha'_1\alpha_1 - 1),$$

where λ is a Lagrange multiplier. Differentiation with respect to α_1 gives

$$\sum\alpha_1 - \lambda\alpha_1 = 0,$$

or

$$(\sum - \lambda I_\rho)\alpha_1 = 0,$$

Where $I_{\wp}$ is the $(\wp\, x\, \wp)$ identity matrix. Thus, λ is an eigenvalue of $\sum$ and α_1 is the corresponding eigenvector. To decide which of the $\wp$ eigenvectors is the maximizing value of α_1, note that the quantity to be maximized is

$$\alpha'_1\sum\alpha_1 = \alpha'_1\lambda\alpha_1 = \lambda\alpha'_1\alpha_1 = \lambda,$$

so λ must be as large as possible. Thus, α_1 is the eigenvector corresponding to the largest eigenvalues of $\sum$, and var($\alpha'_1 x$) $= \alpha'_1\sum\alpha_1 = \lambda_1$, the largest eigenvalue.

In general, the kth PC of x is $\alpha'_k x$ and var($\alpha'_1 x$) $= \lambda_k$, where λ_k is the kth largest eigenvalue of $\sum$, and α_k is the corresponding eigenvector. This will now be proved for k=2;

the proof for $k \geq 3$ is slightly more complicated, but very similar.

The second PC, $\alpha'_2 x$, maximizes $\alpha'_2 \Sigma \alpha_2$ subject to being uncorrelated with $\alpha'_1 x$ (i.e. subject to $\mathrm{cov}[\alpha'_1 x, \alpha'_2 x] = 0$, where cov(x,y) denotes the covariance between the random variables x and y). But

$$\mathrm{cov}[\alpha'_1 x, \alpha'_2 x] = \alpha'_1 \Sigma \alpha_2 = \alpha'_2 \Sigma \alpha_1 = \alpha'_2 \lambda_1 \alpha'_1 = \lambda_1 \alpha'_2 \alpha_1 = \lambda_1 \alpha'_1 \alpha_2.$$

Thus any of the equations

$$\alpha'_1 \Sigma \alpha_2 = 0 \qquad \alpha'_2 \Sigma \alpha_1 = 0,$$
$$\alpha'_1 \alpha_2 = 0 \qquad \alpha'_2 \alpha_1 = 0$$

could be used to specify no correlation between $\alpha'_1 x$ and $\alpha'_2 x$. Choosing the last of these (an arbitrary choice), and noting that, once again, a normalization constraint is necessary, the quantity to be maximized is

$$\alpha'_2 \Sigma \alpha_1 - \lambda(\alpha'_2 \alpha_2 - 1) - \phi \alpha'_2 \alpha_1,$$

where λ, ϕ are Lagrange multipliers. Differentiation with respect to α_2 gives

$$\Sigma \alpha_2 - \lambda \alpha_2 - \phi \alpha_1 = 0$$

and multiplication of this equation on the left by α'_1 gives

$$\alpha'_1 \sum \alpha_2 - \lambda(\alpha'_1 \alpha_2 - \phi \alpha'_1 \alpha_1 = 0,$$

which, since the first two terms are zero and $\alpha'_1 \alpha_1 = 1$, reduces to $\phi = 0$. Therefore, $\sum \alpha_2 - \lambda \alpha_2 = 0$, i.e. $(\sum - \lambda \mathrm{I}_\rho)\alpha_2 = 0$, so, once again, λ is an eigenvalue of $\sum$ and α_2 the corresponding eigenvector.

Again, $\lambda = \alpha'_2 \sum \alpha_2$, so λ is to be as large as possible. Thus $\lambda = \lambda_2$, the second largest eigenvalue (it cannot equal λ_1 (unless $\lambda_1 = \lambda_2$), since then $\alpha_2 = \alpha_1$ so $\alpha'_2 \alpha_1 = 0$ does not hold) and α_2 is the corresponding eigenvector.

As stated above, it can be shown that for the third, fourth, …, p^{th} PCs, the vectors of coefficients $\alpha_{3,}\ \alpha_{3,} \ldots,\ \alpha_\rho$ are the eigenvectors of $\sum$ corresponding to $\lambda_{3,}\ \lambda_{3,} \ldots,\ \lambda_\rho$, the third and fourth largest, …, and the smallest eigenvalue, respectively. Furthermore,

$$\mathrm{var}(\alpha'_1 x) = \lambda_k \qquad \text{for k} = 1, 2, \ldots, p.$$

APPENDIX 4 – THE RESEARCH MODEL

The research model depicts the operationalization of the objective of the dissertation on a high level of abstraction. It emphasizes the relationship of the variables to illustrate the context of the two research streams (Architectural Innovation and Dynamic Capabilities).

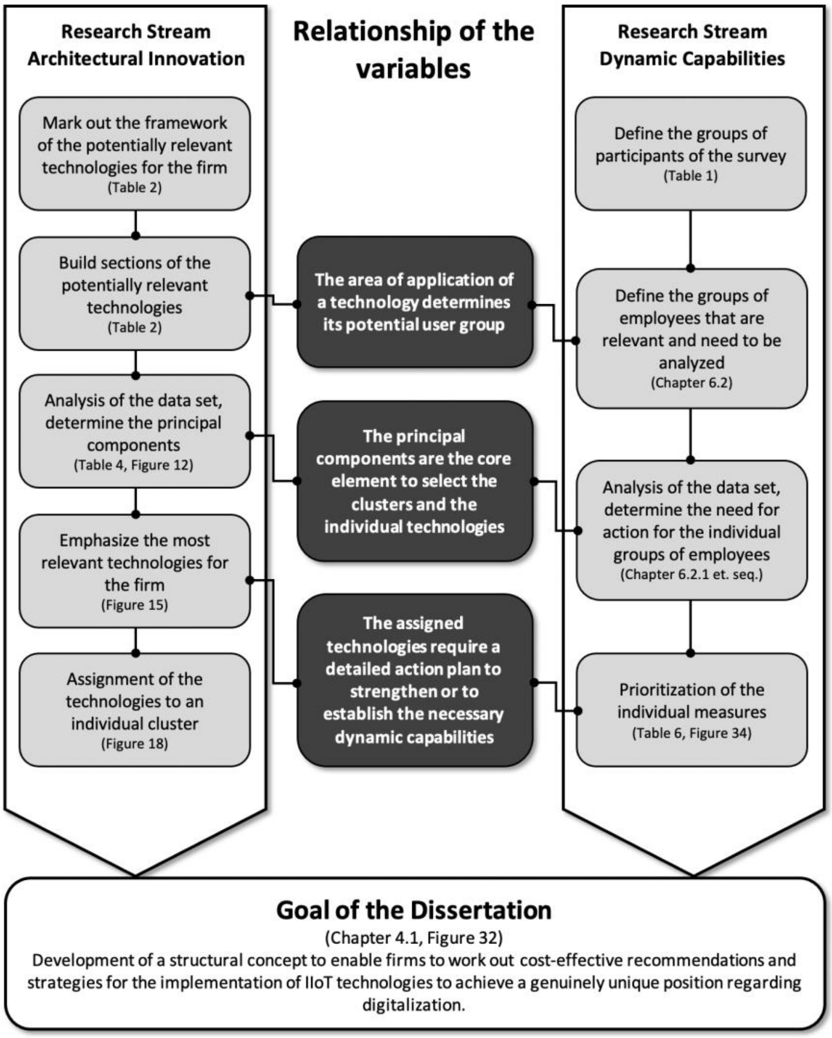


Figure 48: The Research Model (self-edited).