

Managerial Practices for the Digital Transformation of Manufacturers

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Abstract: The digital transformation is a complex and multi-faceted phenomenon, which companies hamper to manage effectively. One particular facet of this phenomenon is the role of managers, which is still underrepresented in research. This study aims to identify and explain why and what managerial practices and competencies are particularly needed to effectively govern through this transformation. We choose the case study methodology as the research design with eight manufacturing companies in Western Europe, where we applied within- and cross-case analyses. Specific barriers for digital transformation and four aggregated managerial practices, such as strategy/organization, collaboration, cross-functionality and data-driven use cases, were identified. These were supported by 13 competencies to facilitate digitalization. We explicate these practices based on the change management theory and provide a model describing the impact of these practices on profitability. This study contributes to the emergent change theory by analyzing practices and competencies that managers should be equipped with to foster digitalization.

Keywords: digital transformation; Industry 4.0; change management; digitalization; smart factory

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1. Introduction

In recent years, Industry 4.0, or digitalization in general, received a great deal of attention as a technological and data-driven concept in theory and practice [1]. Digital transformation can address the exploitation of digital technologies to enhance internal processes and the reinvention of existing products, services, or business models [2,3]. While from the first perspective digitalization can increase production efficiency and thus decrease costs [4], it, from the second perspective, might increase customer value, sales, and a company's revenue [5]. Digital technologies such as sensors, cloud computing, big data, as well as many innovative use cases have proven to have an enormous impact on the transformation and success of manufacturing companies [2,6,7].

As promising as the idea of the future of manufacturing sounds, there are still plenty of risks and unsolved challenges ahead. The implementation of further digital technologies is increasingly complex [8]. The collaboration with stakeholders, required infrastructure or standards, organizational changes, and data management are only a few weak spots in the context of digitalization [9]. Notably, digital innovation requires a change of thinking in the entire company, including, adaptations among others in R&D, marketing, and production. Moreover, it affects strategic decisions, products, and processes [10]. While most publications on digitalization, Industry 4.0, or smart manufacturing mainly focus on the technological potentials [11] and technical issues [12], they hardly address the role of managers to facilitate the transformation towards this digitalization [13].

Although different approaches to guide the digital transformation have been investigated and developed, such as digitalization strategies [14,15], the impact of business model transformation [10,16], frameworks and roadmaps [17,18], consequences for single

functions [19,20] or transformation effects on an operational level [21], only a few publications are concentrating on competences and practices of managers to facilitate this change [22,23]. In theory, the “micro-mechanisms of the transformation remain hidden” [13] and a theoretical basis is missing.

Therefore, further research in the field of digital manufacturing transformation is required [24,25], especially on the role of managers, which has been taken as the main unit of analysis in this study. To capture these mechanisms, we make use of the case study methodology to deeply analyze this new phenomenon within eight manufacturing companies. Since change theory focuses on the process of continually renewing an organization’s direction, structure, and capabilities and thus how to manage the changes required to get there, we base our study on it. Our study is motivated by several questions: (i) What organizational structures, responsibilities, and decision processes are required for mastering digital transformation? (ii) How do external stakeholders influence the transformation process? (iii) What factors support the implementation process? These questions result in our following main research question: “*What competences and managerial practices do managers need to facilitate the digital transformation in industrial companies?*” To answer that question, this paper first reviews the theoretical background and existing approaches related to digitalization and transformations. Section 3 describes the research design, including data analysis methodology. Section 4 includes case description and case analyses, which serve as the foundation for the managerial practices and competencies in our digital transformation model. Section 5 provides a discussion of the findings and presents the derived propositions. Therefore, we contribute to the debate on managerial practices in the context of digitalization. Finally, Section 6 provides conclusions, implications, and suggestions for future research.

2. Theoretical Background

In this chapter, we introduce definitions and the theoretical foundation for our research study.

2.1. Digitalization and Digital Transformation

We understand Industry 4.0 or digitalization as the emerging digital transformation of companies, products, and production systems [12]. “The term digitalization has been coined to describe the manifold sociotechnical phenomena and processes of adopting and using these technologies in broader individual, organizational, and societal contexts” [26]. The concept stands for a new industrial stage where emerging and convergent technologies add value to the entire value chain. Today, digitalization is among the most noteworthy transformational trends for society and influences everyday life as well as most organizations [27]. “Digital technologies complement and/or enrich existing products and services and allow building entirely new business models” [26]. Furthermore, these concepts enable companies to increase quality, productivity and flexibility [4,28]. In the context of this paper, we defined “digital technologies” as the arrangement of computing and information processing abilities combined with communication and connectivity techniques [15,29]. Organizational change or transformation represents the “transition between organizational states that differ substantially in crucial features such as strategy and structure” [30]. Thus, we defined “digital transformations” as the change process that enables an industrial enterprise to develop and implement new digital technologies in products, services, processes, and organizations.

2.2. Theoretical Perspective on Manager Competencies and Roles in Digital Transformations

In recent years, both researchers and practitioners paid special attention to the change and transformation of organizations [14,31–36]. Change and transformation are a permanent characteristic of organizations on a strategic as well as operational level [37].

It affects all industries, organization forms, company sizes, and is triggered by internal and external causes [38,39].

To manage a multidimensional change, there are mainly two approach types: planned or emergent. The planned approach is based on Lewin's [40] idea that the three stages "unfreezing, moving, and freezing of a level" [40] are needed to discard a company's existing structures, processes, and culture and to cope with change successfully [41]. In other words, to manage a change process, old operations must be left behind before reaching a new, desired organizational configuration [34]. While the planned approach manages changes from top-down, the emergent approach handles changes from bottom-up [37,42,43]. Emergent change is seen to be "less dependent on detailed plans and projections than on reaching an actual understanding of the complexity of the issues involved and identifying the range of possible options" [41]. Moreover, Dawson (1994) stresses that change is connected to organizational relationships [44], market developments, the management system and work organization. Thus, an organization can manage change by transforming to a learning system and by reacting appropriately to internal and external influences [45].

Different frameworks have been developed [46–48] and factors for successful transformation have been identified and extensively examined by research [48–52]. Factors, such as top management commitment, effective communication [53], project team competence and interdepartmental cooperation [54] have been identified over and over again. Many of these factors and practices to lead and manage change, as well as the sequences of actions, remain rather abstract and difficult to comply with [37]. Approaches to master change such as Kanter's [55] Ten Commandments for Executing Change, Kotter's [38] Eight-Stage Process for Successful Organizational Transformation, and Luecke's [56] Seven Steps offer more guidance to managers to facilitate change.

Beside the common challenges of change and transformations, digitalization comes along with several new aspects that managers must deal with. These include the emergence of the ecosystem where digitalization plays a key role, as well as new digital tools for communication and teamwork that in turn affect the leadership and the organization itself. Findings and concepts regarding the competencies and managerial practices which are specific to digital transformation were identified by Kretschmer and Khashabi [57]. Five recommendations and decision rules to boost and enable digitalization were presented (e.g., prioritize your organization's processes by their permanence and potential for digitalization, identify dominant benefits of digital transformation and co-develop your strategy).

Information availability and digital tools change the way firms define, divide, and group tasks to reach an expected outcome. Digitalization allows one to reduce communication costs and to group interdependent activities, even if they were separated in the past due to geographical distance. Managers are challenged to make use of these new tools and to rethink organizational design and processes across functional departments. Neumeier and Liu [23] identified managerial competencies to foster this digital transformation. In their contribution, they provide insights into how managers can enhance their managerial competencies by expanding digital literacy and adaptability.

However, literature around the emergent approach of digitalization and change, especially the role of managers, is still relatively new and lacks coherence and a diversity of techniques [42]. To manage a digital transformation is complex [8] and many different barriers need to be overcome, such as, for example, the lack of management support, financial constraints, and resistance to change [58]. Increasing complexity inhibits an organization's ability to adopt technological innovations globally, to innovate business models, or to satisfy new regulatory requirements. The key challenge here is not the elimination or suppression of complexity originating from digital transformation, but rather finding effective ways to address these problems for managers. This also includes the necessary leadership and change competencies of managers. Consequently, traditional practices are hardly applicable in the digital transformation context. "More empirical work is

needed to determine the paths managers take when engaging in digital transformation...” [23]. Notwithstanding the particularities of governance in the digital transformation context, we are lacking a coherent theoretical account to systematically theorize on the digital transformation [59]. Hence, this paper aims to fill this theoretical gap on digital transformation and develop managerial practices that can guide companies through it.

3. Method

Following the argumentation of several researchers concerning advantages and rigor of case study research method [60–62], we employed a case study research approach. Case study research provides lots of information in fields with exploratory character, as in our explorative “what” research question [62]. Case research enables the study of digital transformations within its “real” setting and thus providing richer insights through observing actual practice in context. A multiple case study approach enhances external validity and reduces observer bias as long as the cases differ in several terms such as industry, product type, company size, or operations [60,62]. An overview of the research approach and process is available in Figure 1.

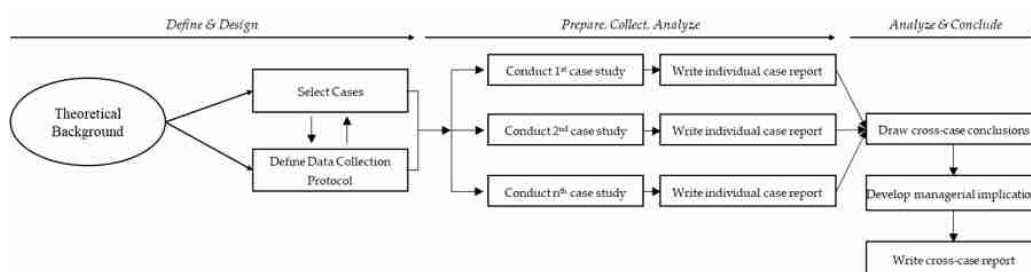


Figure 1. Multiple-case-study approach [62].

3.1. Case Selection

The careful selection of the case studies is a prerequisite for rigorous case study research [61,63]. The selection methodology followed the recommendations described in the literature [64]. Therefore, we established boundaries for the study to make sure that selection criteria are linked to the research question. The criteria for the selection were defined based on factors discussed in literature and practice, such as:

- Drivers of digital transformations (e.g., customization pressure, technology change, etc.);
- Barriers along transformation (e.g., lack of capabilities, lack of management commitment, etc.);
- Number of finished and ongoing digital technology projects (e.g., cloud, big data, etc.).

Using this information, the research team developed a summary of the basic constructs underlying digital transformations. We used this framework to categorize a number of companies that could serve as ideal case candidates, representing situations in which the digital transformation was observable. Based on a previous survey study about digital technologies with 115 participating companies, we used this sample as a basis to select cases for our study, as we know that these companies started or were in the digital transformation process. We listed potential companies (19) based on the defined criteria in the targeted industries and contacted them for initial interviews. After speaking with representatives in 13 companies, we selected and obtained participation from eight companies as the final sample. These companies were deemed to be different enough to explore the phenomenon of digital transformations.

Table 1 compares the eight companies concerning different digital transformation selection criteria along with other relevant company statistics.

The companies do not operate in the same markets, nor do they cooperate. This broad approach increases the validity of the cases [60,62]. We used descriptive monikers to substitute the company names.

Table 1. Case characteristics.

Technological and Commercial Factors	WPC	ASC	PPC	EMC	AGC	MFC	ABC	PTC
Cost pressure	→	→	↗	→	↑	↑	→	→
Delivery speed	↑	↗	↗	→	↘	→	→	↘
Quality	↗	↗	↑	↑	↑	↑	→	↑
Flexibility	↘	→	→	↗	→	↗	↘	→
Innovativeness (product, process)	→	↑	↑	↗	↗	↑	↗	↗
Overcome/face barriers in the digital transformation (lack of capabilities, feasibility, resistance,...)	3/6	7/12	0/7	4/8	7/10	5/12	3/13	5/9
Finished/ongoing projects related to digital transformation	5/3	10/30	5/10	5/15	50/200	6/8	20/10	10/5
Market diversity/demand variety	↗	→	↘	↘	↗	↗	→	↘
Product diversity	→	↗	↘	↘	↗	↗	→	↘
Employees (FTE)	8200	18,800	11,500	36,300	29,500	9000	6200	37,200
FTE dedicated to digitalization	30	20	30	120	50	30	20	90
Revenue (in bn USD)	2.81	3.23	2.95	7.63	5.89	1.00	1.5	11.6
4-year revenue development (CAGR)	+2.1%	+3.2%	+2.2%	+11.7%	-3.1%	+1.7%	+6.3%	-2.5%
R&D expenditures of revenue	9.2%	8.0%	4.7%	11.9%	6.5%	3.0%	n/a	4.2%
Digitalization invests of revenue	0.5%	1.0%	10%	1.0%	0.3%	2.0%	0.5%	0.1%

WPC: Wood-Processing Company, ASC: Automation Solution Company, PPC: Precision Printing Company, EMC: Electronic Miniature Company, AGC: Automotive Gear Company, MFC: Mechanical Fastening Company, ABC: Advanced Building Company, PTC: Power Transformation Company. ↓: very low/strong decrease; ↘: low/decreasing; →: medium/stable; ↗: high/increasing; ↑: very high/strong increase.

Through ‘theoretical replication’ [62], we choose case companies operating in different business-to-business markets and representing multiple industries such as automation solutions, wood processing, printing, automotive supply, building, and more to increase variety among the case firms and increase generalizability.

3.2. Data Gathering

The distinguishing characteristic of a case study research design is the usage of multiple sources of evidence for evaluation [61,62,65]. For our research, we generated case data by semi-structured interviews, printed and quantitative data, and a workshop meeting with our research team and industry experts from each case company. Hence, we applied multiple sources for the evaluation to enhance the case study research process. Each source of data strengthened the analysis by enabling triangulation for essential factors to cross-verify the understanding and knowledge building.

3.2.1. Semi-Structured Interviews

In order to achieve more detailed findings than those revealed in the questionnaire, specific interviews enhanced the data collection in a second step. A total of 22 interviews were conducted over seven months by telephone or in person, with an average of 2.75 interviews per company. Table 2 provides an overview of the participants and duration of each interview. The research team was consequently re-staffed for the different interviews for investigator triangulation and to reduce the bias [66,67]. All interviews were recorded and transcribed for multiple analyses and to facilitate a comparison between the cases.

Table 2. Overview of interviews with case company.

Company	Industry Type	Position	Workshop	Durations (min)
WPC	Wood Processing Industry	COO, Head of Operational Excellence and Projects	1-day on-site plant tour	1 × 30, 1 × 90, 1 × 30
ASC	Automation Solution	Chief Digital Officer, Lean Team	1-day on-site plant tour	1 × 60, 1 × 100, 1 × 30
PPC	Precision Printing	Lean Manager	1-day on-site plant tour	1 × 90, 1 × 30, 1 × 30
EMC	Electronic Miniature	Plant Manager, Head of Lean	1-day on-site plant tour	1 × 60, 1 × 90, 1 × 30
AGC	Automotive Gear	CEO of Division, Lean Team	1-day on-site plant tour	1 × 60, 1 × 60, 1 × 30
MFC	Mechanical Fastening	COO	1-day on-site plant tour	1 × 90, 1 × 30
ABC	Advanced Building	COO	1-day on-site plant tour	1 × 90, 1 × 30
PTC	Power Transformation	CEO, Head of Operational Excellence	1-day on-site plant tour	1 × 30, 1 × 90, 1 × 30

The interviews lasted from 90 to 120 min in length with one to three interview partners from different functions (e.g., manufacturing, R&D, strategy, business development, technology, product development) as well as hierarchy levels (e.g., CEO, COO, VP, head of business unit, project leader, R&D specialist, plant manager). The interviewees had different periods of employment, educational backgrounds, and career histories. A semi-structured interview guideline was prepared in advance and slightly refined by experienced researchers and industry experts within the course of data collection [68]. It contained guiding questions from eight areas: Use of digitalization, digitalization technology portfolio, strategy, and business model as well as the use of real-time data, digitalization product performance, employee integration, digitalization investments, and profitability.

Additionally, each interviewee could highlight the activity he rated most notable for his company's digitalization activities. The case reports were written directly after the interview to comply with the "24-h" rule [69]. We conducted the interviews until the researchers thought the information from different interviewees became repetitive [61].

We complemented the interviews with one-day plant tours. During the plant visits, three to eight representatives per case company were present in order to avoid single response bias and ensure data triangulation [62,70]. We documented impressions and observations during the tour to improve the consistency of the interviews and supplement the findings.

3.2.2. Printed and Quantitative Data

Additional documents and data such as company presentations, annual statements, marketing material, product lists, financial information, and confidential reports enhanced the interview outcomes. The latter documents were received exclusively from the case study companies for this research and comprised information about technology setup, supplier contracts, production information, organizational rules, and standards. The former documents stemmed from public websites.

3.2.3. Conference

All eight case companies were invited to a final conference to discuss and share their successful practices with experts from each other. Nine representatives from six companies took part in this workshop. Each participant prepared a presentation and a Q&A session with a summary of internal lessons learned and procedures. The other companies, as well as research experts, evaluated and discussed these presented approaches. Hence, the key-learnings of all participants from academia and industry across all study activities were summarized and aligned. The representatives concluded that the most significant aspects concerning the implementation of digitalization respective digital transformation were gathered and correctly reproduced. All participants agreed that the results are valid, widely replicable, and in the context of these cases, generalizable, which supports the

conclusion that future researchers studying the same phenomenon would generate similar results. External validity was also addressed through a one-day seminar (>20 companies), which the research team conducted to present the study results. Each participant found the conclusions by the research team to be meaningful. This supports the conclusion that the research results are reliable, valid, and generalizable to other similar companies.

3.3. Data Analysis

The most critical aspect of rigor in qualitative research is the data analysis process. To avoid research bias, we applied a coding process after the data collection was finished [65]. In the first step of the coding, we assigned descriptive codes to identify the first-level theme categories, such as drivers of digital transformation, barriers, managerial practices, and results/outcomes. Based on that, we developed codes in an iterative process within each of these main topics. We assigned four codes within the drivers for digital transformation: codes that describe the different impulses that foster a change (e.g., customer requirements, cost pressure). In the category barriers, we used 12 codes to describe the specific types that companies faced (e.g., budget restrictions, lack of capabilities). We assigned seven codes within the category of managerial practices (e.g., strategy approach, organization) to capture the practices that companies used to govern through the digital transformation. For the theme category of results/outcomes, we assigned codes to capture the impact on profitability by differentiating two further codes, such as productivity and new revenues. Moreover, we included additional researchers from the departments of the authors to audit our coding process and to discuss patterns in and possible propositions from the data. To increase reliability and to verify that the results are reproducible, we let a researcher do the coding again, who had not been involved in the research process and part of any interviews or workshops. Based on the codes, we began to develop a set of propositions to describe and identify the specific governance practices to facilitate a digital transformation in an industrial company. In the end of this iterative process, we defined four main managerial practices.

4. Results

Our research analysis aims at finding patterns of managerial practices within and between companies following the standards for rigorous case study research [71]. We took multiple case studies with companies from different industries inductively to reveal industry practices and to identify conspicuous characteristics. Therefore, we first conducted multiple case interviews to identify the explicit and implicit management practices deployed by each company.

With the completion of the within-case analyses, we started the cross-case analyses to compare and contrast the practices along with the managers' perceptions regarding their effectiveness. This step led to differences and similarities of the different implementation and managerial practices of the case companies.

4.1. Case Description

In the first analysis phase, we described and discussed each company separately. The focus was to identify:

1. Drivers for the digital transformation;
2. Challenges in the digital transformation process;
3. Needed competences and managerial practices used to overcome these challenges;
4. The outcome/results.

Besides this core information, the research team gathered and discussed further information about each company according to the interview guideline: industry and market characteristics, organization and strategic approach, process and product maturity, collaboration forms, data usage and management, IT systems, investments, as well as

productivity gains of the case companies. We state the effects on productivity in a purely qualitative way based on the interviews. Investments in digitalization include both investments in technologies as well as investments in people. The second part of Table 3 provides an overview of the case studies and is an extract of individual six-to-eight pages of case descriptions for each company. It shows distinctive commonalities and differences between the companies related to their managerial practices and how they treat change towards further digitalization.

Table 3. Case descriptions.

Industry	WPC	ASC	PPC	EMC	AGC	MFC	ABC	PTC
Dominance	↑	↗	↑	→	↑	→	→	↑
Growth	→	↗	↘	→	↑	→	↻	→
Market characteristics								
Product customization	↑	↗	→	→	↗	↓	↑	↘
Product life-cycle duration	→	↗	↑	→	→	→	↑	→
Organization								
Degree of centralization	↗	↗	→	↘	→	→	↘	→
Digitalization emphasis	↑	↑	↗	↗	→	↗	↓	↘
Barriers								
Budget restrictions	✓	X	X	X		X	X	
Time pressure		✓				X	X	✓
Shortage of manpower	X	X	X	✓	X	X	X	X
Lack of capabilities		X	X	✓	✓	X	X	✓
Expensive technologies		✓	X		✓	X	X	
Existing infrastructures restrictions		✓		X	X	✓	X	X
Technical feasibility		✓		X	✓	✓	✓	✓
Missing norms and standards	X	X		X		✓	X	X
IT security	X	X	X	✓	X	X	X	X
Lack of management commitment	✓	✓	X		✓	X	X	✓
Resistance of employees	✓	✓		✓	✓	✓	X	✓
Timing		✓	X		✓	✓	✓	
Strategic digitalization approach								
Top-down ↓/ bottom-up ↑	↓ and ↑	↓ and ↑	↓ and ↑	↓ and ↑	↓ and ↑	↑	↓	↓ and ↑
Growth emphasis	↗	↗	↑	↑	↗	↑	↗	↗
Production emphasis	↑	↗	↗	↗	↗	→	↘	↗
Collaboration with								
Customers	✓	✓	✓	✓	✓	✓		✓
Suppliers	✓	✓	✓	✓	✓	✓	✓	
research institutions		✓	✓	✓	✓	✓	✓	
Associations	✓	✓		✓	✓			
work councils				✓				
competitors			✓	✓				
Data usage and management								
Production data	A/P	A/P	A/P	A/P	A/P	P	P	P
Logistics data	A	A/P	P	A/P	P	A/P		A/P
Field data	P	A/P		A/P	A	A/P		
IT Systems								
Integration level	↑	↑	↑	↑	↘	↓	↑	↓
Mobile devices on shop-floor		✓	✓	✓	✓		✓	
Process and product maturity								
Digitally advanced products	✓	✓	✓	✓	✓		✓	✓

Digitally advanced processes	✓	✓	✓	✓	✓	✓
Effect on productivity						
Direct labor hours	↓		↓	↓	↘	↓
Raw material input	↓			↓		↓
Energy consumption		↓		↓	↓	
Machine hours			↘		↘	
Indirect labor hours	↓			↘		

WPC: Wood-Processing Company, ASC: Automation Solution Company, PPC: Precision Printing Company, EMC: Electronic Miniature Company, AGC: Automotive Gear Company, MFC: Mechanical Fastening Company, ABC: Advanced Building Company, PTC: Power Transformation Company. ↓: very low/strong decrease; ↘: low/decreasing; →: medium/stable; ↗: high/increasing; ↑: very high/strong increase. A: active; P: passive

4.2. Case Analysis

We discuss these crucial relations between the cases with the focus on managerial practices in detail in the next chapters along four main fields of topics.

4.2.1. Strategic Approaches

Most case companies, namely, WPC, ASC, PPC, EMC, AGC, and PTC, use a combined top-down and bottom-up approach. They make use of decentralized competencies in their units as well as of an overarching strategic vision by corporate management for all digitalization activities. This vision also includes inputs of middle management and experts. Top management supports and coordinates the companies’ activities regarding digital manufacturing and defines the appropriate parameters and strategic goals. They break down to targets for each daughter factory. The plant managers and their teams then define the actions and digitalization solutions necessary to reach their targets. Hence, digitalization use cases are initiated bottom-up and benefit from the daily operations knowledge of shop floor and lower management.

The case companies with a combined approach have high employee involvement and satisfaction, which simplifies their digital transformation through commitment across the entire firm and all hierarchical levels. Accordingly, the combined approach resulted in various beneficial outcomes for the companies. Bottom-up activities ensure documentation of ideas while top-down enforces the existing strategy and creates new strategic options. Top management coordinates the knowledge exchange of successful solutions between sites and sets standards regarding technologies and interfaces within the firm. All in all, top management draws the big picture, brings the bottom-up approaches together, and manages the conflicts resulting from the conflicting goals (i.e., ensure autonomy and set standards).

ABC and MFC are both unhappy with their approach. ABC applies only a top-down approach but without a clear digitalization strategy and coordination. The missing bottom-up approach leads to various obstacles. The employee’s commitment is quite low, as the management steers the organization, and the shop floor has fewer rights of co-determination. Thus, employees tend to resist change due to the uncertainty of future tasks and jobs. MFC, in contrast, relies on bottom-up initiatives only. This approach also leads to a struggling organization. As the top management is not involved in most decisions, only small or inexpensive solutions can be implemented that result in either limited benefits or in unfavorable outcomes, not initially intended by the top management. Despite these obstacles, local digitalization champions appeared. However, MFC cannot make use of these local champions, as there is limited internal knowledge exchange across sites and many internal attempts are redundant and not coordinated. Due to this research project, MFC, as well as ABC, will attempt to adapt their organizational approach to allow all hierarchal levels to be part of the digitalization discussions and implementation.

4.2.2. Collaborations

In general, business collaborations offer a possible platform for learning and experimental fields. This section shows the opportunities and benefits of active collaboration with key partners. For example, possible internal resistances against change and transformation get reduced, routines get challenged, and mutual learning, as well as development, promoted. We split the collaborations into two types: First, collaboration with the demand side of a company. The demand side includes customers but also other similar organizations such as competitors, which collaborate, for example, in a standardization committee. Second, collaboration with the supply side of a company, for example, with material suppliers but also other providers, such as consultancies and research institutions.

All case companies but ABC collaborate with external partners from the demand side. For them, collaboration with customers is vital for the implementation of measures that increase internal efficiency and add value for the customer. They implement visions, such as minimum lot sizes, faster delivery, traceability of products, or learning from data for predictive maintenance, only if customers value them. PPC, for example, developed remote service solutions in close cooperation with its customers, which reduced service time by more than 20% and are a commercial success. PPC also cooperates with leading competitors to increase the entrance barriers for new competitors. Together, they develop new standards and machine characteristics that are hard to imitate. MFC, as another example, sells more unique products and strengthens customers' loyalty by monitoring their data.

In contrast, ABC mentioned that they were not collaborating with customers. The missing collaboration led to product failures. Moreover, the products could not be sold on the market successfully. Thus, ABC is about to increase its customer collaborations.

Even more critical for the majority of case companies (except PTC) is the interaction with suppliers and technology providers. Together with them, these companies develop solutions to enhance their production. WPC, for example, enhanced the process of material handling and made it more efficient together with the supplier by using digital technologies. ASC increased productivity through a similar joint digital solution by new packaging and reduced efforts in the receiving department and storage.

For EMC and AGC, data management is the main collaboration point with suppliers and technology providers. Both decided which IT skills should remain internally and which competencies should be obtained externally with the help of core-competence and make-or-buy analysis. Both companies considered the analyses of data as their core competence and outsourced technical connection and storage technologies to external experts. Therefore, they focused their competencies and resources on crucial activities.

Additionally, WPC, PPC, ASC, and AGC are also cooperating extensively with research institutes or universities. Research on specific topics of digitalization supports these companies and offers new perspectives on the topics. The companies see research institutions as valuable partners because of their objectivity and their interdisciplinary knowledge.

In conclusion, in-depth collaboration with the supply side allows companies to broaden their resources through access to external expertise and spread risks for development expenditures over several partners. The mutual use of process and production data are crucial design features in cooperation. By implementing faster delivery and order processing or increased data transparency, companies and suppliers benefit equally. Hence, collaboration is crucial and leads to benefits such as compensating lacking competences, joint developments, and an integrated supply chain.

4.2.3. Cross-Functionality

All case companies use an integrated approach, which crosses functional borders and fosters working along the process. They see digitalization as an interdisciplinary concept

that requires expertise from different fields, such as R&D, manufacturing, and IT. AGC, for example, applies cross-functional teams over all functions in digitalization projects, such as IT, supply chain, logistics, R&D, and production. Therefore, it includes all employees into the digital transformation or change process. Thanks to a similar approach, MFC is today able to seamlessly process an incoming order through all departments with automatic steering of objects and processes.

ABC has changed its work organization and encouraged workers to perform interdisciplinary jobs to overcome departmental boundaries. In order to manage multiple technologies and provide an overarching strategic approach, PPC uses a technology roadmap. This tool links technologies with potential implementation plans and activities in each function, such as production or service.

The cases indicate that dedicated digitalization supporters typically occupy positions in top management (ASC, WPC), production (ABC, AGC), IT (EMC, PPC), or R&D (MFC), and manage interdisciplinary teams (WPC, ASC, AGC, PPC, and ABC).

Cross-functional integration is not only a matter of people working together. All case companies except MFC and PTC use integrated IT systems. These support the integrated digitalization process. One of the most significant past projects of WPC was the introduction of an improved Manufacturing Execution System (MES) in order to be able to control and monitor the complete manufacturing process and improve productivity. The system completely fulfilled its promises.

AGC created a software-backed corporate knowledge transfer unit to collect and distribute innovations, technological developments, and best practices. Therefore, it wanted to avoid redundancies and double functions. Through integrating R&D, production planning, and the IT department, ABC created an ecosystem for efficient processes.

In contrast, MFC still relies on isolated applications and wants to overcome them. PTC has similar problems but is already working on a company internal cloud solution.

4.2.4. Usage of Data

All case companies show that gathering comprehensive internal and external data is vital since data-driven improvements for both processes and products are reaching new levels. Further, the case companies expect that data might be a source of future competitive advantages, for example, concerning data-driven services. ASC, EMC, PPC, and MFC collect production and product information in real time. In contrast, ABC and PTC are usually not able to collect data in real time. However, they recognized that this slows their process improvements. PPC, for example, has a connection to 85% of the machines it sold. They report a vast amount of data every month, which builds the base for service contracts and internal process optimization at PPC. R&D, engineering, and quality department benefit from real user experiences and sophisticated feedback. Therefore, PPC combines previously isolated value stream activities such as product life cycle management, supply chain management, or customer relationship management.

ASC and EMC successfully collect and analyze data for clearly defined needs such as traceability, quality improvement, delivery speed improvement, increased flexibility, or other strategic reasons. They are the only companies in the sample that collect active and passive production, logistic, and field data to improve internal and transportation processes as well as product reliability in the field. ASC was able to improve complaints handling, especially the ones related to the misuse of their product. Consequently, claims were guaranteed and costs went down. Moreover, the collected field data are a valuable input for future product development. WPC and AGC created a roadmap to collect and analyze all necessary data within the next few years. Overall, digitalization provides both improvements in the production process as well as smart products and services for net business models.

4.2.5. Project Organization and Learning

The case companies apply many digitalization use cases and application examples. Through failures, they found that the identification of relevant use cases needs to be managed professionally and with a particular focus. All case companies, except MFC and PTC, perform well in this field. To avoid paper in production, EMC, for example, uses tablet computers instead of paper in its manufacturing processes. However, the IT and the financial department prevented the initiative for some time from implementation. In the first use case, costs exceeded the estimated expenditures and IT security was inadequate. However, some months after implementation, EMC was able to identify measurable benefits based on paper-free production.

Accordingly, PPC, ASC, and WPC implemented new technologies as soon as use cases promised success. Among them were robotics for automation, autonomous transport systems, and collaborative robots for reduced or more efficient employee workload. Continually re-challenging projects and use cases is a priority for ABC. It sees digitalization as an evolutionary approach and wants to learn from each project for the success of future ones. However, with some exceptions, all case companies state rather qualitative than quantitative improvements, seemingly because it is hard to calculate them.

At ASC, if a pilot turns out well, it is rolled out to the whole company to avoid redundancies. R&D, production, and IT evaluate and coordinate all projects and technologies systematically. AGC's factories, in contrast, are very autonomous regarding digitalization activities. Hence, the company established a central knowledge transfer and standardization unit.

MFC neglected the central tracking and coordination of its use cases. Hence, all their plants use different solutions. The lack of central coordination led to double work and undesired redundancies. Nowadays, they spend many resources to align all use cases and to roll out standardized solutions. PTC lacks knowledge and competences regarding possible use cases. Thus, they were not able to implement promising use cases, yet, and strive to close this gap.

5. Discussion

Our observations indicated that specific managerial practices and competences are required to cope with the barriers and to facilitate the digital transformation in industrial companies. Based on the introduced theoretical perspective, we linked the identified practices from the cases with the existing literature. Table 4 describes identified competencies and practices along with the foundational change theory of Kotter [38]. Based on the case study analysis, we derived our propositions and synthesized a model with four main managerial practices for digital transformation. Aggregated competencies are displayed in Table 5.

Table 4. Theoretical view on managerial competencies and practices of managers to guide digital transformation.

Theoretical Foundation (Based on Kotter 1996)	Barriers	Managerial Practices for Digital Transformation	Managerial Competencies for Digital Transformation	Propositions
Create a sense of urgency	No specific challenge identified	<ul style="list-style-type: none"> - Communicate and make the need for the digital transformation visible (e.g., importance of efficiency-increase, new business models endanger existing business, show how other companies were disrupted) 	<ul style="list-style-type: none"> - Strong communication skills to get employees on board, openness about challenges, facing the brutal facts 	PA
Build a guiding coalition	Variety of needed capabilities	<ul style="list-style-type: none"> - Select and group dedicated employees for digitalization 	<ul style="list-style-type: none"> - Digital natives and the experience for the implementation of new technologies - Understand what competencies are needed and missing in the firm 	
Form a strategic vision and initiatives	Variety of opportunities, uncertain ROI	<ul style="list-style-type: none"> - Set strategic vision through a combination of top-down and bottom-up approaches: reduce uncertainty and get employees involved as an active and constructive actor - Cut vision into smaller projects (e.g., specific data-based use case projects for the factory) 	<ul style="list-style-type: none"> - Understand and know the potential of digital technologies - Understand the link between digital technologies and strategic objectives of the firm, envision a new way of working - Know the impact of digital technologies on internal processes and organization - Experimental mindset and understand iterative approach 	
Enlist a volunteer army	Options of organizational forms	<ul style="list-style-type: none"> - Build a center of excellence or establish lead factory concepts with “digital natives” with people in the organization thinking and moving in the same direction - Build a process to achieve results by small iterative steps, stay as a manager closer 	<ul style="list-style-type: none"> - Different competencies are needed to form this group: digital natives, experienced managers for transformations, communication experts, experimentation skills motivating by plotting the future path, form strong alliance with partners by being open to new ideas and approaches 	
Enable action by removing barrier	Resistance of employees (e.g., job danger)	<ul style="list-style-type: none"> - Clarify the transformation rules upfront (e.g., define perspectives for employees) - Employees as an integral part of new digital solutions - Ensure Top Management commitment 	<ul style="list-style-type: none"> - Employees get familiar with digital technologies and learn how to make use of it 	

			<ul style="list-style-type: none"> - Learn the benefits and how to reinvent processes and communication, be open about the change including risks and opportunities - Stay on course even if difficulties and problems surface 	
Enable action by removing barrier	<p>Variety and interdependencies of digital technologies, existing infrastructures restrictions and technical feasibility</p>	<ul style="list-style-type: none"> - Generate a picture of new technologies (big data, cloud, etc.) and related fields of applications (e.g., smart manufacturing, smart products) - Cut vision into smaller projects (e.g., specific data-based use case projects for the factory) - Bring it into a logical order to sketch a road towards the vision 	<ul style="list-style-type: none"> - Understand the potential of digital technologies and their interdependencies (what are prerequisites?) - Get familiar with local requirements - Develop an understanding for the degree of freedom for digital solutions, standardization vs. individualization needs 	PA
	<p>Lack of capabilities, shortage of manpower</p>	<ul style="list-style-type: none"> - Foster collaboration with customers, suppliers, and external partners - Training of employees on new digital tools (communication, data sharing etc.) - Foster open innovation activities, define what data an enterprise can share (e.g., share data on platforms to develop innovative solutions) 	<ul style="list-style-type: none"> - Digital competencies, data analytics and IT - Knowing suitable use cases - Collaboration and understanding of potential partner network (ecosystem) 	PB
	<p>Organizational silos</p>	<ul style="list-style-type: none"> - Involve functions that contribute to the project with their implicit knowledge (e.g., employees that control a manufacturing process step—process knowledge) - Foster competences exchange between sites in the network when different competences are needed for use case implementation (e.g., experiences with new technologies and respective applications) 	<ul style="list-style-type: none"> - Forming interdisciplinary teams under one leadership or reduced number of managers, form new organization to start-up - Learn how to integrate digital tools to break up silos 	PC
	<p>Increasing decentralization reduces manageability</p>	<ul style="list-style-type: none"> - Foster decentralized activities and bring it back into the big context of the business development of the company (e.g., coordinate via the center of excellence) 	<ul style="list-style-type: none"> - Holistic management skills - Standardized monitoring and controlling of projects - Evaluation skills on scalability of digital use cases need to be controlled to decide on further investments 	

Enable action by removing barrier	Willingness to learn from and share mistakes	- Create a culture of testing and implementing (e.g., failing is allowed: adapt, reject, scale, and learn) - See data as the source for innovations, as an enabler	- Leadership team should empower employees to make decisions and experiments - Change leadership style from predict and control to experiment (self-control of teams, more degrees of freedom for teams) to accept risks and failures, foster a culture of feed-back and lesson learned	PD
	Risks of investments, uncertain ROI (Budget restrictions)	- Select smaller projects as playground - Set clear targets for the use cases and establish short-term control cycles (e.g., decisions about further continuation of use case projects)	- Experimentation skills, build a process to achieve results by small iterative steps, stay as a manager closer to the team (go to Gemba)	
Generate short-term wins	Uncertain ROI	- Communication of successful projects in the entire organization - Show multiple effects of technologies on processes, organization, products, and services	- Communication skills, communicate success regularly	PA
Sustain acceleration	Variety of prerequisites for local implementations	- Roll-out and scale of use cases in the entire company - Training of employees on new digital tools and new processes	- Understand local specification and needs - Standardization vs. Individualization, standardize only what brings benefits, encourage decentralize initiatives	PA
Institute change	Sustain new ways of working and behaviors	- Set the basis for the continuation of the new way of working with new management principles	- Understand and consider the needs of employees, change the organization to build change into the organization	PD

Table 5. Aggregated competencies.

Aggregated Competencies for Managers to Foster Digital Transformation
1. Visionary mindset
2. Digital literacy (connectivity, cloud, data, analytics...)
3. Experience for technological implementations in organizations
4. Understand the potential and impact of digital technologies (internally and externally)
5. Strong communication skills
6. Understand what competencies are missing internally
7. Ecosystem understanding—Collaboration willingness
8. Bridgebuilder, walls and silo breaker
9. Holistic management, monitoring and control of complex projects
10. Cooperative leadership style—from predict and control to self-control
11. Experimental mindset and co-creation
12. A sense for the balance of standardization vs. needed individualization
13. Endurance to stay course

Figure 2 presents the derived propositions from the case data synthesis of managerial competencies and managerial practices. Each proposition is relevant in the transformational journey to overcome digitalization barriers and achieve profitability. Below, each proposition is explicated in greater detail.

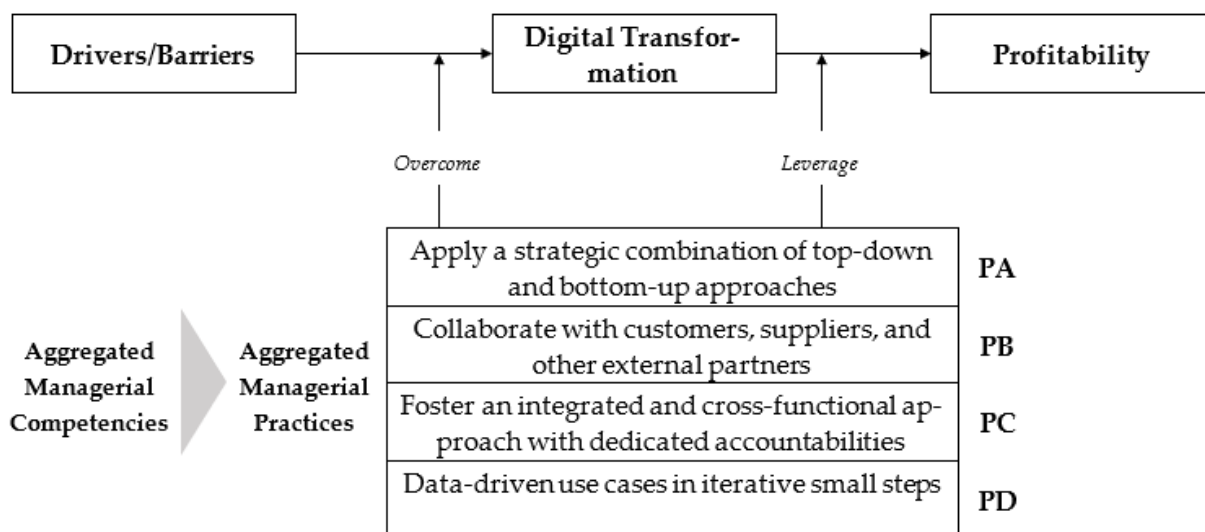


Figure 2. Transformation model.

Prop. 1 (PA): Apply a strategic combination of top-down and bottom-up approaches to facilitate digital transformation.

As all the cases reveal, the bottom-up approach is a meaningful aspect to enable digitalization. For digital transformations, the integration of employees from every hierarchical level as an active actor is important and drives innovation because higher degrees of multidisciplinary competencies are necessary since the digitalization affects all functions and areas of the company. Managers of the case companies PPC, AGC and MFC were especially driven by cost pressure to create the sense of urgency, following the bottom-up approach to increase productivity by implementing digital technologies. These observations are in line with the existing theory of emergent change [37,43] and the

findings from Womack et al. (1991), who emphasized that bottom-up is essential for continuous improvement, organizational learning, and employee involvement. Often there are lots of improvement potentials available, but these topics are not visible to Top Management. Only the involvement of the base allows for bringing these potentials to the surface [57].

A strong bottom-up process also limits the fear of change due to new technologies. Therefore, the focus is on bottom-up. Its importance is relevant and new to top management and is often overlooked [72]. Decentralization of activities needs to be fostered to create an intrinsic motivation to go in this direction.

Companies operating in a global supply chain and production networks have different technological prerequisites and face different challenges and opportunities at local sites. Therefore, digital transformations require differentiated implementations. “Industry 4.0 is innovative change management” (AGC). The peculiarity here is that it is not like a standardized recipe (e.g., Lean Production Philosophy) you can globally roll-out in a standardized way. In consequence, this leads to a higher variety of solutions and possible redundancies in companies. To address this challenge, companies need to foster local ideas and need to centrally consolidate and evaluate a potential global scaling to ensure manageability as observed in the companies WPC, ASC, AGC and MFC. By the combination of top-down and bottom-up approaches, companies can manage the global-local conflict (global standardized vs. individualized local solutions) that arise in the digital transformation. Innovations, which are developed locally, but relevant for the entire supply and production network, could be standardized and roll-out entirely. With this change approach, the application of digital technologies leads to an increase in efficiency or higher levels of profitability.

Prop. 2 (PB): Foster collaboration with customers, suppliers, and other external partners to facilitate digital transformations.

For the implementation of digital technologies in enterprises, the collaboration needs to be taken to another level. Although collaboration was important already in other transformations or in the daily operational business, for the digital transformation the meaning is even higher, especially for external collaborations (ecosystem paradigm) [73,74]. The collaboration pursues the aim to close internal capability gaps and to generate innovations. This is true for all the cases we observed.

Through the digitalization, the collaboration gets/requires a new aspect, “data” transparency. By sharing data of processes, usage, and performance to generate innovations, enterprises (suppliers, OEM) and even customers open the door to internal and confidential information (e.g., production data), which is somehow a prerequisite to drive innovations and to allow for a digital transformation. In the case companies (PPC, AGC), where customization and cost pressure are drivers for the transformation, extensive collaborations, especially with customers, suppliers and competitors, had been observed.

This new way and level of collaboration in digital transformations can be described with a “dilemma”, the sharing of data to generate innovations on the one side without losing control of the businesses (e.g., customer, business insights) on the other side. Companies need to be clear about what kind of data they want to share, what they expect from collaborations and what kind of role they have in other arising (digital) ecosystems [57]. If enterprises want to digitally transform, they need to handle even more collaborations and data streams and interfaces in the future. Other researchers agree and state that close cooperation with the customer supports the identification of specific solutions best [75,76].

Collaboration is also key due the fact that knowledge on new technologies is often not available in the companies. This open sharing with technology partners is key to be successful. By doing so, companies need to share a lot of confidential information (mainly data, business models and drives new strategy objectives). This is often a big hurdle, but if they are not changing the way of operating, they will not leverage the full potential of the technical knowledge of external partners for their benefit. Case companies that were

clear about the sharing of data, managed to develop new business models together with partners to generate new revenue streams.

Prop. 3 (PC): Foster decentralized activities in an integrated and cross-functional approach with dedicated accountabilities to facilitate digital transformation.

A digital transformation is not the digital illustration of the existing processes. It is about how to fundamentally rethink processes and to value creation products and services. To foster this thinking, it is required to combine implicit process knowledge (domain knowledge) together with different competencies from various functional areas, much more than in every other transformation. “You need a strong focus on project work in cross-functional, interdisciplinary and international teams—instead of working on closed departments in teams that don’t change over years” (EMC). Hierarchies and organization silos must be overcome though IT connects employees, machines, and products across business units [36], and data do not know any hierarchies.

Managers in the case companies that built new structures for these ways of working and collaboration (e.g., new rooms for creative work) and fostered decentralization of activities were able to overcome cross-functional barriers and employee resistance. “Employees are receiving higher level of responsibility and leaders have more time to focus on their original task: leading” (PTC). As the cases reveal, this contributed to the achievement of higher levels of profitability.

To enable these effective cross-functional collaborations, managers need to build up more basic IT knowledge widely in the organization to find a common language in these project teams full of different competencies and levels. Since IT has become an essential function, it is necessary to improve IT expertise in the executive departments [77] as well as to increase business knowledge in the IT department [78]. “The more we move towards Industry 4.0, the more important will be to really have process and system know-how on all levels of the company [...]. I think we need to have specially qualified people with this know-how to keep a production running with Industry 4.0” (PPC).

Prop. 4 (PD): Data-driven use cases in iterative small steps to facilitate digital transformation.

Use cases in the digitalization are related to data. This requires a new mindset to data as the fuel of the future. Often, managers in industrial companies are organized and led by a “hardware thinking”, the value of data is underestimated, and data do not get the required focus. Data transparency is new to organizations and will revolutionize ways of working and decision-making in manufacturing.

Based on this increasing transparency of processes and performance by data, managers need to create a culture of testing and learning in interdisciplinary projects. To reduce the economic uncertainty of the added value of data analytics project, we observed that case companies fostered a use-case-based approach to test new technologies and gain experience of potential impacts [23]. Therefore, companies did not stop innovative ideas because of IT infrastructural constraints. For industrial companies with long-lasting heritage, this start-up mindset is new. By setting clear targets and short iterative cycles in use case projects, the financial risks can be reduced. “It needs a lot of communication and also leaders need the courage to stop projects without any benefit” (MFC)

Especially in industrial companies, the data are often available, but not transparent to the whole company and often not interconnected. We are here speaking of internal as well as customer data. This integrated view to companies is essential. As the extensive usage of different types of data of our case companies revealed, it enables the company to achieve higher levels of profitability. Managers need to drive this transparency across functions and hierarchical levels and have to stay the course when problems arise.

6. Conclusions

This research makes several contributions to the role of managers in digital transformations of manufacturing companies. The first contribution is the definition of a digital transformation and its related particularities compared to other transformations in

industrial companies. The second contribution comes along with the insights generated from the case studies, where we uncovered core barriers and derived competences and managerial practices to facilitate digital transformations. A combination of a top-down and bottom-up approach in the strategy definition, together with a decentral responsibility in implementation, was identified as a crucial practice to overcome barriers such as employee resistance. To overcome capability constraints and benefit from external ideas, companies should rethink their attitude towards data sharing. Collaboration with suppliers, customers, technology providers, and research institutes in an open innovation-like manner will facilitate digital transformation. Use-case-organized projects, encompassing definition, data collection, handling, analysis, scaling, rejection, or adjustment, are crucial for organizational learning.

The underlying research methodology limits generalizability and replicability. Our case studies represent larger companies; hence, small and medium-sized companies require further research. Moreover, we expect that collaborations in terms of open innovation will be even more promising, as the internal resource capacity is limited in smaller companies. Future research should provide patterns of data models that help companies to derive suitable open innovation data strategies. Another aspect of future research could focus on the dynamic aspects of the transformation in longitudinal analysis, as markets and technologies are continuously changing.

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