Barriers to Digital Transformation in Manufacturing: Development of a Research Agenda

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Abstract

Digital Transformation (DT) is expected to have a massive impact on different branches and even societies. In the manufacturing industry, value creation processes change as information and communication technologies merge with production processes. The change may enable efficiency gains and new business models. However, many firms still struggle to drive their digital transformation forward. To understand the barriers which hinder or even stop DT is essential for the successful transformation. Our study aims at identifying the barriers on the basis of 46 expert interviews. These practical insights are further used to develop a research agenda. To determine the research gaps, we conduct a literature review on the topics mentioned by the interviewees. Thus, we contribute by first of all identifying major barriers which can support firms by reflecting their DT. Moreover, we give an outlook for researchers on possible future exploration. So, we bring together perspectives from research and practice.

1. Motivation

The increasing digitalization massively shapes the actual and future industry and industrial processes [1]. The implications of technology and the change in the way of working in manufacturing are known under different terms like the "second machine age" [2]. It describes the opportunities by "combinations of information, computing, communication, and connectivity technologies" [3, p. 471] (like cyber-physical production systems and the Internet of Things). The core of digital transformation (DT) in manufacturing is the overall digitalization and cross-linking of the value creation process. Information and communication technologies join and change production processes. So, to transform means to "fundamentally alter traditional ways of doing business by redefining business processes and relationships" [4, p. 651]. The use of information technologies (IT) changes workflows dramatically [5].

For a successful DT, these trends must be taken up by the enterprises' strategy [6], [7]. DT implies new ways of combining products and services [8]. New business models such as digital platforms emerge [9], [10]. Competitive advantages can be achieved by using real-time data to monitor and optimize processes [11]. Enterprises expect major long-term gains in efficiency and productivity by applying DT [12]. The improved working conditions also affect employees, their roles, skills and job descriptions [8], [13].

Besides changes in production, the communication and interaction with customers and suppliers must lift up to new and modified contents and services [14]. Customers are getting more integrated into value creation processes [15], [16], e.g., via digital platforms [9], [17]. They benefit from new products and services which improve the quality of their life [12]. The ability of real-time tracing functionalities also influences the interaction with suppliers [18]. In sum, DT affects people, processes, and products on all levels [19].

However, these (desired) alterations are also linked to risks [6]. Many firms still struggle to realize transformation potential due to different barriers [20]. The development, implementation, and diffusion of new digitalized processes face many complications [21]. Especially firms from the manufacturing industry struggle with new technologies compared to more agile sectors like entertainment or IT [22]. Less innovative firms also tend to underestimate the effort to push innovation [23]. Companies need to be able to reflect these challenges. Otherwise, barriers can hinder the realization of DT or even lead to a complete failure. Although barriers research is already a topic in related areas like innovation management, recent findings cover only partly the field of DT research. Lists of barriers in specific contexts already exist [22], [24]. However, these are all bound to specific technologies. For our research, we follow a more holistic view from a manufacturing perspective. Research on barriers is

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less common than research on success [23], [25]. Critical success factors are defined as "those few things that must go well to ensure success" [26, p. 17]. We define barriers to DT as the absence of success as *those few things that can hinder or stop the successful implementation of DT*. In accordance with the creativity technique called thinking in worst cases, it is essential to understand a negative situation in order to evaluate potential risks [27]. In this case, understanding the nature of barriers, their roots and stakeholders is important to be able to counteract.

Our study aims at (1) the identification and description of key-barriers to DT in manufacturing and (2) the deduction of an agenda of questions to be answered by practitioners and researchers in order to defeat the obstacles. On the base 46 expert interviews, we will detect and describe current barriers from a merged holistic view. Furthermore, we use the identified barriers to formulate keywords for the deduction of the research agenda. Researchers can profit from the distinct description of the barriers to DT. Future findings can easily be aligned to actual and further studies. Practitioners from industry can use the results to understand and detect obstacles of DT as well as deduce action plans for a successful transformation.

In the next chapter, we will describe our research approach. The 2 phases of the study are presented one by one: 1. by explaining the method used during the phase and 2. by pointing out the results. Finally, this paper describes limitations and gives an outlook.

2. Research approach

It is the goal of the study to combine perceptions and actual problems of practitioners with recent studies to trigger the reciprocal exchange between research and practical experience. As there is a lot of conceptual research about the future potentials of DT [3], [28], [29] rather than analyses based on real data from enterprises [20], we expect to gain a common understanding of major barriers to DT. Furthermore, we will clarify the need for research to overcome the barriers to DT for enterprises.

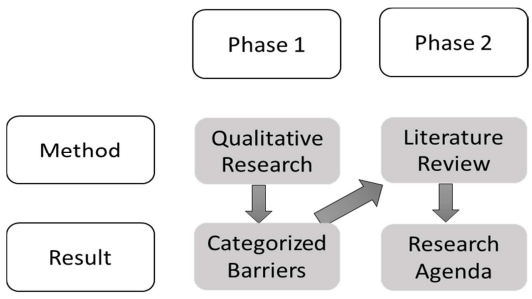

Figure 1. Research approach

Our research consists of two sequential phases (see figure 1). Phase one is marked by qualitative research, based on interviews with practitioners. As a result, we deduce major barriers to DT from the qualitative data and categorize them (practical perspective). In the following phase two, we use the findings from the first phase to develop a system of keywords for a literature review (research perspective) that mirror the significant fields of barriers deduced. After the intense literature study of the selected fields, we develop a comprehensive research agenda (multiple perspectives).

3. Phase I – Deduction of barriers to DT in manufacturing

Which factors disturb the digital transformation process? Who is affected and which implications do occur? There is only little specific research regarding the nature of barriers to DT. Following a qualitative approach, we aim to understand "what is going on in the minds of the participants [and what are their] views, thoughts, feelings, intentions, and experiences?" [30, p. 33]

3.1. Method phase I - Qualitative research

Semi-structured interviews with experts from manufacturing companies were conducted to identify major barriers. We carefully arranged the sample with a clear focus on the interviewee`s experience and state of DT of the enterprise. The interviewees were identified mainly by calls in social network groups dealing with DT. Interested conversation partners contacted us directly and received the project information and interview questions. So, the potential participants could in the first step evaluate themselves as possible interview partners. Afterward, we gathered information about current projects in the companies. If the projects had a significant impact on the value creation process of the firm, the interviews were conducted. Data from 30 participants were gathered in a first round. To check theoretical saturation [31], we collected data from 16 more participants. As no further impulses could be observed, we assessed the data set as useful for our purposes. We preceded the 46 interviews in 31 different enterprises in various (manufacturing) industries. The dominant industries were automotive (7 companies) (abbreviations Au1-Au7) with mostly original equipment manufacturers and agriculture (8 companies) (AC1-AC8) with agricultural machinery manufacturers. Moreover, we spoke to employees of 3 firms from the plastics industry (P1-P3), 3 firms from the steels industry (SI1-SI3), 3 service providers for

manufacturing companies (S1-S3), 3 consultants (C1-C3) and 4 other manufacturing companies (OM1-OM4). Most interviewees try to digitalize their production processes and work on the vertical integration. Some also offer products for this integration or consult on this topic. In sum, we chose a well-mixed sample including different roles and a variety of industries to get a broad picture from different perspectives. According to Yin [32], variations are helpful to collect a broad range of possible impressions within the data. We talked to people from the executive boards, managers, workers, and consultants to gain multi-level views of the barriers occurring to DT. Most of the enterprises already implemented digital technologies successfully or/and were involved in digitalizing their processes and products.

All interviews were recorded, transcribed and translated for research purposes. The interviews consisted of three major parts. Each of the parts has one primary focus and several follow-up questions [33]:

(1) introduction of the interviewee and description of occurred changes in the companies' processes due to DT (e.g., How did you start your DT? Which technologies are in use already? What else are you planning?);

(2) free narration of the actual situation of the digital transformation in general and DT barriers (e.g., How do new technologies change the way of working? What eases/ enables the use of new technologies? Which other changes were expected/ hoped for? Why did these not happen yet? Which are the major barriers? Do you perceive inhibitions regarding [for example] more collaboration/ agile working?);

(3) subsumed report of three major barriers to digital transformation.

The follow-up questions reflect characteristics from the DT definition. If participants did not talk about specific topics, the interviewer used the characteristics to phrase follow-up questions.

As we define barriers as those few things that can hinder or stop DT, we openly coded the third part of the interviews. The interviewees were asked to name three major barriers to DT. By this, we were able to reduce the complexity down to the main problems our interviewees see. Many of the subsuming statements contained not much more than a word. For longer statements, we assigned codes to the data. We iteratively revised and discussed the barriers within the research team. For the discussion and deeper understanding of barriers, the free-narration part of the interviews was analyzed by a coding process of relevant statements (using the barriers identified before). These were useful because the interviewees explained their concerns in detail. Examples of these statements can be found in the next chapter to explain the identified barriers. All authors were permanently involved in the research process of data generation and analysis. This led to a repetitive induction and discussion of concepts [34].

3.2. Results phase I - Identification of barriers

We identified several barriers. To reduce the complexity, we aligned the findings into five different categories that mirror the primary fields of attention of the interviewees and the areas in which the problems are noticeable (see table 1). The categories adhere to a socio-technical perspective [21], [35].

Table 1. Major barriers to DT

Barrier Scope	Code
Missing skills	IT knowledge
	information about and decision on technologies
	process knowledge
Technical barriers	dependency on other technologies
	security (data exchange)
	current infrastructure
Individual barriers	fear of data loss of control
	fear of transparency /acceptance
	fear of job loss
Organizational and cultural barriers	keeping traditional roles/principles
	no clear vision/ strategy
	resistance to cultural change / mistake culture
	risk aversion
	lack of financial resources
	lack of time
Environmental barriers	lack of standards
	lack of laws

Most of the interviewees mentioned **missing skills**. The focus here is on IT knowledge as information and communication technologies are more and more integrated into production processes. “Especially mechanical engineering companies are missing software- and IT knowledge.” (OM1)[1] They report a lack of “necessary competencies in informatics” (Au5) and “technological shortcomings” (AC2). Moreover, process knowledge is becoming more important because DT cannot be successful “if you implement the new technology without questioning your processes.” (AC7) Besides these more specific skills,

[1] Abbreviations for case companies were presented in section 3.1.

companies also do not know “which possibilities they have [with digital technologies].” (Au7) “The second topic is the lack of transparency regarding things which are already possible today or the huge range of technologies.” (Au1) “We also need to change our education system […] because we need special skills in the future.” (SI1)

Technical barriers show that the use of single technologies is not enough to be successful because these are dependent on other technologies like “[…] mobile data. No matter if this affects the internal infrastructure or the infrastructure outside.” (OM5) Moreover, “data security” (OM1, SI3) is mentioned as companies are worried about “hacker attacks” (OM2). This is especially relevant because of an increasing exchange of information. “Security in the meaning of exchanging information with customers and suppliers.” (P3) So, theft of market relevant information by competitors is becoming more likely. Moreover, hackers could shut down entire factories because the machines are connected via the internet. The current infrastructure was also mentioned as one of the three major barriers. “Especially if you have machines that are a bit older, the conversion is not worth it.” (AC8)

One of the most mentioned topics implies fears and acceptance problems of **individuals**, like “skepticism of customers” (OM3, Au6) regarding changes or missing “acceptance of people” (OM1, AC2, OM5) in general. This impedes the work as fears are often “diffuse” (Au5) and thus hard to handle. The interviewees report fears they perceive. “To be too transparent and connected.” (C2) “We have a lot of company-related and personal data […] This means: we could theoretically check why colleague A produced more than colleague B. This is a huge problem with our workers' council." (Au1) So, the transparency regarding performance could lead to more monitoring of work. “People dislike the connection and ask themselves: what happens to my data.” (C2) This impacts users inside the company but also customers who use connected devices. These devices are mainly used in agriculture, where collected data are used to monitor and control the processing of farmers' goods. Finally, the loss of jobs is a discussed topic. “Many think that the digitalization means a loss of their jobs.” (AC8) Although the job loss was mentioned as an actual fear, many interviewees believe that in most cases jobs will rather alter than vanish. "Automation technology always means that workplaces will change. […] We try to balance efficiency gains through growth and new products. So, in the end, those working places do not disappear but change." (OM1)

From the **organizational perspective, cultural barriers,** like keeping up with traditional roles, principles or working conditions, hampers the DT. "People who say, we also did it this way before, and it worked" (AC4) is a typical statement regarding innovations. "From a market perspective it is the keeping up to proven [methods] or self-developed [technologies]. You need the courage to rethink your business model." (Au5) The interviewees lament a "missing of cultural change" (Au5) and state it is a problem "if, in the end, you just don´t know where to go and how to put it into practice.” (C2) Moreover, enterprises must develop a culture of mistakes in which pilot projects are a part of a trial-and-error method. “Working more agile. [..] Of course making mistakes, accept mistakes and forgive mistakes is important.” (SI1) Especially in traditional branches like the steel industry, implementing changes is difficult.

Finally, we identified **environmental barriers**. The interviewees mention a “lack of standards” (OM2, OM3, Au5). “We need to agree on standards how to exchange the information. I cannot tell someone, I need this format and tell the next one another. This will not work.” (Au5) The interfaces to suppliers in the automotive industry were an important topic for all respondents from this industry. In particular, smaller providers could suffer and be left behind. Moreover, legal foundations that cover the transnational digital legal space are needed. “There are legal problems. Maybe you need the contract processing done by the technologies.” (OM2) The whole “works agreements [represent a barrier and have] extended the project duration” (Au1). Traditional ways can hamper the implementation of prototypes and the new way of working.

Interviewees from the automotive sector mention most problems in the field of technical and organizational barriers. Environmental threats are predominantly regarded in the service industries for the manufacturing sector. All barriers identified lead to either one of three different reactions. The interviewees sense the feeling of (a) missing something (e.g., support, training, resources), (b) fear (the new development) or (c) react with resistance to change against the implications of DT.

All barriers are distinct but mutually influence each other. For example, the lack of standards and laws leads to fear of losing data which can impact the cultural change and the risk aversion of the company.

4. Phase II - Deduction of a research agenda

We use our findings as a guideline for a structured literature review. To the best of our knowledge, there is recently no current stream that deals with barriers to DT. Thus, we collected barriers based on the

perceptions of the interviewees and combined these with actual research within these subfields. This is a merge of *what people sense* and how *does research deal* with these barriers. This second phase aims at detecting what is actually done and what still needs attention in research to overcome these barriers.

4.1. Method phase II - Literature review

Literature reviews are an established method to discover what other researchers have achieved. “Even more importantly, it allows them to perform incremental research by building on what other researchers have done” [36]. We developed the search terms for the review of recent literature on the base of the findings from the barriers named by the interviewees. According to the identified fields of barriers, we deduced a set of relevant buzzwords combining the research streams: digital transformation and barriers to DT research. We enrich the field of “digital transformation” research with similar concepts with a focus on manufacturing. Therefore, we used the terms "digitization", "Industry 4.0" and “smart factory”. These were combined with terms deduced from the barriers. Table 2 gives an overview of the deduced search-terms used.

Table 2. Deduced keywords related to barriers

Field	Keywords
Missing skills	education, skills, worker, employee, career, job growth, human resource
Technical barriers	interdependency, security, safety, interface, integration
Individual barriers	acceptance, TAM, adoption, transparency, fears, job loss, threads, dark side
Organizational and cultural barriers	organization, strategy, change resistance, inertia, culture, mistakes, barriers, risk, investment
Environmental barriers	standards, laws

We used ProQuest as a relevant database for IS research including many of the most important journals [37]. The different compositions of terms were searched in title, keywords or abstracts by using the field ‘topic’. We conducted the search by May/June 2018 and limited the searching period to the last three years (2015-2018). We consider this brief period to be valuable for this study, as we aim at insights about current knowledge. To stay focused on the management and IS perspective, we restricted the research areas and excluded research from roughly related fields like e-health, library management or e-government. We excluded articles not written in English. We identified 260 research papers which were analyzed. The dominant publication organs were the MIT Sloan Management Review (13 articles) and the International Journal of Production Research (8 Articles). Many contributions appeared in more than one research field. We take this as a proof of the strong intercorrelation within the identified fields as they all belong to the socio-technical aspects of software use [21], [35]. In a second step, we went through the articles and dismissed those without relation to our major fields of barriers. We additionally conducted forward and backward search and complemented the results by literature from the barriers to innovation research. Significant research contributions were selected to deduce the research agenda. As it was not our aim to give a most exhaustive overview of the research fields, we will present the major articles identified in the next chapter. We also focus on the articles which already identified research gaps to build the agenda on these results.

4.2. Results phase II - Research agenda for DT

The developed research agenda orients on the dimensions used before (missing skills, technical, individual, organizational and environmental barriers). A table with the identified topics (T.) and research questions is presented for each dimension.

Missing skills are a central barrier to DT. On an organizational level, companies have first of all to know, identify and choose fitting technologies for their business from diverse fields. A digital agenda can help to align the technical change with the strategy [20]. On an individual skill level, schools and universities play a significant role. To train the learners properly, the education of teachers and the integration of useful tools in the classes are critical [38]. New opportunities for the design of teaching arise. Everybody has the opportunity to educate oneself further by using online offers [39], [40]. Massive Online Open Courses (MOOCs), for example, offer new potential. Still, there are deficiencies regarding the quality assessment of these offers [41]. E-learning is also becoming more important in education at the workplace [42]. This way of teaching can be one answer to the rapidly changing needs for technical education. Collaborations between human recourses (HR) and universities should be fostered [43]. Technical skills in areas like operations management, and product-service innovation management need to be (further) developed [44]. Digital guidelines in the sense of compliance agreements may reduce the risks that come up with the

increasing interaction [45]. A general categorization of skills and best practices how to react and teach these in time are still missing.

Table 3. Research agenda on missing skills

T.	Examples of research questions
Schools and universities	How can IT skills be trained at school? Which impacts (positive and negative) do result from this? What is the future role of schools for lifelong and immediate learning? How can digital opportunities be used for education and fast-changing needs?
Forms of education	How do organizations and individuals evaluate the quality of MOOCs and find decent offers? Which factors foster collaboration between universities and companies in education?
Reali-zation	How can skills be categorized, so that they become useful to develop curricula? How can missing skills be identified by time and taught immediately?
Strategic embedding	Which steps are necessary for firms to identify appropriate technologies? How could compliance agreements minimize risks?

The field of **technical barriers,** investigated in the context of DT, is very diverse. As our interviewees state, wireless networks are considered as success factors for DT. Topics like communication protocols and dynamic topologies are identified as crucial future research [46]. This will foster the integration of technologies and machines. More approaches dealing with the interplay of many different technologies could be promising for research and practice. Regarding interfaces, the rapid emergence of open APIs is investigated [47]. A critical discussion of security vs. openness is ongoing [48]. Interoperability has to be assured, and authorization, as well as authentication issues, need to be managed [49].

Table 4. Research agenda on technical barriers

T.	Examples of research questions
Security	Which new security issues come up by implementing higher vertical integration? How can interoperability be assured?
Inter-faces	What are the impacts of open API´s? Can open API´s lead to dynamic capabilities and strengthen competitiveness?
Wireless networks	Do requirements on communication protocols change? How can uniform identification and authentication be ensured and controlled?

In the field of **individual barriers,** we summarize the fears of employees that occur by the uncertainty in the field of DT [50]. DT is often regarded as a threat [19], [51]. Calitz et al. [52] prove that this fearfulness is not limited to the western world. Barriers can only be overcome if one not only looks at the symptoms but also recognizes the causes [53]. The research draws attention to cultural differences in human-robot interaction [54] and asks to include cultural values to improve DT success [55]. Socially acceptable solutions have to be developed [7], [29] to overcome the worries of job loss [56], transparency [44], [57] and overstraining, as well as to increase the personal acceptance of DT technologies. Some authors suggest the integration of change management, for example by using change agents [58], [59]. To involve employees and provide a culture of innovation is critical [60]. We assume there is a common understanding regarding individual barriers to DT. Overcoming barriers by focusing on lowering the resistance to change is a critical point [61]. On a general level, researchers already know what should be done [44], [62]. However, there are only limited findings of existing best practices on how to deal with acceptance problems and prepare employees, e.g., by expedient training. We draw attention towards the question of how the future workplace will look like.

Table 5. Research on individual barriers

T.	Examples of research questions
Fear and acceptance	Which factors foster the acceptance and lower the uncertainty of DT? Which tools and methods are useful to integrate employees in change processes? What is the role of change agents?
Training	How can HR develop methods for lifelong training? What will the training of the future look like to make it easier to get used to arising technologies?
Workp-laces	How can future workplaces be designed? How can human-robot interaction be designed in the sense of a trusting cooperation?

Within the field **culture and organization** research is done on the effects of digital transformation on organizations but also markets. First approaches to measure the impact on organizational performance [63] came up, whereby more general approaches are still missing. As DT leads to higher integration of customers [15] and collaborations between companies [7], impacts and necessary conditions need to be investigated. Roles play an essential role to harness the potential benefits provided. For example, the role of the chief information officer (CIO) is discussed. DT is not only the goal of the CIO but needs the attention of the whole management board [64]. Others suggest implementing a new role - the chief data officer (CDO) to focus more on opportunities of collecting and using data [65]. A clear job description and the organizational integration of the role, measured by its responsibility, are necessary. This may help to minimize the risk that comes up by changes. Still, responsibilities and thus strategic impacts are unclear. Furthermore, barriers such as a lack of financial resources and a lack of time are regarded as a somewhat practical problem [66]. Resolving these barriers is also recognized as very complicated and thus an obstacle for firms [67].

Table 6. Research on organizational barriers

T.	Examples of research questions
Collaboration	Which kinds of collaboration will arise considering technical, social and legal aspects? How do new roles of customer arising within DT look like?
Role of CIO/CDO	What is the effect of the CIO/CDI regarding best practices and strategic alignment of DT? Which responsibilities do the CIO/CDO need to be given? Do conflicts with other management roles occur? Who is responsible for the culture following and fostering the technical change?
Performance	What is the impact of DT regarding the organizational performance?

The **environmental** barriers also play a central role. In comparative case research regarding the use of digital twin technologies, Rodič [68] states: especially larger enterprises suffer from a lack of technical standards and interfaces [69]. More interdisciplinary cooperation between research and industry is motivated [68], [70]. The definition and application of standards could lead to safety improvements [52], [54]. Others see the threat by giving access to the own database when common interfaces are used [10], [17], [71]. Creating standards or following existing ones [6] is a question of strategic orientation. The role of open standards is linked to the discussion about property rights in a digital world [69], [71]. Furthermore, new ways of work (e.g., crowd working) need a new judicial background [72]. International cooperation focusing on common laws in the field of digital transformation is not yet in focus.

Table 7. Research on environmental barriers

T.	Examples of research questions
Laws	What is the future role of legacy, law, and governments in a digitally transformed world? Where will property jurisdiction regarding data take place? Who owns data rights?
Standards	Who is responsible for the development, implementation and quality management of DT standards?

The summary of Tables 3-7 represents the research agenda. The agenda combines what the interviewees perceive as a barrier to DT and where the research needs to increase or offers no reply yet. Though we followed the classification shown before, we request more research that combines different scientific disciplines as a cross-fertilize network.

5. Conclusion and outlook

We analyzed barriers towards the digitalization of enterprises in manufacturing. Any barrier in the field of DT leads to a slow down or complete termination of the digital change in enterprises. The results of this study rely on the base of a qualitative analysis of 46 in-depth interviews in combination with detailed literature research. We gained several significant barriers to DT. The identified barriers are grouped into individual, organizational, environmental and technical barriers as well as a lack of skills. These fields are all closely related which can also be learned from the socio-technical approach [35]. Our findings from the literature research prove the mutual interrelation. Research approaches actually name the fields of action, but the integrating view is still outstanding. There is, for example, a declared need for better education and skill training (individual) to improve the digital change management (acceptance, organization), but we could not identify a trainers' skill profile gained from best practices.

Though we carefully conducted this research, there are limitations to our work. The classification into the

five research fields was a result of discussions of the authors. Maybe other fields could be identified when looking at different companies implementing DT. We see the fields as a guiding start for more research on barriers to DT. Moreover, it could be of great value to combine the findings of this study with case study research focusing on the overcoming of barriers and the development of best practices. The research agenda was developed by identifying research in the different fields. Thus, this study is also limited to the articles found. As DT is a prominent topic, we only searched for articles published within the last three years. However, there is no guarantee that research projects have already started trying to answer these questions. The agenda is nevertheless useful to guide researchers to look for challenges which actually occur in practice at the moment.

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