



Road to digital manufacturing – A longitudinal case-based analysis

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Abstract

Purpose: Our main objective is to examine the resource alteration underlying the digital manufacturing transformation. We rely on the adaptation aspect of dynamic capabilities (DC) theory and our analysis shows how and why a factory adapts its resources and capabilities during digital transformation.

Methodology: To grasp the change we apply the longitudinal case-study method within a revelatory case setting. The digital transformation is detailed from the perspective of a subsidiary that has played a key role in the division's digital transformation.

Findings: Analysing the revealed four stages of the transformation through the lenses of the DC components of adaptation (sensing capability, absorptive capacity, integrative capability, relational capability) our study suggests a sequence with unbalanced characteristics. Each stage starts with sensing capability, each component appears during each stage and each stage is dominated by a different component. Relying on the path dependency concept, we also present that the interplay between lean as an old resource stock and digital manufacturing as a new resource stock is rather a necessity, especially at the beginning of the transformation (at a corporation that pursues lean for years).

Practical implications: Digital strategy development is rather an intermediate element of the transformation, since committed personnel (or maybe their network) starts bottom-up and coordinate initiatives as they sense the opportunities in the environment. Top managers should rely on their accumulated knowledge and involve them into the transfer coalition in the top-down phase of digitalisation. Our case also underlines that starting to experiment with novel technologies requires a solid (and usually expensive) technological and human basis. Finally, process improvement focused developments at a high performing factory might be just enough to deal with ever demanding customer expectations.

Originality/value: Our study is among the firsts in Operations Management that relies on the DC theory to follow up the digital transformation of a factory. A further valuable contribution that the adaptation process is examined in a longitudinal case study.

Keywords: Industry 4.0, digitalisation, case study, automotive industry

1. Introduction

Operations Management (OM) has become noisy with digitalisation related concepts like smart manufacturing or Industry 4.0 (I4.0). The most widespread cross-sectional empirical (quantitative) research approach in OM underlines that more and more plants gain digital experience and that plants can expect improvements in operations measures (Behrendt et al., 2017; Dalenogare et al., 2018; López-Gómez et al., 2018; Martin, et al., 2018; Tortorella, et al., 2019). Still, at the beginning of the digital manufacturing turnaround, this positive performance impact narrative could boost the deployment of digital technologies. However, these studies contribute little to the exploration of how the transformation process looks like or how it is managed at all.

To guide the digital transformation conscious and deliberate organization-wide efforts are detailed by frameworks, roadmaps and strategies (Ghobakhloo, 2018). In line with these rather theoretical considerations, the maturity models (Viharos et al., 2017; Cordeiro, 2019) emphasize a step-by-step accumulation process. Unfortunately, the micro-mechanisms of the transformation remain hidden.

This study details the process underlying the digital transformation at the factory level. We seize the opportunity that we do live in a unique laboratory context and can follow up the birth of a digital factory in 'real-time'. According to the methodological recommendations, we apply the case study method for this newly emerging phenomenon (Eisenhardt, 1989; Voss, et al., 2002). To grasp the changes we develop a longitudinal case (Laaksonen and Peltoniemi, 2018) by analyzing an approximately 5-years long organization-wide digital transformation at a factory of a leading multinational automotive supplier.

Available works related to the digital manufacturing usually dismiss a solid theoretical basis. We decided to contribute to the discourse surrounding I4.0 by applying the dynamic capabilities (DC) theory (Teece et al., 1997). DC theory focuses on the adaptation of an organization to the changing environment and examines how by this adaptation the firm

purposefully modify its resource base. Relying on this powerful theory *our paper aims to examine how and why a factory adapts its resources and capabilities during the digital transformation.*

The paper first discusses the key principles of the digital economy and its appearance in an industrial context. Our work proposes a maturity-based structure for new technologies. Then the research framework is explained. The next sections introduce the case factory and its digital journey. After describing the stages of the digital transformation they are examined through the lens of the framework. Since DC theory is about modifying resources and capabilities we can also *contribute to the debate on the relationship between Industry 4.0 as a new stock of resources and lean as an older stock of resources* (Buer et al., 2018). Our concluding remarks touch upon the managerial implications. The paper closes with potential research topics.

2. Digital manufacturing

2.1 Digital manufacturing in the digital economy

We consider Industry 4.0 as the deployment of the 4th Industrial Revolution's (IR) technologies in the manufacturing sector. Industry 4.0 can be linked to all types of innovation, so it may go beyond production (even in German high-tech strategy (Die neue Hightech-Strategie Innovationen für Deutschland, 2014)). We define digital or smart manufacturing as an adaptation of the available new technological solutions to the production system (Frank et al., 2019). We acknowledge that in professional, and even in academic life, smart manufacturing is often used as a synonym for I4.0, although it limits the scope of I4.0, which e.g. embraces smart products as well.

The appearance of a new concept is accompanied by the proliferation of definitions. We argue here, that in OM a rather common understanding has emerged: **I4.0 is a technology-enabled phenomenon that exploits technologies to offer highly customized products with digital content. Furthermore, in its vision organizations rely on a new 'modus operandi': interconnectedness via vertical and horizontal integrations reshapes both value chains and supply chains.** The ultimate vision of the transformation is a customized mix of services and the product and this complex mix (e.g., low volume, high variety) can only be dealt with cyber-physical systems, where the virtual and real world cannot be separated (Huber, 2016; Goerzig and Bauernhansl, 2018).

Currently, we are far from that vision. Manufacturing companies most frequently move into the direction of renewing their production system (digital/smart manufacturing). The momentum of the renewal is a multifaceted phenomenon: some companies are undergoing significant transformations (Martin et al., 2018), but most firms make only minor changes (Frank et al., 2019; Tortorella et al., 2020). Detailed analysis of project-level (López-Gómez et al., 2018) and company level changes (Martin, et al., 2018) have shown positive impacts of smart manufacturing on many performance indicators. However, due to its manufacturing focus, it is also highlighted that dominantly operations measures are impacted.

2.2. Technologies in manufacturing context

The emergence of the I4.0 concept shows that the development and adoption of digital (data-based) and physical (processing technology based) innovations have reached a critical mass in the manufacturing context. In **Error! Reference source not found.** we show eight of the I4.0 technologies (Ghobakhloo, 2018). We consider them as the core I4.0 technologies since authors with different backgrounds and target audiences: top consultancy companies (Rüssmann et al., 2015), policy papers for decision-makers (Davies, 2015; Probst et al., 2018) and researchers (Fettermann et al., 2018) usually refer to them.

These technologies are the building blocks of I4.0 efforts and the practical applications generally implement a specific technology (e.g., 3D printing) and/or the combination of

technologies (e.g., digital quality management, real-time supply chain optimisation, predictive maintenance) (Goran et al., 2017).

To go beyond a list of technologies, we have structured them based on several dimensions.

(1) According to Schwab (2016), we have grouped the technologies into digitally and physically dominated categories. While each technology has digital and physical parts, one of them is more dominating. By glue we mean the group of different sensors and actuators which transform signals of real world into electronic data and vice versa.

(2) Relying on the Gartner Hype Cycles we assessed the maturity of technologies. The annual hype cycle defines the actual stage of many emerging technologies alongside the following phases of a “life cycle”: innovation trigger, peak of inflated expectations, trough of disillusionment, slope of enlightenment, plateau of productivity (Gartner, s.a.). Furthermore, the analysis predicts the time horizon when the specific technology arrives at the plateau of productivity phase. To assess the maturity of the eight I4.0 technologies, we have reviewed the Gartner analyses on emerging technologies for three selected years: 2009 (Carpenter, 2009), 2013 (Gartner, 2013), and 2018 (Panetta, 2018).

To assess a specific technology, we have looked at its appearance (yes/no) on Gartner Hype Cycle, the date of appearance and the predicted year of arriving at the plateau phase. The eight technologies are classified into four groups:

1. Long history and *well-known technologies*: simulation and modelling and sensor technologies (in general) are not mentioned on the hype cycle at all. While these technologies have a long history, in our opinion, other I4.0 technologies (e.g., IoT, big data) can leverage the applicability of them (see the reasoning by Valenduc and Vendramin, 2016). IoT enables to collect data on a large scale and use them as input for simulations.
2. *Mature I4.0* technologies have appeared a decade ago and are predicted (by different analyses) to have already arrived at plateau phase. Cloud, 3D and further sensor linked applications like RFID, GPS belong to this group.
3. Several well-known technologies (e.g., IoT, VAR, smart robots) belong to the *emerging* group that will arrive at the plateau stage in the long term.
4. Big Data lies between the latter two groups. Despite its shorter history, it is predicted to be productive technology at the start of the next decade. It is called *experimental* technology.

Table 1. Core technologies of Industry 4.0

| Appearance | Industry 4.0 technology | Description | Maturity* |
|-------------------|-------------------------------------|--|-----------|
| Digital dominated | Internet of Things (IoT) | A network of physical items which connect and exchange data. | 4 |
| | Cloud computing | Users are able to access software and applications from wherever they need, while they are being hosted by an outside party. | 2 |
| | Big Data (analytics) | Large volume, large variety, real-time data, which can be used for advanced simulations and automatic inquiries. | 3 |
| | Simulation and modelling | Creating and analysing a digital/theoretical prototype of a physical model to predict its performance in the real world. | 1 |
| | Virtual and augmented reality (VAR) | Virtual reality offers a digital recreation of a real-life setting; augmented reality delivers virtual elements as an overlay to the real world. | 4 |
| “Glue” | Sensors and actuators | Collect and transmit data, more intelligent ones are also capable of self-calibration or sending warning signals. | 1 |

| | | | |
|--------------------|--------------------------------------|---|---|
| Physical dominated | Additive manufacturing (3D printing) | The material is joined or solidified under computer control to create a three-dimensional object, with material being added together. | 2 |
| | Autonomous robots and cobots | Machines that can substitute for or complement humans. | 2 |

*1-well-known, 2-mature, 3- experimental, 4-emerging

As **Error! Reference source not found.** reveals the physically dominated technologies are more mature than the digitally dominated ones. When the entire production process becomes I4.0-minded and instead of isolated solutions a comprehensive system is created, we achieve the digital factory (or smart factory), that is what really makes a difference.

3. The adaptation of resources to the new environment

The adopted new technological solutions require firms to change their ‘modus operandi’ in many fields like strategy (e.g., Ghobakhloo, 2018), organizational structure (Gauger et al., 2017) and worker organization (Cagliano, et al., 2019). As stages of maturity models (Fettermann, et al., 2018; Geissbauer, et al., 2016; Viharos et al., 2017; Cordeiro, 2019) indicate all these changes are closely linked to *the stock of the accumulated knowledge*. The new resource stock related to I4.0 is best illustrated by companies ahead in the digital journey that builds new internal organizational capacities like “centre of excellences” or “digital powerhouses”. To get a clear understanding of the firm’s adaptation we rely on the powerful theory of DC. In the next section, we show that we can use the components of DC to analyse changes. Due to our OM inclination, we place production processes (i.e., factory) into the focus.

3.1. From the resource-based view to the dynamic capabilities theory

The resource-based view (RBV) (Penrose, 1959) (Wernerfelt, 1984) focuses primarily on the exploitation of existing resources and explains firm heterogeneity based on the characteristics of resources. RBV-based dynamic capabilities theory reveals how firms renew a broad set of their resources (including routines, capabilities). Dynamic capabilities (DC) are about “... *the firm’s ability to integrate, build, and reconfigure internal and external competencies to address a rapidly changing environment*” (Teece et al., 1997, p. 516). According to DC theory, (1) the dynamic capabilities are about **adaptation** since they “... *extend, modify or create ordinary capabilities*” (Winter, 2003, p. 991) (2) in an **environment** where there is a strong need to adapt to rapid environmental changes. (3) They are primarily **assessed** by their contribution to the source(s) of competitive advantage, and hence new resources’ fungibility (Pisano, 2017) and VRIN (valuable, rare, inimitable, nonsubstitutable) (Eisenhardt and Martin, 2000) characteristics are highlighted.

Although DC theory is more than 20 years old, there is still a search for consensus on the concept (Pisano, 2017). There are significantly different interpretations both on the above points (e.g., rapid or moderate change in the environment) and on their interplay (e.g., do DC necessarily contribute to competitive advantage, or their deterministic relation simply leads to a tautology in definitions) (Ambrosini and Bowmanx, 2009) (Laaksonen and Peltoniemi, 2018). In line with a broadly followed approach in the literature, our paper highlights how DC theory grasps the adaptation of resource stocks (to the changing environment). Companies nowadays adapt to the environment shaped by the 4th IR. In manufacturing adaptation of resources and capabilities are driven by the I4.0 initiative. At the factory level, the transformation is framed by smart manufacturing.

Many different approaches exist about DC theory’s adaptation “process”. A common point that most researches advocate a multidimensional construct view. Teece (2007) claim that sensing capability, seizing capability and reconfiguring capability are exercised. These capabilities have been examined in a longitudinal case study about Hummels’ B2C digital

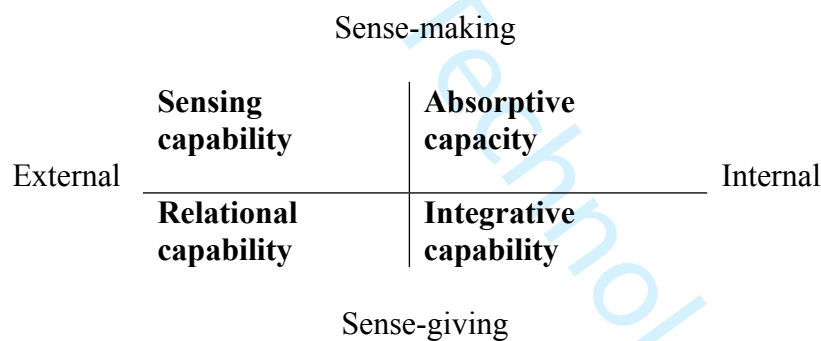
strategy (Yeow et al., 2018). Eisenhardt and Martin's seminal work (2000) defined slightly different modes: leveraging existing resources, creating new resources, accessing external resources, and realising resources. These modes were later elaborated by Danneels (2011) in his longitudinal (extended) case study about a typewriter corporation failing to alter its resource stock.

As Lin et al. (Lin et al., 2016) presented, the decade long interpretation efforts of the originally blurred components seem to have arrived at a common pattern. They found four common components in the international journals: sensing capability, absorptive capacity, relational capability and integrative capability. We decided to apply this general DC framework of Lin et al. (2016) for our research, as shown in Figure 1.

3.2. Components of the adaptation – a research framework

This framework was developed for identifying how DC affect the adoption of management innovation. Although the core of digital transformation is technological innovation, it necessarily goes hand in hand with organizational and management changes, as well. The dimensions of the framework are internal-external and sense-making – sense-giving. By internal we mean the investigated factory in this research. Things related to the case factory are internal, everything else is external. For the other dimension, the framework uses the definition of Gioia and Chittipeddi (1991): „*the sense-making phases are those that deal primarily with understanding processes and the sense-giving phases are those that concern attempts to influence the way that another party understands or makes sense*” (p. 443). In other words, sense-making is more a cognitive stage, while sense-giving is more about actions.

Figure 1: The general dynamic capability framework



Source: Lin et al, 2016, p. 866

Based on these dimensions, *sensing capability* is the company's subjective perception of environmental change, its ability to identify and exploit opportunities. Managers' perceptions might be the main drivers of sensing capability. Sensing capability can affect the entire process of adoptive management innovation.

Absorptive capacity is a set of abilities to manage knowledge. Zahra and George (2002) state that absorptive capacity is a multidimensional construct. It is influenced by four factors, such as knowledge acquisition (identifying and initiating knowledge), assimilation (analysing, processing, interpreting and understanding information), transformation (combining existing and newly acquired knowledge) and exploitation (creating further knowledge). Organizational absorptive capacity depends on the absorptive capacities of its members and their relationship. The more prior knowledge individuals have, the more they can absorb. That is not enough, because they should share and combine their knowledge with others, who have a different knowledge base. So, clearly, “*a firm's absorptive capacity is not simply the sum of the absorptive capacities of its employees*” (Cohen and Levinthal, 1990, p. 131). To link

1
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3 individuals and to support the combinative capabilities structural and coordination issues have
4 to be resolved.

5 *Integrative capability* refers to the ability of a company to use its existing resources and
6 capabilities to rebuild organizational routines and practices. Existing resources and
7 capabilities can be enhanced, replicated or eliminated if it is needed to renew the routines.

8 *Relational capability* refers to the ability of a company to build and maintain close
9 relationships and utilize resources in its network to achieve goals (of management innovation).

10 **4. Methodology**

11 Our research relies on a revelatory case study (Yin, 2012), describing a “*situation not*
12 *normally accessible to social scientists*” (p. 49). It is also an exemplary case study providing
13 an “*instance of an exceedingly successful venture*” (p. 49). Our case factory is ahead of digital
14 transformation compared to most of the factories within the internal network of the division.
15 Therefore, the process they have gone through provides important learnings on what the key
16 actions and issues are in such a transformation (McCutcheon and Meredith, 1993).

17 There is a consensus in DC theory related literature that “*to study change, one needs*
18 *longitudinal data*” (Laaksonen and Peltoniemi, 2018 p. 187). Therefore, we chose the
19 longitudinal case study method.

20 *Data sources and triangulation.* We have used several information sources through the years
21 (interviews, managerial presentations, student theses on digital tools based on their internship
22 experiences, company visits with student groups, public and internal documents). We
23 personally interviewed the head of the company’s process development team (the lean
24 manager from now on) four times between 2015 and 2019. Although not each interview was
25 about 14.0 (we had a previous research project, see: **source will be revealed after acception**),
26 the series of interviews provided deep insight into the actual focuses, achievements and
27 challenges. We also made interviews with the supply chain manager of the subsidiary, a
28 business analyst and prepared three additional interviews with members of the process
29 development team responsible for digital projects. The length of the interviews varied from 30
30 minutes to 2 hours. The interviews were transcribed.

31 Following McCutcheon and Meredith’s (1993) guidelines for case research the authors did
32 not play an active role in the digital transformation. We just observed and documented the
33 changes and did not manipulated the events.

34 *Analysing within case data.* Based on the information a case description was prepared and
35 verified by the company. In the analysis we realized that actions taken by the factory and later
36 by the division could be associated with different stages of transformation. So, we have gone
37 beyond the chronological description of transformation and developed an initial (and more
38 detailed) version of stage-based transformation. As Table 2 shows, this logical analysis
39 (McCutcheon and Meredith, 1993) resulted in stages that are different regarding main
40 stakeholders, strategic orientation, initiators etc. To increase the internal validity of the case
41 this version of four distinct stages was also discussed, completed and improved together with
42 the lean manager. To link the observations to theory, the identified stages were examined
43 through the lenses of the DC theory.

44 **5. The corporation and the case factory**

45 The Hungarian subsidiary is part of a global corporation with American roots, headquartered
46 in Switzerland. It produces half a million different precision products in almost 100 factories,
47 with 80,000 employees worldwide. The corporation is vastly profitable with continuously
48 increasing sales.

49 The case subsidiary operates with about 1,500 employees belonging to the automotive
50 division and the EMEA region. Product variety, size differences and volumes are all large in
51 the factory. The factory primarily delivers self-labelled cables and jacks to TIER1 customers.
52 They do both fabrication and assembly. Beyond these products, ambient lighting and

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2
3 electronic components get a place in their product portfolio. The factory is the most modern
4 unit within the corporation. In recent years the factory has experienced considerable changes
5 in the demand. Parallel to the increase in production volume, it is a clear trend on wider
6 variety, smaller batch sizes and fluctuating demand patterns.

7
8 The corporation's manufacturing network resembles the global-integrated manufacturing
9 network configuration. In this configuration, the supply chain is dispersed in many countries
10 and between several factories, with the objective to optimize value added at the global level.
11 In these networks, the control of the HQ is very high over the individual subsidiaries (Shi and
12 Gregory, 1998, p. 203). Manufacturing processes and their improvements are the most
13 important for managers, these are prioritized when decisions on the development of resources
14 are made. In the case factory, for example, I4.0-minded solutions for manufacturing are
15 preferred, while intralogistics related projects are only in the planning phase.

16
17 The company deploys a multi-plant improvement program (MPIP). It serves as a coordination
18 tool to facilitate process improvement efforts in the internal network. According to the
19 internal assessment report, the case factory is among the most matured lean factories in the
20 EMEA region and among the top 10 worldwide.

21 22 23 24 **6. The journey towards digital manufacturing**

25 We identified four stages of development in the factory's journey. First, we describe each
26 stage in detail.

27 28 *Stage 1: The first steps (2012-2013)*

29
30 The first experiments with digital solutions have started in 2012 in the factory. The factory
31 realised that the prerequisite of any digital efforts is data collection and storage and they spent
32 most of their free financial sources (given to subsidiaries for development) for this. The first
33 essential step was the installation of tools and/or software that can capture the desired
34 observations at any corner of the factory. Many machines have been equipped with sensors,
35 scanners, 3D cameras. They established a central database where all data are collected and
36 available. Tools like machines, laptops, PCs, Android devices, smart screens and kiosks on
37 the shop floors etc. in the factory are connected to this central database. Some of the tools are
38 capable to communicate with each other, as well. Nevertheless, they are able to utilize only
39 fragments of data.

40
41 The department responsible for lean improvements also initiated small local projects with the
42 objective to increase process efficiency and competitiveness by digitalisation. The customers
43 at that time had no expectations yet regarding any form of digitalisation. Initiatives focused on
44 internal processes, especially on manufacturing. The factory involved external partners to
45 develop their digital andon system (an electronic notification is sent first to the operator and
46 then to the supervisor and/or the maintenance personnel if needed). They replaced paper-
47 based systems in visualizing production sequences and shop floor dashboard, the latter
48 providing daily data on smart screens in the shop floor area (not yet from sensor data).
49 Collaborations with universities also started/intensified in this period.

50 51 52 *Stage 2: Pilot companies (2014-2017)*

53
54 The key initial event of this stage was a one-week workshop in Germany in 2014 for
55 representatives of the automotive division in the EMEA region. Enthusiastic digital fans,
56 mainly lean managers, from various factories in the network, organized the event. Participants
57 mapped processes to identify focus areas of digital transformation. They worked out a list of
58 potential areas and business processes, where digitalisation can lead to cost cutting, and where
59 they have to start developments as soon as possible. The list has contained 160 items, which
60 were categorized into the following groups:

- Real-time KPI (key performance indicators) visualisation
- Visualisation of process parameters
- Digital quality inspection
- Full digital tracing of tools
- Production warning, signals (Andon)
- Total productive maintenance
- Big data
- Agile supply chain planning
- Digital education

On the workshop participants also decided that within the region the German and Hungarian subsidiaries are designated to be the pilot factories. It means that these two factories can first test the I4.0 tools and technologies, and after achieving positive results, these factories will coordinate further adoptions in other factories. The German factory primarily deals with the tracking and tracing of tools, with life cycle analysis of tools, and other digital solutions related to tools (30%). All the rest (70%) are assigned to the Hungarian factory. Production efficiency is in the centre of all the experiments and developments. There was also a decision at the HQ of the division that within 3 years each subsidiary bigger than 600 employees should employ a data miner.

From 2014 on, the subsidiary has received significant financial support for digital transformation. They installed further data collectors in the shop floor. In this stage, the process development team with its head became officially responsible for the digital efforts at the factory. They organized training in big data and R for developers. The team started to develop the Operator Learning Management System (OLMS), a *digital learning platform*, which monitors and permanently matches employee's skills (and authority) with the specific tasks and machine. If a worker does not have the required qualifications, the system directs her/him to an e-learning interface on the shop floor to learn the necessary routines. It further improved the *digital dashboard*, started *pilots in 3D printing* (by installing a big metal-based technology at the end of this period). They also have some pilot projects on *big data analytics*. These pilots aim to transform preventive maintenance to predictive maintenance by analysing data collected from assembly machine operations. They work on these projects with industrial partners and with universities. The corporation acquired small companies producing digital tools (e.g., sensors).

Regarding their context, in Hungary there were only 4-5 multinational companies in the piloting phase at that time. In general, there has been a lack of both skilled (like engineers, data miners), but also low skilled workers in the country, which resulted in high labour fluctuations. Nevertheless, the company have sensed reducing order batches, which had negative impact on their profit margin.

Stage 3: Develop digital transformation roadmap and governance (2017-2018)

This stage started with a 6-week meeting directed by Boston Consulting Group (BCG). The meeting was initiated by the Global Operations Director of the automotive division worldwide, because there were very diverse approaches followed by different units, which led to parallel efforts, waste of resources and very different maturity levels in various technologies. Although, in the previous stage the company decided on the "pilot factory" concept, it did not work as expected. The factories went on with their projects and they even extended their digital journey mainly due to the sharply emerging interests in the field. In this turbulent context, the coordination of bottom-up developments has become crucial instead of sticking to the pilot factory concept and of the follow up of the selected paths.

The main objective of this stage was to develop a digital transformation strategy by identifying focus areas and including a roadmap; furthermore, to create a digital governance

model by adapting the organizational structure and setting the role of leaders. The new digital transformation roadmap contains two waves of development over time, around the focus areas. They created a digital transformation unit to direct changes and tied this unit to the highest levels of management, as well as with other organizational units.

Table 2: Technology, strategy and organization

| Aspects | | 2012-13 | 2014-17 | 2017-18 | 2018- |
|--|---|--|---|---|--|
| <i>Milestone</i> | | Raising awareness on the use of digital tools in process improvement | Establishing bottom-up coordinated efforts among interested factories and to identify focus areas of digital transformation-based pilot factories' experience | Setting direction for the division with proper strategy and organization structure | Focusing digital efforts on financially viable projects |
| <i>Initiator of change</i> | | Local initiatives of lean teams to improve processes (informal, bottom-up) | Lean teams at EMEA to improve process and set up directions (informal, bottom-up) | Global network level: develop central strategy for digital transformation (focus areas, role of leaders, organization) (formal, top down) | Digital governance sets goals at regional level (formal, top down) |
| <i>Technology, applications at factory level</i> | | Small experiments, pilots Solutions: Dashboard; Production sequence visualisation; Digital andon; One central database; | Experiments, pilots (3D printing, self-calibration, predictive maintenance) New solutions: OLMS | Experiments, pilots (predictive maintenance, digital quality, big data analytics and advanced machine connectivity) New Solutions: e-QCPC new feature of OLMS (taken over by HQ) | Business cases available Solutions in supply chain S&OP 2.0 on digital platform; SAP IPP (under implementation) |
| <i>Knowledge</i> | <i>Internal (new periods embrace previous ones)</i> | | Data miner recruiting policy; digital learning for operators; Big data, R training for developers | Worker roles in projects (champion, SME, accelerator, coordinator) | Data analyst: three levels: basic / advanced analyst, data scientist SCRUM training, plans for MIR |
| | <i>External</i> | Local partner for the Andon system, collaboration with universities (from this period on) | Buy small companies producing sensors; Cooperation with local technology provider company | Cooperation with BCG (strategy), Fraunhofer Institute and IBM (stamping data analytics) | Cooperation with Siemens (digital quality) |

The corporation has a sophisticated system for assessing the level of lean maturity based on 13 items, giving 1 (worse) to 5 (best) stars to subsidiaries. The level of digitalisation (e.g., machine connectivity) is added to this audit system as a separate, 14th item. The division built a so-called accelerator-based organizational model. In this model, there are global digital

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3 champions, one in each region. Global accelerators, people with deep knowledge in a I4.0
4 technology, support champions.

5 Locally, at the factory level, there are also champions and accelerators with similar tasks. In
6 case of starting a digital project, the team consists of a) a digital champion leading the project
7 and responsible for the financial (ROI) aspect; b) a subject matter expert (SME), knowing the
8 relevant production technology (e.g. moulding), c) a local accelerator, who is familiar with the
9 digital solution (e.g. big data applications); and d) a person from the lean/digital department
10 coordinating the project.

11 The case factory has had more than 10 different digital projects/solutions at different maturity
12 levels. They made the first steps to channel in sensor-based real-time data in the dashboard on
13 the shop floor. They also improved the digital learning platform with a new module, which
14 analyses the previous performance of an employee (e.g., topics, points) to propose a personal
15 and customized capability development plan. OLMS is implemented in other factories and its
16 further development is taken over at EMEA division level. They also developed the electronic
17 quality control process chart (e-QCPC), which is an electronic version of problem reporting in
18 the shop floor and beyond. They made progress in building the local IT infrastructure, digital
19 quality and machine connectivity, and still put effort into big data analytics working together
20 with Fraunhofer Institute and IBM.

24 25 *Stage 4: Value creation (2018-)*

26 Since 2017 the company did strategic efforts to find focal points of digital transformation and
27 to enhance the financial viability of projects, however, they have not really succeeded. To
28 resolve the shortcomings, the 4th stage is built around value creation.

29 This stage started with the first value creation workshop in the Hungarian factory. The
30 objective of the workshop was to figure out how to use digital tools to real value creation.
31 This expectation is derived from the experience of the previous stages: the company made
32 many efforts towards digital operations, but practically they did not know and did not try to
33 find out if the efforts indeed paid off. A further issue was that there were far too many
34 ongoing projects, so their attention on various projects was not focused enough. In order to
35 handle these problems, they started to create business cases, golden examples or plans of pilot
36 projects. The business case contains detailed documentation of required resources (manhours,
37 capabilities, tools), costs, videos, project plans, as well as financial and non-financial benefits,
38 etc. Business cases support the planning of similar projects in other subsidiaries and provide
39 inputs for business strategy, as well. Due to the accelerator model, people from the
40 lean/digital department receive SCRUM trainings. Based on the digital governance model
41 goals are set at regional levels and supported by regional champions (6 in EMEA – including
42 3D printing, digital quality; 2-2 in America and Asia).

43 Efforts in this stage already go beyond manufacturing for the supply chain, including a digital
44 platform for sales and operations planning (S and OP), implementation of SAP IPP module
45 (data visualisation) and plans for installing mobile industrial robots (MIR) for production
46 logistics. The company started to cooperate with Siemens on digital quality.

51 52 53 **7. Discussion of the main characteristics of the digital journey**

54 Our case represents a unique endeavour about how digital transformation takes place in a
55 factory. We apply the DC framework to reveal how the interplay between the case factory
56 (more precisely the process development department) and its tighter network, including the
57 headquarter and other factories within the division, as well as direct partners in the supply
58 chain have undergone developments. Besides enriching the DC framework, we also provide
59 some insights into the debate between two resource stocks, namely lean and digital initiatives.
60 Finally, the trajectory of the factory is examined from a technological point of view.

7.1 Stages within the dynamic capabilities framework

Stage 1

The case factory and the whole corporation has had an elaborated multi-plant improvement program based on the lean management system with value stream-based organization, factory level process development departments, division-wide knowledge management and lean offices, internal audit, etc. Looking for new process improvement opportunities, the lean manager at the case factory continuously scanned the information from benchmark factories, books, conferences, universities, partners, etc., so he was completely aware of digital changes in manufacturing around. Due to his role in the factory's operations, the lean manager focused his attention exclusively on solutions which could support the process improvement at the factory level. Due to his scanning efforts he **sensed** the changes and initiated digital solutions at the factory (**seizing, absorptive capacity**). Besides exploiting and extending his team's knowledge, he also involved external experts and technology providers (**relational** capability) into the projects many times. These projects ran typically without financial and return on investment expectations. An intended "by-product" of digital initiatives was the generation of new knowledge through experimenting and learning.

Stage 2

The factory identified significant constraints in financial and human resources devoted to digital projects, especially due to its large initial hardware investment costs and difficulties in knowledge acquiring. Furthermore, the lean manager, having regular **relationship** with other factories' lean managers, **sensed** that their problems are similar. They realized that by unifying their efforts and sharing knowledge related to the digital solution they might be able to go on more efficiently. Having a 2-day workshop, the group of EMEA division's lean managers identified potential digital development directions. Furthermore, they also initiated a loose cooperation among factories and appointed two factories for making pilot applications. The idea was that the pilot factories could **absorb** the digital knowledge better (and faster) on the assigned areas. This stage has been supported by the routinized knowledge sharing activities, coordination mechanisms and social relationships built by the division for lean developments before (Lewin et al., 2011; Van den Bosch et al., 1999; **source to be revealed later**). The final objective of the pilots has been to develop turnkey digital solutions including changes in organizational routines (**integrative** capability).

Stage 3

The division's global headquarter **sensed** the parallel efforts of factories and regions and decided to take the lead by developing a top-down digital transformation strategy including a roadmap and governance structure. The first remarkable step of this turnaround from bottom-up to top-down was a 6-week long meeting with some selected factory representatives and the Boston Consulting Group. In this stage, the sensing capability was supplemented by the experiences of the consulting company, in addition to the environmental changes perceived by the headquarter and factories (**relational** capability). Since decisions made on the meeting had to be put into practice, this stage also initiated an "action" part. The action part emphasized the digital governance structure (**integrative** capability). New organizational routines were created, such as new organizational roles related to digitalisation, a specific organizational setup for the digital projects was introduced (who to involve as participants), and the HQ added a new digital element to the operations auditing system.

Stage 4

HQ turned the digital efforts towards supporting business goals and financial benefits. It tried to resolve the tension that while digital solutions promise improvements these aspects have

not been systematically measured or expected at all till then (**sensing**). The goal here has been to develop business cases with supporting materials (project description, time and resource requirement of implementation steps, return-on-investment calculations, videos, etc.). The business cases have been expected to make faster and more successful implementation (**absorption**) possible in the network of factories. This stage also supports the standardisation of project (management) routines (**integrative capability**).

7.2. Deploying smart manufacturing

From the RBV aspect our analysis of digital manufacturing transformation leads to two main clusters of findings.

First, our single case has revealed that the digital journey potentially develops alongside an evolutionary path with **distinctive phases**. Digital strategy is not a starting or final step, but an intermediate stage of the digital transformation. As we have documented, the division needed 3-4 years of experiments at the factory level to arrive at the top-down stages. We call the first two stages as the “road to the roadmap” phase, when mainly the lean-related resources were modified and exploited at the factory. This behaviour reflects DC as “... *tools that manipulate resource configurations*” (Eisenhardt and Martin, 2000 p. 1118). In the second phase (Stage 3 and Stage 4) the division follows a conscious and proactive behaviour that is suggested by Ghobakloo (2018) during digital transformation. This phase is supported by formal administrative processes that aim to “*build new resource configuration*” (Eisenhardt and Martin, 2000 p. 1118). Even during this phase, we see stages with different orientations: Stage 3 resolved the suboptimal level of relational capabilities at the unit level, and Stage 4 focused around absorption and integrative capabilities to contribute to financial results. Finally, while it is somewhat straightforward that the digital path develops in the interplay of different levels of the organization and that decision making goes upwards in the hierarchy, the main players at the plant level are the same units (i.e., lean departments) throughout the stages.

Second, our study reveals the **orchestration of components in each stage** of the digital path (Table 3). On one hand, our case demonstrates that the path has stand-alone, inseparable and strongly interrelated stages that are built on one other. This accumulation from the case factory’s point of view follows ***a sequence in the deployment of components*** as noted by Yeow et al. (2018) during a digital business model change. Our study also highlights that each new stage deploys the components again and again and that each new stage is triggered by the “tensions” in the previous stage’s resource stocks. On the other hand, our study also emphasizes that ***components have different characteristics during the stages***:

- *A stage starts with sensing* a constraint or an opportunity (sensing capability), let it be an external factor (i.e., the availability of digital solutions) as in Stage 1 at the case factory level; a mix of external (i.e., the spread of digital manufacturing) and internal factors at the network level (Stage 2 about exploiting cooperation) and HQ level with strategy (Stage 3 about turning to top-down); and business focus (Stage 4 about focusing on business goals). This sensing requires adequate knowledge and openness to discover and start to work on the constraint or opportunity (Cohen and Levinthal, 1990). But we also argue here, that neither sensing, nor knowledge is enough, but an initiator is needed at each stage to swing processes further. At our case factory DC involves the lean manager. This situation is noted by Winter (Winter, 2003 p. 993) when specialized and committed personnel “... *could step out of their zero-level roles and into their dynamic capabilities roles ... and then step back again when change is completed.*” We detail the reason of lean manager’s step in the next Section.
- We can identify *dominant capabilities/capacities at various stages*. In Stage 1 this is the sensing capability at the case factory, in Stage 2 the absorptive capacity building in pilot factories to leverage the knowledge of units afterwards, in Stage 3 the relational

capability by developing the digital transformation system to turn from bottom-up to top-down, and finally, in Stage 4 the integrative capability to standardize the developed solutions. Being dominant, however, does not mean that the other capabilities are not important or not needed at a stage's sequence.

Table 3: Capability development by stages and hierarchical levels

| Level of hierarchy | Stage 1 | Stage 2 | Stage 3 | Stage 4 |
|--------------------------|--|--|--|--|
| HQ | | | sensing – turn suboptimal efforts at factory level to HQ initiative; relational capability – top-down strategy and digital governance | sensing – going beyond experiments and have financial impact; integrative capability – business cases |
| Cooperation of factories | | sensing – experiments at many factories, unify efforts; relational capability - cooperate and appoint pilot plants | | |
| Factory | sensing – digital applications are available to improve processes; relational capability – involve external experts and technology providers; absorptive capacity – first steps to develop and experiment with digital applications | absorptive capacity – pilot factories | | |
| “Title” of the stages | “road to the roadmap” phase | | “digital admin machine” phase | |
| Main driver | towards the e-lean system: exploring digitalisation to exploit lean | | approaching the smart factory | |

Bold: dominant capacity/capability

7.3. Pursuing performance improvement - lean and/or smart manufacturing

The first phase of the transformation at the case factory was about an exploration path, and about generating new knowledge by reconfiguring existing knowledge base (Eisenhardt and Martin, 2000). As we have detailed efforts of Stage 1 and 2 contributed to the renewal of MIPs' routines. Can DC theory help us to explain the revealed link between lean and manufacturing focused I4.0?

An underpinning concept of DC theory is **path dependency**, that is, a company's “*current position is often shaped by the path it has travelled*” (Teece et al., 1997, p. 522). Specifically, management cognition implies that managers' cognitive schemas (knowledge, assumptions about the firm's competitive advantage) significantly influence the direction in which the firm seizes opportunities as a result of the change (Danneels, 2011). When at a manufacturing company, the buzzword for mainly operational improvements so far has been based on the

lean process and quality improvement (as an existing resource stock), then this organization pursuing further operational improvements is likely to move towards smart manufacturing (as a new resource stock) (Tortorella et al., 2019). Our case factory's experience underlines that **the interplay between the two concepts is rather a necessity**, and that during the first stages of developments I4.0 could support the lean initiatives (Buer et al., 2018).

Our case also demonstrates that **digitalisation only leads to minor changes in the elements of MPIPs**. At the company MPIP had 13 items before, and now digital manufacturing has been added as a new element. Netland (2013) claimed that MPIPs do not reflect essential elements of modern operations, like ERP or automation. Based on our findings, we argue that we can expect only adjustments in the MPIP's elements, since e-lean or digital lean systems are pervaded by digital solutions under the surface.

Finally, our work provides a possible interpretation on how digital efforts support mature lean factories on the S curve plateau to maintain performance (improvements). In our opinion, the receptivity of the lean team towards digitalisation at the factory might be amplified by the fact that **it has reached MPIP's limits regarding improvements**. The factory is among the most matured lean plant within the division globally. The concept of the S curve (Netland and Ferdows, 2016) suggest that further "pure" lean efforts would have only marginal impact on operations measures. Due to the ever increasing customer expectations (product complexity, order size) maintaining the ordinary performance level (time, price) is already a challenge. Therefore, the use of agility and/or digitally dominated technologies (IoT, big data in scheduling, etc.) (Goerzig and Bauernhansl, 2018) do not necessarily lead to any (substantial) performance increase, which contrasts the dominating positive performance narrative related to I4.0. The explanation can be that they are oriented towards enabling technologies that usually leads to faster decision-making and more transparent processes (dashboard, OLMS), and do not opt for replacing technologies that could have more significant direct effects (robot vs worker) (Acemoglu, 2017). It might be that at the case factory the *"...increased knowledge seems ... to reduce the variability of performance rather than increase it"* (March, 1991 p. 83).

7.4. Technology

Our case factory's experiences lead to several interesting findings on technology usage.

First, and most importantly, the technologies are highly **interrelated and hence start-up costs can be extremely high**. By interrelated we mean that, even theoretically, the proper use of big data analysis assumes IoT (the network of machines with sensors), data storage and calculation capacity and the availability of software solutions and human knowledge at the same time. The physical sphere of I4.0 like smart machines, RFID systems etc. should be embedded into this network. Our case plant represents this interrelated nature of the phenomenon: the chain of pilot projects required high-quality technological infrastructure (e.g., sensors for machines) and human capacity from the very beginning. This high start-up costs of technology-led innovations might result in an even wider gap between superior and lagging companies than it is today (Andrews et al., 2016).

Second, even if the maturity of technologies varies considerably (as discussed in Table 1), beyond a specific level of technological basis neither the scope of their usage nor the related depth of knowledge necessarily depends on their **maturity** (Panetta, 2018). Our case factory has reached this specific (high) level of technology in the first place by building a matured Manufacturing Execution System (MES) relying on the extended data collection system as a prerequisite of I4.0. For a long time the case factory has already had traditional industrial robots as part of the core manufacturing system and these machines have been upgraded by sensors (well-known technology). Beyond the base technology, the case factory has experiences with IoT (emerging technology) and it also runs pilots with Big Data analytics (experimental). Simulation, a well-known technology, was not mentioned. 3D printing

(mature) is available and it has plans for mobile industrial robots (mature). The maturity-independence is best captured by the extremes: on the one hand by the lack of simulation (well-known) and on the other hand, the large scale IoT application (emerging) of OLMS.

Third, the application of I4.0 technologies and the e-business enabled operations are implemented at the same time under the 'digital' umbrella. The efforts of the case factory are inclined to some extent towards rather "traditional" visualisation and digitisation (e-andon, e-QCPC, dashboard). This situation resembles Frank et al.'s (2019) experience. Leading plants in I4.0 are even more ahead in traditional digital solutions. The maturity model of Shuch et al. (2017) also underline that the preceding stage of utilising I4.0 applications (e.g. for visualisation) is a strong computer base and its connectedness.

8. Conclusions and implications for practice

Highlighting the adaptation aspect of dynamic capabilities theory, we examined the process of resource alteration underlying the digital manufacturing journey at a single case factory. The methodology (single case) and factory-focused setting of the research together limits the generalisation. However, we believe that our findings – through logical extrapolation – could be useful and more than illustrative for subsidiaries pursuing digitalisation in multinational's internal production network. Our work has also proved that the DC theory usually applied in the strategic management literature can be useful in a case study about an OM-focused topic. This approach allowed us to crystallize an emerging concept by "hows" and "whys". The main findings are clustered around five messages, and each is related to management implications.

(1) *What technology should be used?* There are many factories thinking of single digital solutions to resolve their problems, and they will go ahead with experiments in this manner. However, if a factory wants to have a complex I4.0, it has to embed interrelated technologies into a solid technological (and human) infrastructure. Managers should be aware that the decision on this trajectory costs a lot of money.

(2) Factories should develop *digital manufacturing strategy* to avoid the "Babel chaos" when building the complex I4.0 system. However, managers should bear in mind that digital strategy is only an intermediate element of the digital transformation. It is not the first step, since open-minded and committed personnel scanning the environment and sensing the changes most likely have started their bottom-up projects. Their experience should be exploited. Furthermore, since the content (i.e., available and feasible I4.0 applications) constantly changes the organization should be ready for frequent iteration and adjustments in the strategy. A strategy would reflect the commitment by helping to identify responsible stakeholders, resolving financial constraints and most importantly setting up the technological basis and proposing the intended (and not intended) set of technologies. A conclusion we can draw from the DC theory, that we have very similar issues during the adaptation every time we arrive at a milestone, but the actual tensions triggered by the current resource stock will lead to different answers.

(3) *Who should do it?* Exploiting new opportunities within the organization spontaneously starts because committed individuals do it on their own (scanning, experimentation). Of course, the push to maintain or even improve performance motivates experiments. At a factory where process improvement has a crucial role lean personnel is linked immediately to digitalisation. In our case company we witnessed this lean-dominated absorption of I4.0. In practice the RBV and especially its path dependency concepts suggest that there could be technology-oriented endeavor as well (or maybe this is more likely). Finally, we expect that even if I4.0 absorbed by (lean) process improvements initially, due to the widespread deployments of technological solutions I4.0 soon exceeds the capabilities of lean teams, and knowledge of lean team members.

1
2
3 (4) *What can a plant manager expect regarding performance improvements?* At a factory that
4 has a mature lean system or has a high level of performance I4.0 might align its average
5 operational performance level with more demanding expectations. In our opinion, at this kind
6 of factory an outstanding performance gain is only achievable by major technology upgrades.
7 If we look at the spread (and implementation failure rate) of previous management innovation
8 systems (TQM, lean), we realize that they were usually blocked by organizational status quo
9 (e.g., culture and leadership (Beer, 2003) (Losonci, et al., 2017)). The “filtering” role of
10 organizational status quo will also strongly limit the potential gains of I4.0.

11
12 (5) *Who will be the ambassadors of the change and how can one set up a transfer coalition?*
13 As noted, smaller-scale solutions are likely to be tried anywhere, anytime. In case of process
14 improvements, the basis of broader scope actions may be the lean system, and lean personnel
15 forms the backbone of the transfer coalition to exploit the initiative. However, at larger
16 corporations it is only a matter of time and digitalisation will be embedded into the formal
17 structure with unified roles and main directions (and non-directions). This formalisation leads
18 to new positions and results in a new transfer coalition of top managers, plant managers and
19 digital experts (most likely some of them from center of excellence groups). The
20 organizational bureaucracy tends to further expand the opportunities for open-minded and
21 committed subsidiaries. In this context they can obtain extra support from the HQ and
22 elaborate their plans for building the complex (and expensive) I4.0 system.

23 24 25 26 **9. Limitations and further research**

27 The main limitation of this research is methodological, but even one case study based on a
28 limited number of interviews can provide useful information in the case of an emerging topic
29 like I4.0. But one case is still not enough to draw generalisable conclusions, since the
30 documented transformation might be only one out of the possible digital trajectories. External
31 validity of the research could be enhanced by examining other factories in similar situation.

32 The findings related to the stages could be useful for other factories, as well. However, as the
33 DC theory highlights the ambition of key personnel, in our case the lean/digital manager is an
34 important factor to consider. If this kind of ambition and commitment is missing, a factory
35 might get into the digital transformation only at Stage 2, if it would be approached by other
36 subsidiaries in the network. Or even later, in Stage 3, when changes are already initiated by
37 the HQ. The later a factory joins the more likely that due to the lack of knowledge and
38 experience (and commitment) the plant manager encounters difficulties by deployment. This
39 problem, however, is not new for the digital transformation, but visible for MPIP programs
40 (Netland and Ferdows, 2016), or in upgrading competencies within a global network (Shi and
41 Gregory, 1998). Altogether here we have examined the viewpoint of a committed subsidiary,
42 but future research could analyse late-comer factories and HQ’s experience, even in bi- or
43 multidirectional ways.

44 A further potentially promising research should link the different interpretations of I4.0 at
45 factory level. Beyond the production system and technology innovation smart product
46 innovation and business model innovation (see Tesla) are at the forefront of the automotive
47 discourse. It is expected that factories will be hardly hit by these changes at all levels of the
48 supply chain. With the help of the researchers, factories could have a better understanding
49 how “smartisation” of their final products affects their position, their operations and the way
50 they manufacture.

51 Finally, the close relationship with the case factory enables us to follow up its journey in the
52 future. Considering some additional years of digital transformation efforts and the
53 involvement of other managers bear the opportunity to continue the current case.

10. Acknowledgement

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3 Answer to the reviews of the paper titled Road to digital manufacturing – A longitudinal case-based analysis submitted to Journal of
4 Manufacturing Technology Management
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8 Dear Reviewers,
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10 First of all, we would like to thank you for reviewing our paper and giving feedbacks, comments and improvement suggestions to help us
11 develop a high-quality paper that really contributes to the topic. We appreciate your work.
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13 We hope that we could provide appropriate answers to the reviewers' comments and you will find our paper acceptable to be published in this
14 prestigious journal.
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16 The authors
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| Reviewer 1 comments | Answers to comments |
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| <p>18 Major revision</p> <p>19 The paper has enormous potential, but in its present form it is 20 not ready for publication. The authors should invest the effort 21 and transform the content from a description of what they 22 have seen to a theory-driven analysis and discussion of the 23 empirical evidence. They authors have a rich case at hand, and 24 it would be unfortunate if the opportunity to leverage it 25 accordingly was lost. 26 27</p> | <p>28 Thank you for the support and the instructions. We developed our paper in 29 this regard. For our research, we applied the dynamic capability (DC) theory 30 (Teece et al. 1997). Our examination relies on the adaptation aspect of DC 31 and applies the framework developed by Lin et al. (2016). This framework 32 was developed for analysing how dynamic capabilities affect the adoption of 33 innovation. 34 The discussion is restructured accordingly: what we know about hows and 35 whys based on the resource-based view.</p> |
| <p>36 1. Originality and contribution:</p> <p>37 The paper does not formulate a research goal, nor a 38 research question. Thus, it is impossible to assess its 39 contribution and outcome. 40 41 Recommendation: Deliver a clear scientific and practical 42 motivation for the work described in the paper. Formulate a</p> | <p>43 We made the research goal clear in the abstract and highlighted in the 44 introduction as well: 45 <i>“Purpose: Our main objective is to examine the resource alteration 46 underlying the digital manufacturing transformation. We rely on the adaptation aspect of dynamic capabilities (DC) theory and our analysis shows how and why a factory adapts its resources and capabilities during digital transformation.”</i></p> |

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| <p>research goal and a research question and make sure that in the conclusion section you refer to these.</p> | |
| <p>2. Relationship to Literature and Previous Work:</p> <p>a) I like the use of both scientific and practitioner sources in the development of a research framework. However, terms and concepts are not properly defined (e.g. digital-physical systems? digital factory? digital transition?)</p> <p>b) Furthermore, the research framework is too simplified. What about maturity of Technologies as introduced in section 2? Does the initial maturity of a company/factory play a role (as suggested by the authors when they refer to the "our case company is ahead of digital transformation compared to the most companies" (p. 7, l. 49).</p> <p>c) In Table 1, where do the concepts in column 1 come from and what do they mean? They aren't properly introduced in section 2, nor do they appear in the research framework.</p> <p>d) Apart from that, why does the paper use absorptive capacity and not something else? Dynamic capability for instance?</p> <p>e) Recommendation: Spend some more effort in elaborating the research framework. Make sure it is functional regarding your research goal. It must guide the course of research work and support the presentation of your results. Furthermore, a research framework used in case study research functions as a theoretical lens through which the</p> | <p>a) We restructured the literature review: first we provide a general view on digitalisation as an economy wide phenomenon, and then we turn to smart manufacturing. We eliminated the term of digital transition, as we used that as a synonym of digital transformation, probably not correctly. And we give more clue for what we mean by digital factory or digital-physical systems.</p> <p>b) Our paper now relies to a great extent on the DC theory. However, we still stick to the maturity-based classification of technologies. And as you suggested, we refer to this in the discussion. We also elaborated the maturity of the case factory. They can compare themselves to their peers in the internal network, so it was changed in the text. Regarding the development level of the case company, we processed its internal assessment report, which states that the case factory is among the most matured lean factories in the EMEA region and among the top 10 worldwide.</p> <p>c) <i>"To go beyond a list of technologies, we have structured them based on several dimensions. (1) According to Schwab (2016), we have grouped the technologies into digitally and physically dominated categories."</i></p> <p>d) We have followed your recommendations., thank you for the idea. We have completely "reengineered" the paper. DC theory seems to be applicable, since it is about adaptation to the changing environment.</p> <p>e) We hope that the DC approach now provides the theoretical lens and shows clearly why our results emerged. Following your recommendation, we also have formulated a conclusion around the maturity of technologies: <i>"Beyond a high level of basic infrastructure an organisation might feel</i></p> |

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| <p>case is analyzed. In this sense, one could refer to the research framework as modelled propositions derived from literature. To this end, elaborate why a certain theoretical foundation (such as absorptive capacity) has been chosen over other potential theories (such as dynamic capabilities). Finally, link the practitioners' approaches (e.g. Gartner's hype cycle) to theoretical concepts (such as maturity of capabilities or similar) to make sure your research framework is theoretically and conceptually consistent and solid.</p> | <p><i>free to experiment with technologies regardless of their maturity. A strategy could help them to define the appropriate scope.”</i></p> |
| <p>3. Methodology and Approach:</p> <p>a) What is the scope of the case? Factory, division, company? Apparently the factory, but what role do organizational interdependencies on division or group level play then?</p> <p>b) Furthermore, what was the role of the researchers? Did they take an active role? The paper should provide more details on data collection and data analysis.</p> <p>c) Moreover, there are some unproven claims "Our case company is ahead of digital transformation compared to the most companies" - How do the authors come to that conclusion?</p> <p>d) Recommendation: Elaborate on your role in the case study and how data was collected and - more importantly - analyzed. How does the empirical data inform your conclusions?</p> | <p>a) We focus on factory level adaptation. It is made clear. However, from Stage 3 on, we have realized that even factory level changes are guided by divisional efforts. Furthermore, the divisional efforts exploit the accumulated knowledge at the factory level, e.g., lean manager still plays a key role in the top-down phase.</p> <p>b) We have clarified that it is a case study, we did not manipulate any event. And we gave further information about data collection and analysis. <i>“Following McCutcheon and Meredith’s guidelines for case research (McCutcheon & Meredith, 1993) the authors did not play an active role in the digital transformation, just observed and documented the changes. The cooperation between the authors and the company has long history.”</i></p> <p><i>“Data sources and triangulation. We have used several information sources through the years (interviews, managerial presentations, student theses on digital tools based on their internship experiences, company visits with student groups, public and internal documents). We personally interviewed the head of the company’s process development team (the lean manager from now on) four times between 2015 and 2019. Although not each interview was about I4.0 (we had a previous research project, see: source will be revealed after acceptance), the series of interviews provided deep insight into the actual focuses, achievements and challenges. We also</i></p> |

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| | <p><i>made interviews with the supply chain manager of the subsidiary, a business analyst and prepared three additional interviews with members of the process development team responsible for digital projects. The length of the interviews varied from 30 minutes to 2 hours. The interviews were transcribed.”</i></p> <p>c) As noted, we have changed it: we compare the case factory to peers. We think that their advancement is underlined by the fact that lean managers nominated the case factory for pilot factory in stage 2.</p> <p>d) Based on the previous points we hope we could handle the issues.</p> |
| <p>4. Results and Conclusions:</p> <p>a) From the reviewer's own experience, major challenges in digital Transformation are brown field vs green field, retrofitting of legacy machinery, scalability of Solutions, top line vs bottom line effects, pilots/labs vs. productive use, security, interoperability, and data availability. Some of this is confirmed by the paper, the Reviewer would love to see a more thorough discussion on topics like these if the case showed similar evidence.</p> <p>b) In General, the results are very descriptive, and the paper does not try to explore interdependencies between the individual findings or explaining their occurrence.</p> <p>c) Recommendation: Use your improved research framework (see above) to more thoroughly analyze your findings. Work with the empirical data and reflect it to our current scientific knowledge base. What knowledge can be confirmed? Are there any counter-intuitive findings in your case that have potential of advancing the scientific understanding of digital transformation?</p> | <p>a) Several of the mentioned items are covered by our story, top vs bottom, pilots, data availability, and lean vs i4.0. We integrated them into the discussion. The discussion is based mainly on the resource-based view.</p> <p>b) Thank you for raising that issue, we improved our paper in this regard. After reviewing the development stages of the factory, we linked these phases with the dynamic capability framework. The main findings are clustered around five core messages, and each is related to management implications.</p> <p>c) The most counter-intuitive finding, or better formulated a finding that contrasts the dominating narrative is the lack of substantial performance improvement. We argue here that this is due to the already high standards on the S curve of lean maturity. And that these applications are enough to cope with the ever-demanding expectations – so having the same lead time but the batches are smaller.</p> |
| <p>5. Implications for research, practice and/or society:</p> | <p>a) Our scientific contribution is twofold: examination of changes within the DC framework and the presentation of a longitudinal case study. This</p> |

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| <p>1</p> <p>2</p> <p>3</p> <p>4</p> <p>5</p> <p>6</p> <p>7</p> <p>8</p> <p>9</p> <p>10</p> <p>11</p> <p>12</p> <p>13</p> <p>14</p> <p>15</p> <p>16</p> <p>17</p> <p>18</p> <p>19</p> <p>20</p> <p>21</p> <p>a) How do the findings of the paper contribute to the scientific knowledge base? The paper claims to be one of the first to provide longitudinal insight to digital transformation (what is not wrong), but it leaves the reader alone with what this means in terms of scientific knowledge accumulation and practical use. As a plant manager responsible for Industry 4.0 the paper is only of anecdotal value; it does not address the why and how of digital transformation, nor a structured analysis of the relevant concepts.</p> <p>b) Recommendation: Elaborate on your scientific contribution (see above). As far as managerial implications are concerned, be more specific about what role in what type of enterprise /factory can benefit how from your findings</p> | <p>resource-based view helps us to have a better understanding of hows and whys, e.g. the necessary interplay of lean and industry 4.0; the crucial role of committed personnel; tensions triggered by the resource stocks etc.</p> <p>b) We elaborated the conclusion according to your suggestions. We have clustered the main messages around five topics: technology, strategy, key personnel, performance impact, transfer coalition and directly connected them to managerial implications. Our study's limitation is the setting. However, relying on logical extrapolation we also introduced more general conclusions. <i>"We believe that our findings can be useful and more than illustrative for subsidiaries pursuing digitalisation in multinational's internal production network."</i></p> |
| <p>22</p> <p>23</p> <p>24</p> <p>25</p> <p>26</p> <p>27</p> <p>28</p> <p>29</p> <p>30</p> <p>31</p> <p>32</p> <p>33</p> <p>34</p> <p>35</p> <p>36</p> <p>37</p> <p>38</p> <p>39</p> <p>40</p> <p>41</p> <p>42</p> <p>43</p> <p>44</p> <p>45</p> <p>46</p> <p>6. Quality of Communication:</p> <p>a) The paper uses too many terms with no relevance to the line of argumentation. The paper lacks the accuracy and consistency of terms and concepts required for a scientific paper.</p> <p>b) Furthermore, partially, the reader gets the impression that the authors are "proud of their case" (e.g. "our case company is ahead of digital transformation") which poses questions regarding the required distance between researchers and their case.</p> <p>c) Some specific point: On page 2 in line 14: The text in bold is meant to be a definition? What does it define? Industry 4.0? Digitalization?</p> <p>d) Recommendation: Revise the introduction and use of terms and concepts. Only introduce terminology that is needed for responding to the research question and get rid</p> | <p>a) We tried to handle this problem. We hope the paper is more consistent now.</p> <p>b) We submit a more neutral version.</p> <p>c) Yes, it is a definition. We elaborated the definition: general term is 4th industrial revolution, its specific branch is I4.0; even in I4.0 the same technologies could be used for different purposes (business model, product, process), and so smart manufacturing = I4.0 in manufacturing.</p> <p>d) We hope you will find the introduction better now.</p> |

of everything else. Also, reflect on the required distance to the phenomenon investigated.

Reviewer 2 comments

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| Minor revision | |
| <p>Comments:</p> <p>The paper makes an important contribution, but the ideas and the way they are organized can improve the quality of the work.</p> | Thank you, very much for your encouragement. |
| <p>1. Originality and contribution:</p> <p>a) The paper is relevant to the journal's editorial scope;</p> <p>b) The paper contain new information about practice, but significant contribution is limited to one case study.</p> | <p>a) We completely agree.</p> <p>b) Yes, that is right, it is a single case. Nevertheless, "<i>The process the factory has gone through provides important learnings on what the key actions and issues are in such a transformation (McCutcheon & Meredith, 1993).</i>" By the data collection we tried to ensure construct and internal validity. Of course, its external validity is limited. However, factories in the internal network could see our conclusions matching their challenges. Applying logical extrapolation, we also made some general conclusion.</p> |
| <p>2. Relationship to Literature and Previous Work: :</p> <p>a) Because it is a case study, the article does not review the literature in depth, but cites relevant sources, important for the analysis that is performed;</p> <p>b) Although the scientific literature lacks applied case studies that demonstrate the implementation of the concepts of industry 4.0, there are some works that point in this regard, as is the case of the titled paper "<u>Theoretical proposal of steps for the implementation of the Industry 4.0 concept</u>" that could be cited as one of the examples that There are being made to carry out a phased implementation considering</p> | <p>a) We believe that we used as many sources as possible. We also had to take into account the space limitations we have.</p> <p>b) Thank you for the recommendation. We built in the reference into the paper.</p> |

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| strategic and organizational aspects of the companies. | |
| <p>3. Methodology and Approach:</p> <p>a) The methodology applied is not very clear. For example, chapter 3 and 4 could be one and better explain the stages of the case study and number, level or function of respondents;</p> <p>b) The usefulness of Figure 1 (page 7) is not clear;</p> <p>c) Item "2.2.1. Technologies in manufacturing context" is not clear in the way that Table 1 was organized;</p> | <p>a) Our research relies on a revelatory case study (Yin, 2012), describing a “<i>situation not normally accessible to social scientists</i>” (p. 49). It is also an exemplary case study providing an “<i>instance of an exceedingly successful venture</i>” (p. 49). Our case factory is ahead of digital transformation compared to most of the factories within the internal network of the division. Therefore, the process they have gone through provides important learnings on what the key actions and issues are in such a transformation (McCutcheon & Meredith, 1993). There is a consensus in DC theory related literature that “<i>to study change, one needs longitudinal data</i>” (Laaksonen and Peltoniemi, 2018 p. 187). Therefore, we chose the longitudinal case study method. In two different chapters: 1) we described the development stages of the company, and 2) we analysed it in accordance with the literature and the research framework.</p> <p>b) We deleted Figure 1. from the paper.</p> <p>c) Thank you for the comment. We rewrote this section, described the line of thought in detail, and explained it.</p> |
| <p>4. Results and Conclusions: :</p> <p>a) The results are relevant and consistent with the objectives of the work, but are not presented clearly. Some paragraphs are very dense and some of the expressions are repeated a lot;</p> <p>b) The English text must be revised.</p> | <p>a) This part has been rewritten in the paper. Each stage of development has been described in detail and interpreted in terms of dynamic capabilities. We also found dominant capabilities and main drivers of change in the different stages of digital transition. In the results section, our most important findings are formulated as five messages for managerial implication.</p> <p>b) Thank you for the comment, we tried to improve the language. As soon as the paper pass scientifically, we will try to make further proofreading, if needed. Currently, we were not able to arrange this service due to the corona virus.</p> |
| <p>5. Implications for research, practice and/or society:</p> | <p>a) Thank you for your comment.</p> |

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| <p>1</p> <p>2</p> <p>3 a) The article makes a relevant contribution to the practice;</p> <p>4</p> <p>5 b) The article makes a relevant contribution to the practice,</p> <p>6 shows the tools and concepts that can be used, but some of its</p> <p>7 foundations are subjective, as is the case of the classification</p> <p>8 made in Table 1.</p> <p>9</p> <p>10</p> <p>11</p> <p>12</p> <p>13</p> <p>14</p> <p>15</p> <p>16</p> <p>17</p> <p>18</p> <p>19</p> <p>20</p> <p>21</p> <p>22</p> <p>23</p> <p>24</p> <p>25</p> | <p>b) The number of concepts used has been streamlined and organized into a research framework and supported with the necessary theoretical foundations. In Table 1 we show eight of the I4.0 technologies. We consider them as the core I4.0 technologies since authors with different backgrounds and target audiences: top consultancy companies (Rüssmann et al., 2015), policy papers for decision-makers (Davies, 2015; Probst et al., 2018) and researchers (Fettermann et al., 2018) usually refer to them.</p> <p>To go beyond a list of technologies, we have structured them based on several dimensions.</p> <p>(1) According to Schwab (2016), we have grouped the technologies into digitally and physically dominated categories.</p> <p>(2) Relying on the Gartner Hype Cycles we assessed the maturity of technologies.</p> <p>We acknowledge, that there is some subjectivity in the assessment. We wanted to make a valid examination of the case company. To ensure construct validity we listed the technologies (so we did not want to sell IT developments as I4.0). However, having in mind that the spread of technologies varies, we added their maturity as well, to see whether their application is maturity dependent.</p> |
| <p>26 6. Quality of Communication:</p> <p>27 The technical language needs to be improved</p> <p>28</p> <p>29</p> <p>30</p> <p>31</p> <p>32</p> <p>33</p> <p>34</p> <p>35</p> <p>36</p> <p>37</p> <p>38</p> <p>39</p> <p>40</p> <p>41</p> <p>42</p> <p>43</p> <p>44</p> <p>45</p> <p>46</p> | <p>Thank you for the comment, we tried to improve the language and cleared the terms we used.</p> |