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Integrating Lean Management with Industry 4.0: an explorative Dynamic Capabilities theory perspective

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ABSTRACT

This study examines the modes of action for integrating Lean Management with Industry 4.0 through the lens of the Dynamic Capabilities theory. In addition, the gaps in the present knowledge base are aggregated, and a research plan for the future is proposed. The study is based on a Thematic Analysis of 16 in-depth interviews with industry experts engaged in large German manufacturing firms. Unlike previous analyses, this study concentrates on the 'how' level to inform practical executions and support firms in their journeys of integrating these two transformational paradigms of Operations Management. The findings indicate a strong methodological and capability-driven focus across the views of industrial experts. Furthermore, modes of action as moderators of success were derived from proposing a processual model to be evaluated through quantitative research. Identifying gaps in the present knowledge base and defining a research agenda centred on operational principles opens up opportunities for future research with significant practical value.

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Industry 4.0; lean management; dynamic capabilities; transformation; thematic analysis; modes of action

1. Introduction

Since 1990 Lean Management (LM) has matured into a holistic manufacturing paradigm and represents a worldwide business imperative (Bhamu and Singh Sangwan 2014; Womack, Jones, and Roos 1990). LM builds on philosophical aspects and management techniques to be implemented as a whole (Shah and Ward 2003). However, most firms fall behind their expectations when implementing LM and lack to successfully include all relevant LM practices (Bloom et al. 2014). At the same time, complexity and competition are rising and striving for competitive advantages requires firms to integrate LM with Industry 4.0 (I4.0) rather than managing singular transformations (Buer et al. 2021). The high failure rate and ever-increasing complexity in transformations illustrate the need for more research to inform actual executions of integrating LM with I4.0.

Previous research elaborated on integrating these two paradigms, and publications dramatically increase since 2016 (Ding, Ferràs Hernández, and Agell Jané 2021). From an operational viewpoint, three types of integrations were derived as I4.0 leveraging LM, LM being a prerequisite of I4.0, and a balanced/integrated consideration of both manufacturing paradigms (Anosike et al. 2021; Buer et al. 2021; Tortorella, Giglio, and Dun 2019). However, most research focused on explicating why to integrate (target dimensions) and what to integrate (constituting elements). In contrast, the how-level, which intends to inform the actual execution of integrations, remains less researched (Komkowski et al. 2022).

The Dynamic Capabilities (DC) theory offers valuable perspectives in answering why and how questions (Walker et al. 2015). Anand et al. (2009) derived an infrastructural framework to increase success rates in continuous improvement initiatives such as LM through the lens of DC. Felsberger et al. (2020) also employed DC to develop a framework for implementing I4.0. Concerning the role of DC in integrating both paradigms, we follow the call from Collis and Anand (2021) to contribute in further elaborating on the power and limitations of DC, as well as in deriving operational modes of actions through the example of executing an integration of LM with I4.0. This contributes to further calls for research in deriving sub-capabilities, specific requirements depending on organisational development phases, and deriving industry-specific explications of DC (Collis and Anand 2021; Leemann and Kanbach 2022). As DCs are considered one potential answer to low success rates in organisational transitions, contributions deriving operational levers represent potential answers for improving success rates in LM and I4.0 transitions and support firms in maintaining or regaining their

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competitiveness (Correani et al. 2020; Pearce, Pons, and Neitzert 2018; Yilmaz et al. 2022).

Therefore, this study builds on a Thematic Analysis (TA) of 16 semi-structured in-depth interviews with industry experts informed by the framework of DC to derive detailed insights into 'how' firms may execute an integration (Braun and Clarke 2006; Collis and Anand 2021). Through these steps, two research questions (RQ) will be addressed:

1. How can firms execute an integration of LM with I4.0?; and,
2. What are the skills, resources, and processes necessary to do so?

The findings contribute to practice in explicating the how-level of modes of action to inform firms seeking concrete options in executing the aspired integration of LM with I4.0. Furthermore, it contributes to theory in demonstrating the operational value of the DC framework and deriving concrete aspects of DC levers.

The rest of the paper is structured as follows. Section 2 describes the theoretical background. Section 3 summarises the applied methodology. The results are presented in Section 4. Afterwards, Section 5 presents a discussion and derives implications. In section 6, conclusions and opportunities for future research are provided.

2. Theoretical background

2.1. Integration of Lean with Industry 4.0

Research developed an extensive knowledge base and reflects different levels of integrating LM with I4.0, namely why, what, and how (Komkowski et al. 2022). In contrast to most previous research addressing the former, this study intends to focus on how to execute an integration. Therefore, the three overarching integration types, I4.0 as the dominant theme, LM as the dominant theme, and a balanced consideration of LM and I4.0, are contrasted within this subsection.

In the first case, authors consider LM the dominant theme and typically a prerequisite for I4.0 implementations. It seems agreed that matured LM journeys simplify I4.0 integrations (Anosike et al. 2021). Across various arguments, the application of fundamental LM principles, as outlined by Shah and Ward (2007), prevents the digitalisation of wasteful activities and provides a solid foundation in terms of robust shopfloor processes (Buer, Strandhagen, and Chan 2018; Buer et al. 2021; Tortorella, Narayanamurthy, and Thurer 2021). Through implementing LM, generic success factors are developed, which function as supporting forces in I4.0 integrations. These include a learning culture, top-level leadership, the creation of cross-functional teams, change governance frameworks, and training initiatives, which serve as the DC for an accelerated I4.0 integration (Buer et al. 2021; Pozzi, Rossi, and Secchi 2021). Further research might build on these foundational DC elements for deeper-level and explorative insights (Komkowski et al. 2023). Finally, initial implementation sequences, from basic LM foundations to advanced technological automation and integrations, were derived for further investigation (Rybski and Jochem 2021; Tortorella, Narayanamurthy, and Thurer 2021). Nevertheless, further research should reflect the role of established models, e.g. sand cone model or value-stream orientation, and standardised architectures, e.g. RAMI 4.0 or IIRA (Bortolotti et al. 2015; Hopp and Spearman 2020; Yli-Ojanperä et al. 2019).

Conversely, the second research stream considers I4.0 dominantly due to its power to overcome LM limitations (Rosin et al. 2020; Sanders, Elangeswaran, and Wulfsberg 2016). Besides broad consensus about the transformative role of data and speed of information, specific use cases demonstrated I4.0 employing LM techniques (Davies, Coole, and Smith 2017; D'Orazio, Messina, and Schiraldi 2020; Pagliosa, Tortorella, and Ferreira 2021). Examples are the transition from kanbans to e-kanbans, data-based quality assurance, or robotic preciseness in interaction with human beings (Anosike et al. 2021; Rey et al. 2021). Finally, considering cybersecurity, cloud, and horizontal/vertical integration in LM and I4.0 integrations is relatively marginal (Rosin et al. 2020). Contrarily, prior research indicates that horizontal/vertical integration and cloud services are crucial components of I4.0 integrations (Frank, Dalenogare, and Ayala 2019; Pagliosa, Tortorella, and Ferreira 2021; Sanders, Elangeswaran, and Wulfsberg 2016). In summary, this research stream appreciates I4.0's transforming capacity and evidenced that I4.0 applications do not necessarily require prior LM implementations.

Finally, a balanced consideration intends to integrate the previously outlined perspectives leading to a lower level of trade-offs (Ding, Ferràs Hernández, and Agell Jané 2021). In particular, this camp of authors corroborates the mediating function of LM for I4.0. However, I4.0's leveraging impact is also emphasised, and organisations are advised to integrate both concepts to become smart and lean (Kamble, Gunasekaran, and Dhone 2020). In well-executed integrations, organisations remove LM hurdles through I4.0 practices and vice-versa, e.g. the interfunction of JIT with IIoT, big data analysis, sensors, and other I4.0 practices. By upgrading LM systems in this manner, a virtual manufacturing network that shares both tangible and intangible resources is created (Kamble, Gunasekaran, and Dhone 2020). Financial limitations, inadequate managerial assistance, limited awareness, uncooperative behaviour, and a lack of capabilities were identified as integration barriers (Kamble, Gunasekaran, and Dhone 2020). In conclusion, this camp of authors respects the mediating function of LM but prefers to treat both paradigms equally and supports integrating socio-technical thinking into lean culture (Vlachos et al. 2021). Finally, also this research stream developed initial implementation guidelines. Saabye, Kristensen, and Wæhrens (2020) introduce automatic data collection and analysis to compel second-order problem-solving based on real-time data and problem-solving techniques to handle LM's learning component.

As a result, the three outlined streams generated empirical evidence for their fundamental hypotheses. One cannot neglect the benefits of developed success factors or DC through initial LM implementations. At the same time, this represents no option for firms lacking time for initial LM implementations, and balanced considerations require further

explorative studies (Buer et al. 2021; Pozzi, Rossi, and Secchi 2021). However, independently of the integration perspective, prior research primarily focused on why and what to integrate. Further contributions are possible in explicating how firms may execute integrations practically (Ding, Ferràs Hernández, and Agell Jané 2021). Table 1 concludes the characterising positions and knowledge gaps derived from this literature review.

2.2. Dynamic Capabilities

DC theory focuses on how businesses may adapt and evolve to take advantage of emerging market opportunities and obstacles (Teece 2018a). It implies that successful businesses can create and sustain a set of organisational capabilities, including strategic planning, innovation, and flexible resource allocation, that let them adjust to shifting conditions and seize new opportunities (Teece 2018b). Knowing well the ongoing debate about the power and limitations, as well as constituting elements of DC, we rely on the most widely agreed core elements of the framework if related to innovation and resource-value creation (Katkalo, Pitelis, and Teece 2010; Kump et al. 2018; Peteraf, Di Stefano, and Verona 2013; Teece 2014). These elements are illustrated in Figure 1.

As this research intends to analyse how firms may integrate LM with I4.0, the relevant components are managerial decisions, DC, ordinary capabilities, resources either valuable, rare, inimitable, non-substitutable (VRIN) or non-VRIN, and strategy. In the logic of the framework, competitive advantages and level of profit result from the selected strategies and are not relevant to answer why and how questions as intended by this research. Hence, for this research, we consider integrating LM with I4.0 as the strategy and focus on explicating the previous DC dimensions for this specific context.

The DC framework strongly emphasises a company's capacity to adjust to shifting market conditions through resource adaptations and capability developments. In the context of LM and I4.0 integration, where businesses must be able to react swiftly to shifting client demands, technology breakthroughs, and market trends, this is especially important (Eisenhardt and Martin 2000). Furthermore, the DC framework focuses on how businesses may build skills and assets necessary in organisational developments, as is the realisation of integrating LM with I4.0, acknowledging ambidexterity and, in that way, utilising their current capabilities, which are LM-embossed while at the same time capturing new possibilities offered by I4.0 technologies (Collis and Anand 2021). Finally, the DC framework strongly emphasises the value of a firm's strategies in line with market demands

Table 1. Main research streams in integrating Lean management and Industry 4.0.

Research stream	Core arguments	Exemplary contributions	Knowledge gaps
LM as the dominant theme	A solid foundation of OpEx developed through LM supports I4.0 integrations	Buer et al. (2021); Tortorella, Narayanamurthy, and Thurer (2021)	Examine how technology affects LM implementation strategies. Investigate the connections between individual LM practices and individual technologies. Examine how integrations might be executed in practice.
I4.0 as the dominant theme	I4.0 helps overcome LM limitations and/or requires no previous LM integration	Rosin et al. (2020); Pagliosa, Tortorella, and Ferreira 2021)	Examine the influence on different levels of value chains/organisations. Examine the influence of I4.0 on industrial systems. Examine the impact on health and safety, as well as collaboration or teamwork.
Balanced consideration	Synergistic effects of LM and I4.0	Ding, Ferràs Hernández, and Agell Jané (2021); Vlachos et al. (2021)	Extend research beyond the lab or pilot case study stage. Exploratory inquiries that extend the conceptual level. Derive loosely connected I4.0 and LM components for concurrent implementation.

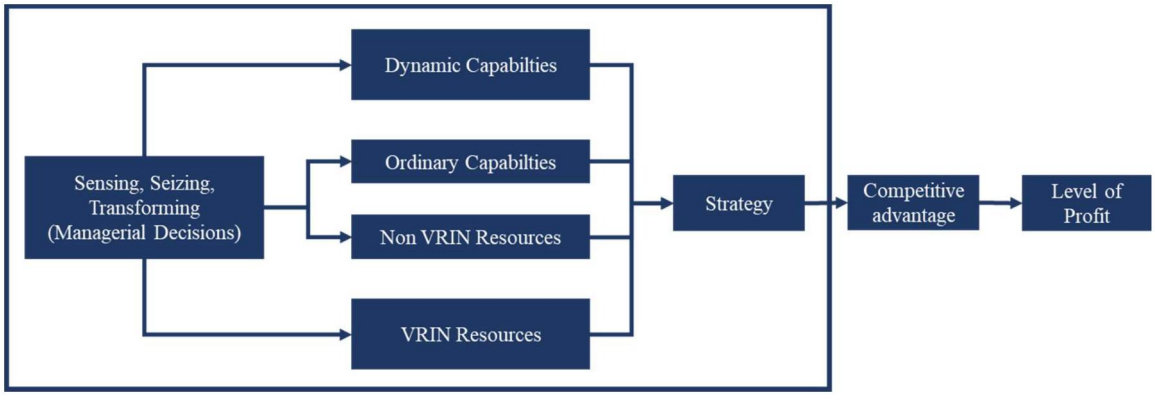

Figure 1. Dynamic capabilities framework (inspired by Teece 2014).

(Gutierrez et al. 2022). In the context of LM and I4.0 integrations, this entails analysing the technology advancements, customer demands, and competitive environment and appropriately adjusting the company's resources and capabilities (Anand et al. 2009).

In the field of LM and I4.0, previous research draws on DC in various methods (Felsberger et al. 2020; Garbellano and Da Veiga 2019; Ghobakhloo and Fathi 2020). As the different DC components suggest, the focus varies depending on the research focus (Birkinshaw et al. 2016). At the core, previous research employed DC to analyse how learning affects the integration of LM and I4.0 (Csiki, Demeter, and Losonci 2023; Demeter, Losonci, and Nagy 2021). Furthermore, the role of capability adaptations represents a prominent theme in deriving concrete capabilities required in LM and I4.0 integrations or higher-level mechanisms of capability adaptations (Mohaghegh, Blasi, and Größler 2021; Saabye, Kristensen, and Wæhrens 2022). Finally, the mediating role of ambidexterity has been investigated, reflecting specific infrastructural modalities (Dixit, Jakhar, and Kumar 2022).

Hence, we consider the nature of the DC framework a helpful lens for comprehending how businesses may successfully integrate LM with I4.0 and helpful for deriving suggestions for businesses wishing to boost their transformation efforts.

3. Methodology

The objective of this study is to explicate actual measures capable of supporting firms in executing an integration of LM with I4.0. Therefore, this research is inspired by a previous systematic literature review (SLR) conducted by the authors team (Komkowski et al. 2022). The findings of this preliminary research step were used to derive the research focus and to inform 16 semi-structured interviews with industry experts engaged in large German manufacturing firms. This setting was chosen based on the strong LM tradition in Germany, allowing to draw on these competencies and capabilities, the sizable and innovative manufacturing sector, which is supported by government initiatives, e.g. Industry 4.0, which increases the chance of rich research contributions (Bloom et al. 2014; Fukuda 2020).

Because the focus of this research is explorative, we followed a deductive-inductive qualitative approach (Edmondson and McManus 2007; Gosling et al. 2014; Sloane and O'Reilly 2013). The interview conduction is informed by DC theory and the SLR findings, while the subsequent analysis follows an inductive version of TA as outlined by Braun and Clarke (2006). The methodological approach used in this work is summarised in Figure 2, and its core elements are described briefly below.

3.1. Sampling

It would have been best to select our study participants by random sampling, given our intention to contribute practically and theoretically. However, due to the explorative research focus, we strongly depend on recruiting high-ranking participants with respectable expertise in both themes, LM and I4.0. Hence, this research builds on purposefully sampled key informants engaged in large German manufacturing firms and holding expertise with LM and I4.0 as the unit of analysis (Kumar, Stern, and Anderson 1993; Tortorella, Narayanamurthy, and Thurer 2021). These experts were recruited through the network of the first author of this paper (Kayikci et al. 2022). On the one hand, the purposeful

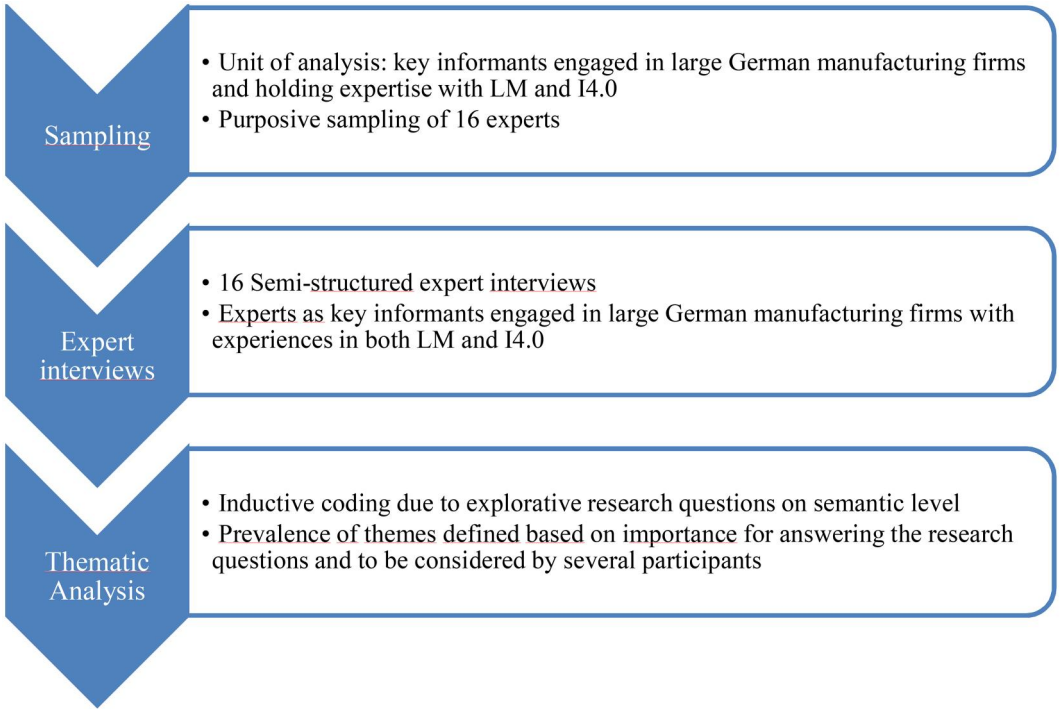

Figure 2. Research design.

sampling of German experts allowed us to recruit a sufficient number of professionals holding respectable expertise in both fields (Rijnsoever 2016). On the other hand, this sampling strategy introduces the central bias of our research, which is the geographic focus (Henry Wai-Chung 2001). Experts are characterised as having at least five years of expertise and practical understanding of LM and I4.0 integrations in at least more than five particular applications (Caiado et al. 2021; Shah and Ward 2003). Key informants should be personally involved in manufacturing firms with more than 100 employees or through consultancies. Previous research has indicated that large organisations enhance the possibility of significant methodological experiences (Shah and Ward 2007).

The sample size definition adheres to the concept of data saturation and follows the norm for this type of research in utilising at least 15 interviews (Mason 2010). The 16th interview was used to validate and ensure data saturation and generated no new insights.

3.2. Data collection

An established approach for gathering in-depth data for qualitative research and producing knowledge through closed-to-open-question forms is conducting interviews. Due to its explorative nature, this study will adhere to the standard practice of using semi-structured interviews, which are suitable for addressing 'how' issues in the manner this study intends (Saunders, Lewis, and Thornhill 2016; Yin 2017).

The literature review discovered knowledge gaps, and ultimately the resulting RQ are used to inform the preparation of the interview guide, following the steps described by Bryman (2016) and Kallio et al. (2016). Initially, the foundations for the interview guide were informed by an extensive literature review considering LM and I4.0, as well as the theoretical lens of DC as a vehicle to answer 'how' questions (Komkowski et al. 2022, 2023; Walker et al. 2015). The resulting interview format begins with an introduction outlining general conditions, such as anonymity or agreement to recordings. Furthermore, it gently reminds participants to focus on their specific perceptions and experiences in integrating LM with I4.0 within large German manufacturing firms (Bryman 2016). The interviewer maintained this focus over the interview's three main building blocks, namely 'integration themes', 'modes of action' and 'specific knowledge gaps', with the support of the interview guide. Questions within 'integration themes' were derived primarily from the DC framework but contextualised to LM and I4.0 integrations. Subsequently, questions within 'modes of action' reflect the core components of successful executions derived from the SLR, and finally specific 'knowledge gaps' are addressed being derived from both sources. Consequently, the content reflected in the interview guide is informed by the theory of DC, the present body of knowledge, and specific knowledge gaps related to the RQ.

Afterwards, a pilot-testing was conducted internally with the author team, externally with academic experts and practitioners, and field testing with five pilot interviews (Kallio et al. 2016). Revisions to the final version of the interview guide primarily concerned the ease of understandability and preciseness of questions. This procedure increased the possibility that the expected contribution would occur during the interviews and ensured that the guide would offer the proper orientation. To achieve the desired level of information, the interview guide comprises opening, structuring, follow-up, specifying, and direct questions (Bryman 2016). The questions focus on integration mechanisms, such as how organisations develop integration drivers or if certain practices, abilities, or resources are required for successfully integrating LM and I4.0 practices (Bloom et al. 2012; Shah and Ward 2007). All questions were asked similarly phrased among interviewees and typically lasted between 45 and 75 min each (Bryman 2016). The interview guide is enclosed in Appendix A1.

3.3. Data analysis

Analysis substantially influences the quality of interview-based research, and a variety of methodologies satisfy robustness requirements. TA is frequently used in qualitative research to discover themes in data within qualitative research, as well as grounded theory and content analysis (Dixon-Woods et al. 2005). However, one specific criticism of qualitative research is that the actual procedures of the analysis are not always transparent (Nowell et al. 2017). Overall, this research follows a deductive-inductive approach with the DC theory and SLR deductively informing the interviews, which are being analysed by an inductive TA (Edmondson and McManus 2007; Gosling et al. 2014; Sloane and O'Reilly 2013). In anticipation of the abovementioned criticism, we decided to adhere to the TA principles outlined by Braun and Clarke (2006). The details of the applied TA are outlined in Table 2.

In this study, data is the sample of answers given by industrial experts within the semi-structured interviews. As a first step, the interviews were transcribed manually following the denaturalised transcription concept to facilitate TA's inductive nature, leading to 440 pages (Nascimento and Steinbruch 2019). The transcripts were coded manually in NVivo by the first author of this paper. Based on the present

Table 2. Process of thematic analysis (Braun and Clarke 2006).

Step	Process	Outcome
1	Data familiarisation	Data transcription, iterative reading and idea generation
2	Coding	Systematic coding of data features of the data set(s)
3	Theme identification	Deriving themes from coded data, aggregating data into themes
4	Review of themes	Cross-evaluation of themes concerning aggregated codes (Level 1) and dataset (Level 2)
5	Definition of themes	Re-analysis and refinement of themes, final naming
6	Reporting	Selection of significant extracts for themes and producing the report

RQ, we decided to rely on inductive coding on a semantic level (Braun and Clarke 2006). The inductive approach fits the explorative nature and our intention to derive integration themes from the experiences and knowledge of the sampled experts. The semantic level seems more appropriate for the current research state as we intended to minimise our interpretations. Based on the coding, themes were derived considering two aspects, on the one hand, the relevance in answering the RQ. On the other hand, we decided to focus on themes mentioned at least by several participants. Initial themes were cross-evaluated against codes and the dataset as a whole. Steps 2–4 were conducted iteratively (Sodhi and Tang 2018). Afterwards, interrater reliability was achieved through the collaboration of the author team in terms of discussions about validation and interpretation (DeCuir-Gunby, Marshall, and McCulloch 2011; Stentoft et al. 2021). Finally, we refined the themes for appropriate naming, which led to the following six themes following a processual logic for integrating LM with I4.0: (1) initiating, (2) sensing, (3) seizing, (4) transforming, (5) sustaining, (6) capabilities/ resources. These themes of integration will be presented in detail in the following section.

4. Results

Based on the patterns of the interviewees' replies, six major themes emerged from the TA: 'initiating', 'sensing', 'seizing', 'transforming', 'sustaining', and 'capabilities and resources'. This section outlines these themes in the sequence of the well-established DC framework by analysing each theme and presenting raw interviewee quotes. While four of the six themes could be assigned to one of the significant DC elements, we uncovered two black spots in the DC framework, namely 'initiating' and 'sustaining' as additional prevalent themes of successful integrations. These themes are located at the beginning and at the end of an integration process and intend to initiate momentum (initiating) or secure the sustainability of an integration (sustaining). Based on the promising findings drawn from the participants' answers, the relevance of these two additional stages should be confirmed quantitatively. Figure 3 summarises the structure of the following subsections as major themes from a processual perspective.

The core idea of each stage is introduced in Table 3 and outlined in more detail in the following subsections. Appendix A2 presents an aggregated overview.

4.1. Initiating

As outlined previously, the processual logic of the DC framework starts with sensing capabilities, which inform seizing and transforming (Teece 2018a). The interviewees prevalently raised activities starting before sensing, especially for late adopters. Firms potentially benefit from developing something before sensing, which was labelled as 'initiating'. This stage intends to create entrainment effects and momentum for sensing capabilities. Hence, this pre-sensing capability might be considered a catalyst for streamlining organisational development, as one participant exemplified:

> The main problem is that operational resources lack understanding of prosperous target states for organisational development, meaning the challenge is to inspire an operational demand for integrating LM with I4.0. This should be achieved in two ways, through LM experts inspiring operational resources with why and how and second, building a bridge from customers deeply into an organisation. (interview, P2)

Besides the example mentioned above, participants raised further insights forming the theme of 'initiating'. Table 4 aggregates the prevalent sub-themes.

Four different sub-themes arose, each diverse enough to merit individual analysis yet related enough to characterise the overarching theme. The first sub-theme highlights the role of generating entrainment effects to 'initiating'. Based on initial successes, participants highlighted perception and recognition from surrounding colleagues or processes. Participant 15 contextualises:

> Through the changes that you can initiate yourself, you can initiate with your team. And… This often develops, not necessarily, but often also a dynamic in the sense of when other areas see: Wow, there's a lot happening, something is changing, something is visibly changing for the better, I'll say in small prototypes, they're really getting it right, then there's also a certain jealousy factor. According to the motto: Wow, they're doing something, now we have to do something too.

Following the logic, small efforts in specific areas can contribute to initiating a broader level of change through entrainment effects. Secondly, participants highlighted the value of routeing customer feedback to corresponding processes. Customer satisfaction potentially plays a specific and prestigious role in many organisations and is also considered to possess the power of initiating entrainment effects if directly routed to related processes – eighter negative or positive - as Participant 1 invites to '[…] integrate the customer deeply into the company, to open all the gates so that the

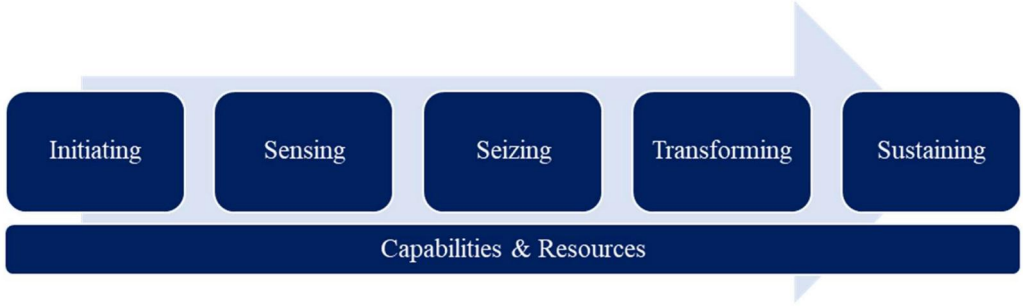

Figure 3. Processual integration of Lean and Industry 4.0 (based on Teece 2014).

Table 3. Prevalent themes of integrating LM with I4.0.

Theme	Exemplary sub-themes	Intention	Participants
Initiating	Practising to see waste and problems with the management team	Develop entrainment effects and momentum for sensing	P1, P2, P3, P8, P10, P12, P13, P14, P15
Sensing	Smaller and more frequent impulses instead of yearly benchmark visits	Identifying opportunities from outside an organisation	P2, P3, P4, P9, P11, P12, P13, P15
Seizing	Deploy logical implementation sequences	Selecting beneficial opportunities	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P14, P15, P16
Transforming	Adopt a hybrid approach of top-down strategic initiatives filled with bottom-up suggestions	Executing the integration	P1, P2, P3, P4, P5, P8, P9, P11, P12, P13, P15, P16
Sustaining	Utilise I4.0 practices as more reliable solutions for process standardisation (e.g. Augmented Reality)	Securing executed integrations	P2, P3, P5, P6, P11, P12, P13, P14, P15
Capabilities/ Resources	Decentralise IT capabilities with an implementation focus on Operations	Holding/developing required capabilities and resources for executing	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P14, P15, P16

Table 4. Initiating sub-themes for integrating LM and I4.0.

Stage	Derived sub-themes
Initiating	Pilots in specific areas to generate entrainment effects
	Routeing customer feedback to corresponding processes
	Practising to see waste and problems with the management team
	Align the management team and develop a convincing change story

Table 5. Sensing sub-themes for integrating LM and I4.0.

Stage	Derived sub-themes
Sensing	Collaboration with industrial partners
	Exchanges on best practices
	Smaller and more frequent impulses instead of yearly benchmark visits
	Input from outside an organisation, especially for I4.0 practices
	Install regular job rotations on the leadership level
	Develop networks with benchmark partners
	Utilise internal cross-functional project teams
	Regularly reflect on own approaches (e.g. quarterly)

pain of the market and the pain of the customer can enter deeply into the company.'

Furthermore, two additional sub-themes are related to management teams, who, based on their multiplying effects, possibly possess a leveraging function to 'initiating'. The participants raised various potential ways a management team might act accordingly. Prevalently two sub-themes can be derived based on the coding. Namely, these are: 'Practising to see waste and problems with the management team' and 'aligning the management team and developing a convincing change story'. Depending on the context, the superior sequence of the sub-themes can be further researched, while the prominent role of leadership is consistently highlighted as Participant 15 declares:

> First and foremost, the management team. Of course, they also need the people afterwards. That is clear. But if, on the one hand, they have a good change story and, on the other hand, they see that the management is setting an example, that change is really wanted, that the management itself is changing something, including its own actions and behaviour, then the mass of people will also follow.

The uniqueness of 'initiating' lies in the specific intention to trigger 'sensing'. The four sub-themes of this foundational stage share the power to get people going. For example, customer feedback concerning the poor quality or a management team that developed capabilities of seeing waste potentially initiates 'sensing' activities to improve the current situation more effectively.

4.2. Sensing

The idea of sensing describes how firms may identify opportunities from their environment (Teece 2018b). While several rather classical measures were part of the findings, e.g. industrial collaborations or networking, participants also proposed less frequently mentioned sub-themes, e.g. job rotations or concretisations as smaller and more frequent impulses being more efficient for the integration of LM and I4.0:

> What we always do in our experience is to take smaller packages, but to do them more regularly. For example, with coaching impulses, rather than always running for a long time and then taking another larger block. So this regularity, and then rather taking them in shorter intervals and in a shorter scope, is much more effective. (interview, P11)

Table 5 presents the prevalent sub-themes informing how this capability might be shaped in LM and I4.0 environments.

The capability of 'sensing' is deeply rooted in the theory of DC and confirmed through the consistent appearance in the participants' answers. Based on the analysis, eight sub-themes were derived, highlighting collaboration, exchange, input from outside an organisation, network engagement, and modern work practices. These sub-themes follow the logic of integrating external knowledge in the early stages to ensure a firm gets aware of the state-of-the-art as potential development targets, as Participant 3 declares:

> You cannot ask for things where you have no idea at all whether there is anything at all, which is why it is all the more important that you keep your head up and look out into the world and also take a look at other solutions and in other companies and also like to look at the whole framework of lean, this best practice, who is doing what, what solutions are there and you should not be afraid to invite specialists, to interview them, to get fresh knowledge and to close this black hole.

Additionally, participants highlighted the role of external knowledge especially concerning digitalisation. For example, Participant 4 remarks:

> That is why you often get a consultant. This is fair enough because: How are companies supposed to know, out of their own

> juice: What do organisational best practice elements look like? What are, what are the best practices in digitisation? Where am I going too far? And then you actually need someone who has seen this before, I don't know, a hundred times, has done it and can then give a bit of guidance. And that's why I'm always critical of carrying out projects like this completely on one's own initiative. That rarely works out.

Besides these concretisations of rather classical sub-themes, participants raised several new insights concerning DC in integrating LM with I4.0: superiority of more frequent and smaller impulses, systematic reflections, and job rotations on the leadership level. Exemplary, Participant 13 elaborates on systematically anchored reflections:

> And I would anchor that quarterly. Workshop. Half a day just to see: Ok, what are the biggest topics that we are currently working on and then have an external person look over them, maybe get a professor from a university, something like that. [...] And on the other hand, so that you also have a look at it from the outside, whether it makes any sense at all, what you're doing now or whether you're already completely lost in the juice of the company. [...] You quickly reach the point where you're stuck, and that's what I mean, as I said.

These approaches can be supported by installing regular job rotations on the leadership level, which helps to prevent operational blindness and introduces end-to-end thinking. Regular job rotations support leadership in developing management competencies instead of specialist knowledge, fit with modern approaches to leadership, and introduce openness to change.

4.3. Seizing

Seizing can be translated into how firms decide upon their sensed opportunities (Teece 2018b). We searched for methods informing firms on how to conduct seizing when integrating LM with I4.0. From the participants broadly, two camps can be abstracted, either following business needs with a problem-oriented perspective or following logical implementation sequences, which do not naturally match the prioritisation of business needs:

> So here it is really important that the pilot projects are not just any C problems, but are actually really A problems. In other words, what is on everyone's mind? Where things really go wrong. Where I really have a bottleneck in production. (interview, P12)

vs.

> How do you proceed now? What measures do you have to take before and where are the others? What are the benefits? What are the costs? If they are partly technologically conditioned, the sequence is of course clear and then you also have to think economically. (interview, P14)

Table 6 introduces the prevalent sub-themes derived from the interviews.

Seven sub-themes form the capability of 'seizing', and the two camps of participants' answers potentially fall into the idea of a problem- or solution-driven approach. Problem-driven approaches rely on prioritising business needs that hold a respectable attention and offer methods, e.g. value-stream mapping or group discussions and analysis-based approaches to decide upon opportunities:

Table 6. Seizing sub-themes for integrating LM with I4.0.

Stage	Derived sub-themes
Seizing	Use value-stream mapping to identify the core value stream
	Use group discussions concerning pain points
	Conduct interviews with employees
	Use a combination of qualitative and quantitative evaluations
	Use process analysis to identify weaknesses
	Deploy logical implementation sequences
	Define, communicate, and deploy a target state

> So the pain ... so mostly you notice that on ... you also know that the people, they also know that, where the shoe pinches and therefore so mostly it is also always good when the project comes to you and you don't have to search for the project. So the project is really painful ... it's actually ... it's open on the table. (interview, P12)

Participants did not propose to rely on qualitative analysis only. Instead, combining qualitative and quantitative types of analysis potentially offers access to validated problems, as Participant 11 explicates:

> And above all, what you can see is that the quality of the analyses and thus the quality of the measures derived from them simply increases. So when you ultimately go through the experience of employees, you are always betting on a good horse. But if you can back it up with really good, validated data, then it simply has another quality improvement.

Potential methods were frequently named value-stream mapping, group discussions, or process analysis. Participants prefer relatively quick assessments instead of deep analysis, as Participant 14 explains:

> And through the analysis, you can at least roughly derive what is actually a realistic goal. And these are actually the most important steps, although I would always say, at least at the beginning, to start the whole thing, on a global level, not too detailed. Just not with MTM or some such nonsense.

Contrary to the problem-driven approach lies the solution-driven approach, as several participants proposed relying on logical implementation sequences or specific solutions related to target states. Participant 14 highlights two arguments. On the one hand, firms should reflect their own adaptive capabilities:

> You always have to look at where you're starting from, and that's also realistic, that you don't skip several levels, where you know afterwards that you're leaving your people behind, technologically. If you know that you're actually starting at the bottom and want to jump up from zero to superstar, that will rarely really work and find acceptance.

On the other hand, when seizing opportunities, firms 'should integrate logical sequences, especially technical dependencies' (interview, P14). Along with the 'definition of core practices from LM and I4.0 through strategy workshops with executives and directors' (interview, P8) as an example of defining and deploying a target state, these arguments underpin the two potentially contrary sub-themes of how seizing capabilities might be formed.

4.4. Transforming

Transforming realises what was sensed and seized before (Teece 2018b). This subsection intends to offer insights specifically suited to transforming an integration of LM with I4.0. The findings are characterised by a hybrid change approach, the relevance of related control mechanisms, and a strong emphasis on the relevance of process owners' responsibilities:

> On the one hand, you can give the use cases and use case ideas, we don't want to suppress them. But we also need the second way, so we build a detour, we look at the use cases on the one hand, but then there is the top-down way, where we say, we look at ourselves target image: Where do I actually have to go? (interview, P15)

Within the hybrid approach, process owners' realisation of responsibilities becomes more critical:

> In that approach, an expert panel defines a backlog of practices and the core team together with process owners classifies as must, should, and can categories. These practices need to be developed as MVPs ready for testing. Then probably monthly, experiences from implementations are reviewed and decided upon proceeding on that path. With that approach, you have a good workaround between LM and I4.0. (interview, P11)

Table 7 summarises the prevalent sub-themes of 'transforming' within LM and I4.0 integrations.

The capability of 'transforming' represents one of the central DC elements. Unsurprisingly, the participants were well informed about the function of this stage and provided various levers that were grouped into eleven sub-themes. These sub-themes concretise transforming by explicating how firms may steer, govern, or execute LM and I4.0 integrations. Fundamentally, participants draw a precise and consistent line between top-down or bottom-up derived initiatives, breaking these initiatives down on a tactical level and achieving high transparency in following up on the level of single measures of LM and I4.0 integrations.

> It starts at the top with strategy and a Hoshin process, for example, which breaks it down again with the catchball principle. So you have at the front, we always divide it into two categories. On the one hand, you have a strategy at the front, where the topics are set, where there is a certain roadmap, and then you come to tactics. So the tactics mean that you then, for example, about just such 'multi-gants', Gantcharts-plans and then you have an overview of the topics: Who does what when? (interview, P11)

In contrast, diverse responses concern the kind of steering, either proposing classical monthly steering committees or considering these as too slow in relation to sprint reviews following agile project management guidelines. Participant 13 proposes to link both approaches:

> In this case, however, the steering committee should rather provide the framework in which this management representative then controls the sprints, i.e. as a product owner. A product owner position that primarily communicates with the stakeholders would be the right thing to do.

Besides these aspects, participants consistently referred to the need for decentralised responsibilities. Process owners should holistically take ownership of integrating LM with I4.0 in their areas of concern, including progress reporting, executions of implementations, and successes. Participant 15 illustrates:

> Firms should rethink their decision-making and accountability system. Decisions should be taken by the one that is accountable for the results – too often decisions are made top down, but accountability is held up on process owner level.

This is taken further by Participant 8, who states:

> Then the person responsible for the process reports to the entire committee, which is both the management and the central department heads. Within the plant, it is done either against the plant manager or, if it is a very small project, against the production manager. But mostly it's the plant manager.

Finally, and to support the accountability aspect, firms need to develop a system that ensures transparency on the integration progress and the realised effects, e.g. through installing a monitoring system including key and operational performance indicators.

> It is always difficult or often difficult to determine a fair indicator, but it is possible. And that also really gives the whole project, the project manager and also the whole team the opportunity to be measured and also, yes, also to see: am I successful with my project at all? Have I achieved what I wanted to achieve? So you should really define that at the beginning. Unfortunately, I have always observed that people somehow get over this point and then somehow start and therefore no one even knew what the goal was: we are driving on sight and so on, which is also fair enough, but in the long run that is of course critical. If everyone thinks it's called agile, we just run off blindly and don't know where we want to go, that's misunderstood. (interview, P12)

4.5. Sustaining

LM strongly emphasises the relevance of sustaining organisational developments, typically referred to as standardisation

Table 7. Transforming sub-themes for integrating LM with I4.0.

Stage	Derived sub-themes
Transforming	Adopt a hybrid approach of top-down strategic initiatives filled with bottom-up suggestions
	Utilise Hoshin Kanri to define "must" LM and I4.0 principles
	Breakdown strategy on a tactical level defining who, what and when
	Develop appropriate transparency and tracking on the measure level
	Conduct classical monthly steering committees vs. agile project management
	Define inputs and outputs to be shared between different governance levels
	Focus reporting on demonstrations on Gemba rather than extensive project documentation
	Focus on inclusion in solving hurdles instead of progress reporting to the hierarchy
	Decentralisation of responsibilities
	Initiate broad communication concerning progress (e.g. regular open reporting meetings in canteens)
	Invite champions or sponsors to demonstrate responsibilities regularly

(Radnor and Johnston 2013). When integrating LM and I4.0, firms naturally increase technological complexity, which strongly influences understanding and potential types of standardisation. The sub-themes within this subsection are mainly characterised by potential levers to keep continuously learning and enabling staff to remain responsible for their processes:

> I no longer get my design drawing in two dimensions as a drawing sheet as I did 20 years ago, but the whole thing is automatically loaded onto the CNC machine and now the programme runs on it, but I am still responsible for providing the right components and the right tools in the right quality. I am responsible, so I am still responsible for my process. (interview, P2)

Besides that, participants highlighted new and supporting opportunities from I4.0 in process standardisation:

> Because digitalisation also means documenting. In the past, it was more like documenting on a piece of paper. When I digitise, the documentation is directly in the system and also shows me when work steps are not adhered to. (interview, P12)

Table 8 presents the prevalent sub-themes of sustaining the integration of LM with I4.0.

The analysis of participants' responses revealed five sub-themes concerning sustaining the integration of LM with I4.0. Two sub-themes reflect the increasing technological complexity, enabling staff to initiate further changes or remain responsible for realising process modifications. Participant 11 describes as follows:

> Then it would be interesting to ask whether there is a kind of kaizen methodology next to it, so to speak. So that one says: Okay, just because the glasses that just because the glasses prescribe it, it doesn't mean that the process is optimal. I should still be able to look at it regularly and then say: Ok, the way we are doing it now, is that the optimal process? Then maybe in the situation, he first has the guideline, but in the end, it's nothing else than following a workflow. From that point of view, it's a very classic instruction. And that's what I have. So, I also have a lean process without the 3D glasses and standardisation as an element, which is always there and yet I always use it as an opportunity to discuss improvements. Yes, that's why I don't see that as mutually exclusive. We just have to think about the appropriate mode. For example, when and how to involve the employee again. In a workshop, for example, to bring in their ideas for improvement or to somehow analyse a recording process.

Further participants provided specific solutions, addressing how to keep operators capable and responsible, e.g. by implementing

> […] classic CIP boxes. If he notices that he has to click through a menu for 10 minutes, he has to say: Here, CIP. If you redesign the menu, I can't do it myself, but if it were redesigned and I could do it with just two clicks, then … (interview, P14)

Principally processes and adaptations should be standardised in a way that the user is supported in fulfilling the specifications of a process in the sense of

> […] that you basically set guard rails, that you can't do otherwise. That would be the best topic if it works that way. It doesn't work in every case and you have to be a bit careful that it doesn't end up in some kind of paternalism from the staff. (interview, P5)

Finally, I4.0 integrations can increase the speed of standardisation, e.g. through smart front-end dashboards where variables of production processes can be adapted or shared across shifts.

The uniqueness of 'sustaining' can be considered as closing the loop of the previous stage of 'transforming'. Firms that developed capabilities falling into the sub-themes of 'sustaining' potentially secure their achievements and set the group for further organisational developments.

4.6. Capabilities/resources

Integrating LM with I4.0 requires specific capabilities and resources (Buer, Strandhagen, and Chan 2018). Our findings contribute to deriving more detailed and precise information for firms to be capable of integrating LM with I4.0.

Principally, participants highlighted the role of holding or developing internal resources in terms of OPEX and IT as a balancing act between hiring and qualifying:

> It is easier to look for someone, to hire someone who has experience there and to give him the freedom and the capacity to get the employees involved and to train them, ok, that is a middle way between - yes, of course - internal qualification, but we first have to really bring that in, because then we have a presence. (interview, P3)

Additionally, participants offered a diverse set of specific resources, capabilities, and structural approaches concerning capabilities and resources for integrating LM with I4.0, e.g. decentralisation of IT to functional areas like Operations or working in tandems were frequently mentioned. Table 9 presents the prevalent sub-themes.

The outlined sub-themes can be grouped into processual and structural approaches, basic requirements concerning capabilities or resources, and functionalities involving external knowledge. Participants' answers reveal a general tendency to overthink structural resource allocations. Strictly technical aspects are centralised preferably in own IT departments, e.g. IT architectures, the middle-level concerns operational technologies rather than falling into operative departments, and finally, processual/organisational aspects to be managed by OPEX personnel.

Table 8. Sustaining sub-themes for integrating LM with I4.0.

Stage	Derived sub-themes
Sustaining	Enable staff to rather introduce change instead of conducting change themselves to overcome increasing technological complexity
	Enable operational staff to remain responsible for realising adaptations, IT/OT function as support
	Install physical or digital Continuous Improvement boxes
	Install regular suggestion meetings with IT/OT on Shopfloor
	Utilise I4.0 practices as more reliable solutions for process standardisation (e.g. Augmented Reality)

Table 9. Capabilities and resources sub-themes for integrating LM with I4.0.

Stage	Derived sub-themes
Capabilities/Resources	Centralise IT architecture capabilities and decentralise IT capabilities with an implementation focus Integrate OPEX and IT within one department Basic requirements concerning roles: hold at least one advanced OPEX expert, internal IT department, and one expert who is able to evaluate implementation capabilities concerning potential LM/I4.0 practices Basic requirements concerning skills: networks and databases, data analysis, low code, broad foundational understanding of LM and I4.0 Constitute a core team based on influence and role-model capabilities Work with tandems of OPEX and IT resources (e.g. within one project team) Evaluate adaptive and digital capabilities to derive a development plan Develop deeper knowledge for voluntary and talented employees (e.g. key users or technical change facilitators) Train OPEX experts rather in applying instead of implementing I4.0 practices Train IT experts in the basics of OPEX Train key users within production staff as first-level support Involve external resources in the early stages of projects or programs to overcome lacking capabilities, capacity shortages or capability transfers

> It's really about automating a real production process. Of course, you also need to know the basics of IT interfaces to IT architecture. You also need to know sensor systems, but that's more like systems engineering. It depends on how complex it will be later, but it's really about doing something on-site. Whether it's a driverless transport system that moves via positioning in production or moves […] whatever. But the share of mechanical engineering is of course much higher than in IT architecture. (interview, P14)

Further, participants framed the above statement in terms of project complexity either in size as '[…] central again, is the theme of strategy and major projects. Decentralised for these small, simple, quick solutions.' (interview, P8). Alternatively, concerning the degree of standard software, Participant 13 additionally intends to leverage internal resources by relying strongly on standard software:

> So I would buy standard software from outside because they simply have much more experience in introducing it. For the topics, I would say lean management, and Industry 4.0, I would have a small on-site team that can map expertise, so to speak, although small can also be relative. However, I am always a friend of bringing in a lot of know-how from outside. Be it universities, be it consulting firms that have seen a lot more companies.

These developments represent flowing boundaries between IT, OT, and OPEX personnel and their organisational localisation. Potentially leading to a more vital decentralisation, as highlighted by Participant 5:

> I personally believe that we need the expertise in the department. IT has to be on board. They have to support it, they have to understand it. Because they have to understand what the department is up to, they have to see that it makes sense and that it is important and useful, because they have to support it. IT must always support. But they can't drive it. I don't believe that central IT can drive digitisation in production.

Concerning required capabilities and resources, the participants frequently mentioned the challenges of recruiting skilled staff, which are even more complicated in terms of skills in both LM and I4.0. Accepting these challenges, potential pathways of overcoming can be derived from the answers given. Participant 13 proposes to focus on 'PostgreSQL' or 'MySQL' for the initial stages due to higher hire-ability representing rather basic database capabilities:

> You actually first take a Postgre or MySQL, a very classic … very classic relational database. Because: you know … so you usually have someone who is familiar with it, who can rummage around a bit with it and on the other hand, you also have broad tool support for these databases. Because I think … …. the problem you often have with Industry 4.0 is not that you can't introduce the tools, but that you simply don't have the people who can manage these tools and work with them.

Furthermore, low- and no-code approaches offer potential pathways for overcoming the initial lack of capabilities and resources, as well as scaling capacities for implementations by working in tandems:

> Perhaps IT should already be looking at the lean process and accompanying it so that they know exactly what you want to digitise so that they also understand it. That is often the problem. Translate your process into IT. That's where a lot of digitalisation fails, that they don't really get to grips with the process and very strange things come out of it. Of course, that would be a possibility, that they accompany it from the beginning, even if they don't have anything to do yet, to build up their digitalisation strategy path at that moment. That could certainly be done. (interview, P10)

In that way, firms may identify various multipliers originating from OPEX and IT, if they 'specifically look for lean people who deal with digitalisation and digitalisation people who deal with lean in order to be able to fill this interface' (interview, P7).

Finally, participants articulated modes of integrating external knowledge, prevalently outlined by Participant 12:

> In the early phase of projects or in projects where the solution is not yet quite obvious. that is certainly good. You can also involve universities. I had also seen consultants or something that you can do to start projects quickly. […]. I would also add consulting to short-term projects. And where I also lack the capacity.

5. Discussion

Following Whetten (1989), we discuss our findings in light of three perspectives: the critical elements of integrating LM with I4.0, how these elements relate to each other, and why this is relevant. Finally, we dedicate two sub-sections for presenting theoretical and managerial implications.

We derived a strong processual and capability-driven procedure in light of the first RQ. We confirmed the three original phases of the DC construct as a promising methodology for executing the integration of LM with I4.0.

This aligns with previous attempts to derive sub-themes or levers of DC (Kump et al. 2018). In contrast, we propose to include the two outlined novel phases, on the one hand, to preload the integration process – we labelled it 'initiating' – and, on the other hand, to secure the sustainability of implementations, which we labelled as 'sustaining'. These two phases increase the value of the original construct in that they preload sensing activities at the beginning of an integration journey and sustain changes realised through the phase of transforming to close the loop. Additionally, 35 concrete modes of action were derived as sub-themes concretising each element of the DC construct, along with 22 sub-themes directly related to the second RQ of capabilities and resources. Schulze and Brusoni (2022) derived control mechanisms realised through attention and KPI monitoring as an essential interaction with problem-solving in DC-oriented LM transformations. While our findings also include KPI-based monitoring, we propose several levers of 'sustaining' as an alternative to enduring attention.

Figure 4 outlines the proposed processual integration model consisting of 'initiating', 'sensing', 'seizing', 'transforming', and 'sustaining', which becomes executable by developing or holding the outlined capabilities and resources. The research builds on Anand et al. (2009), who derived infrastructural components and operational measures through DC-informed semi-structured interviews solely for LM. Hence, we borrow from previous research that we deploy the DC perspective in an extended way on both LM and I4.0 (Felsberger et al. 2020; Garbellano and Da Veiga 2019; Mohaghegh, Blasi, and Größler 2021). Accordingly, the contribution is twofold. On the one hand, we propose to include two additional stages in the DC construct and, on the other hand, present several concrete levers to operationalise the DC elements to support real-life applications.

The relation between the original elements of the DC framework has been outlined in depth by previous research (Collis and Anand 2021; Teece 2018b). We know that the elements of DC preferably work out as a sum and not individually (Teece 2018b). Anyhow, previous research also derived that the relative importance of elements varies depending on contingencies, such as firm size and age, product lifecycle state, specific strengths or weaknesses, and strategies, to name a few (Jantunen et al. 2005; Lampel and Shamsie 2003; McKelvie and Davidsson 2009). As the integration of LM with I4.0 represents a relatively new and fast-developing field of organisational development, we hypothesise the specific importance of earlier stages of DC, namely from 'initiating' to 'transforming'. Based on participants' answers and triangulated with previous literature, we expect firms to benefit from developing solid capabilities in identifying potential integrations of LM with I4.0, deciding upon them and adapting their resource base to overcome increasing technological complexity (Day and Schoemaker 2016). Cleary, longitudinal or quantitative research is advantageous in evaluating relative importance.

When considering sensing, seizing, and transforming previous research-derived scales as an operationalisation of DC, e.g. 'our company knows the best practices in the market' (Kump et al. 2018, 1158). Our findings build on previous contributions by contributing a more executable perspective concerning the established scales, e.g. knowing best practices might be realised through 'developing networks with benchmark partners' as an example of the previously outlined set of levers derived from this research. However, we focus on elaborating on the intervention with 'initiating' and 'sustaining'. By nature, our contribution lies in explicating integration phases, including operational levers. The explorative character called for qualitative research, and quantitative evaluations are required to quantify how the elements of our construct relate interdependently (Edmondson and McManus 2007). The logic behind the proposed model relates to previous research in that we introduce a more profound level in contrast to previously outlined integration purposes, integration types, and integration themes, which are arranged in initial integration frameworks (Anosike et al. 2021; Buer et al. 2021; Tortorella, Giglio, and Dun 2019). Previous findings tend to address a higher level, e.g. what elements of LM and I4.0 should be integrated or what pathways can be applied (Tortorella et al. 2021; Tortorella, Narayanamurthy, and Thurer 2021). Our study concretises how these previous findings can be realised through including our sets of levers within integrations of LM an I4.0. To concretise, Buer et al. (2021) derived the effects of integrating LM with I4.0 on operational performance, Tortorella, Narayanamurthy, and

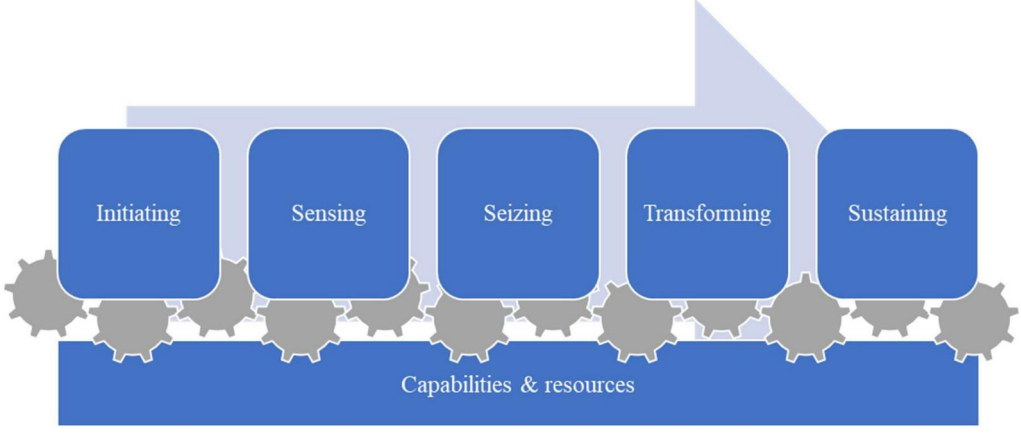

Figure 4. Processual logic of integrating LM with I4.0.

Thurer (2021) derived what practices to integrate at what level of maturity, and with this work, we introduce the operational level of how to execute an integration from a DC perspective.

The 'initiating' phase enriches the concept of DC by a motivating, unleashing, and potentially affirming sense of urgency (Fredberg and Pregmark 2022). This is especially important for firms that have fallen behind, potentially holding low change capabilities (Ben-Menahem et al. 2013). Besides, 'sustaining' intends to take over results from transforming and ultimately secures efforts and achievements (Costa et al. 2019). Based on our analysis, the logic is confirmed throughout the interviews for the relevance of including both additional phases, representing a prevalent theme for integrating LM with I4.0 (Braun and Clarke 2006). Hence, our findings suggest that a well-constructed integration of both themes covers all introduced phases, including respective capabilities and resources.

5.1. Theoretical implications

This subsection presents theoretical implications regarding theoretical advancements and conceptual developments.

This research follows recent calls for more explorative research to elaborate on the power and limitations of the construct (Collis and Anand 2021). We initially focused on the DC framework's original elements as in previous research. However, based on what the involved industrial experts raised, inductively, we derived two additional phases: 'initiating' and 'sustaining'. Our findings reveal that including preloading and sustaining measures potentially increases DC's power by addressing one of its current limitations. In this context, we propose to rethink the holistic nature of the concept and to evaluate and potentially include additional elements as proposed by this research. Previously, authors instead derived scales for the original DC elements, e.g. Kump et al. (2018) or Wilden et al. (2013). These scales simplify the nuancing of DC elements, e.g., sensing or seizing, and highlight the elements' different intentions and processual logic. 'Initiating' intends to unfold entrainment effects, while 'sensing' potentially benefits from these activities in terms of more active sensing.

Additionally, this research offers an operational perspective and presents potential levers for DC in the context of LM and I4.0 integrations. To the best knowledge of the authors, this is the first explorative attempt concerning LM and I4.0 integrations employing the lens of DC and intending to explore the 'how' level, as previous research solely focused either on LM or I4.0 (Csiki, Demeter, and Losonci 2023; Felsberger et al. 2020). Furthermore, previous research focused primarily on outputs or frequencies of applying DC levers and leaves room for further concretisation and operationalisation as offered by this research (Kump et al. 2018; Wilden et al. 2013). Based on the presented findings this research contributes to the ongoing debate about challenges and criticism of DC, specifically concerning being too vaguely defined and too unprecise about how firms actually develop DC through presenting concrete levers and more clarity concerning the distinction between DC elements (Barreto 2009; Collis and Anand 2021).

5.2. Managerial implications

This sub-section outlines what the results mean in terms of practical applications, highlighting potential differences in action enabled through the findings of this research.

First and foremost, we emphasise that managers - if following the DC construct - apply a reasonable methodology for integrating LM with I4.0. The operational level of this research addresses the issue of firms formulating strategies on the why and what level but stumbling in executions (Correani et al. 2020). The findings contribute through a detailed set of potential levers (sub-themes) that allow managers to decide upon and enrich their LM and I4.0 integrations to increase success chances. One way to do so is to evaluate existing integration programs to decide if the outlined sub-themes are covered sufficiently. Due to the qualitative nature of this research, explicating what sufficiently means is open to future research. Based on previous findings, we expect sub-themes to be considered holistically instead of 'either/or' (Galeazzo, Furlan, and Vinelli 2021). Our findings suggest that managers should explicitly address the specific requirements of each integration phase to increase the effectiveness of change. Managers may use these findings as an evaluation checklist or benchmark and identify potential blackspots in the current setup. In doing so, existing sensing, seizing, and transforming actions might be confirmed, extended or exchanged.

Furthermore, our two new phases sensitise managers to evaluate and identify weaknesses in openness to LM and I4.0 integrations, lack of sensing activities, or unsustained results. Considering five instead of three phases enhances holism and represents a novel proposition in contrast to previous research that typically builds on the original elements of the DC construct (Felsberger et al. 2020; Ghobakhloo and Fathi 2020; Kump et al. 2018). Our findings suggest that including entrainment effects and sustaining activities completes the efforts of integrating LM with I4.0. 'Initiating' allows managers to address a psychological element, aligns with initiation efforts in classic change management literature, and is considered an important change success determinant (Balzer et al. 2019; Williams and Williams 2007). Besides, including 'sustaining' efforts in, e.g. Lean Six Sigma projects is a well-established construct (Sunder and Antony 2018). Our findings suggest that including the presented measures of 'sustaining' the program level of integrating LM with I4.0 benefits.

6. Conclusions and agenda for future research

This article addresses the call for more explorative research concerning the integration of LM and I4.0 and its theoretical lens of DC by posing the two RQ of (1) how firms can execute an integration of LM with I4.0, and (2) what skills, resources, and processes are necessary to do so (Buer et al. 2021; Collis and Anand 2021). Subsections 4.1–4.5 address

RQ1, while Subsection 4.6 addresses RQ2. Our findings and their discussion suggest that firms may integrate LM with I4.0 by following the proposed processual model, which consists of the five stages of 'initiating', 'sensing', 'seizing', 'transforming', and 'sustaining'. Compared to the original elements of the DC framework, we suggest including two additional phases of 'initiating' and 'sustaining' (Collis and Anand 2021). Firms should evaluate if their transformation efforts already cover our presented measures according to each phase of the model and close the loop by including further operational measures. Besides including these measures, firms should evaluate their resource and capability base compared to the presented essential resources and capabilities to ensure that the organisation is sufficiently equipped to execute the respective integration.

As with every research, several limitations need to be stated. We derived our findings from German experts engaged in large manufacturing firms. Hence, the findings might hold a country and company-size bias specific to Germany. Furthermore, generalisation needs to be validated by further, preferably quantitative studies, as intended by the research team. Finally, sector-specific requirements were discussed during the interviews and considered present for themes selection, but less concerning the methodological steps and resources of the proposed integration model. Finally, this article follows the theoretical lens of DC. Studying the topic based on other theoretical lenses might introduce different themes or even contrary findings.

We emphasise future research to build on the research direction of challenging and evaluating the outlined subthemes and deriving further or different modes of action to achieve a holistic view informing firms to execute integrated transformations of LM and I4.0. Furthermore, deriving differences between integrated approaches and singular integrations concerning involved resources and capabilities, synergies or specific integration efforts, and specific pathways on operational levels opens up new opportunities for firms on existing recommendations for action. These contributions offer valuable perspectives for practitioners and contributions to the power and limitations of the DC framework (Collis and Anand 2021).

Disclosure statement

No potential conflict of interest was reported by the author(s).

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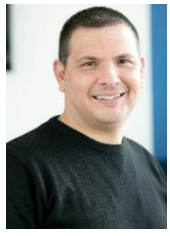

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Appendix A

Table A1. Interview guide.

No.	Question:	Optional Follow-ups	Category
0	Setting the scene on large German manufacturing firms intending to integrate LM with I4.0. Remind participants about anonymity, recording, transcription and to focus on their individual perceptions and experiences		Introduction
1	Age? Position in company? Years of experience in Transformations, Lean Management, Industry 4.0?		Opening
2	What is your experience in integrating Lean and Industry 4.0?	What have you done/changed to execute the integration?	Integration themes
3	How should firms initiate their start in integrating Lean and Industry 4.0?	What kind of governance should firms apply? What kind of resources have been involved?	
4	How can firms adjust or develop their resources and capabilities for executing an integration?	What kind of capabilities have been involved? What kind of processes have been involved?	
5	How can firms identify the right themes of Lean and Industry 4.0 to start with?	Should firms focus first on organisational aspects, network of flows, single value streams or specific processes?	Modes of action
6	Which elements of Industry 4.0 should be deployed separately to Lean?	Which elements of Lean should be deployed separately to Industry 4.0?	
7	Do you know examples, where no previous Lean implementation is reasonable?	Does organisational culture influence the need of a previous Lean implementation?	
8	Does the role of change management change?	Which changes are especially relevant when integrating Lean with Industry 4.0?	
9	How can firms govern an integrated transformation?	How do you think about the following statement: Lean typically utilises problem solving techniques, Industry 4.0 tends to adopt Scrum-projects.	
10	Integration of I4.0 increases technological complexity; how can organisations keep continuously learning?		Specific knowledge gaps
11	Which type of process standardisation is required?	How can standardisation e.g. by working instructions or processes become agile to allow fast adaptations?	
12	How do you consider the role of external knowledge (consultancies, universities etc.)?		
13	Are there important aspects, that were not mentioned, yet?		Ending

Appendix B

Table A2. Aggregation of stages and sub-themes.

Stage	Derived sub-themes
Initiating	Pilots in specific areas to generate entrainment effects
	Routing customer feedback to corresponding processes
	Practising to see waste and problems with the management team
	Align the management team and develop a convincing change story
Sensing	Collaboration with industrial partners
	Exchanges on best practices
	Smaller and more frequent impulses instead of yearly benchmark visits
	Input from outside an organisation, especially for I4.0 practices
	Install regular job rotations on the leadership level
	Develop networks with benchmark partners
	Utilise internal cross-functional project teams
	Regularly reflect on own approaches (e.g. quarterly)
Seizing	Use value-stream mapping to identify the core value stream
	Use group discussions concerning pain points
	Conduct interviews with employees
	Use a combination of qualitative and quantitative evaluations
	Use process analysis to identify weaknesses
	Deploy logical implementation sequences
	Define, communicate, and deploy a target state
Transforming	Adopt a hybrid approach of top-down strategic initiatives filled with bottom-up suggestions
	Utilise Hoshin Kanri to define "must" LM and I4.0 principles
	Breakdown strategy on a tactical level defining who, what and when
	Develop appropriate transparency and tracking on the measure level
	Conduct classical monthly steering committees vs. agile project management
	Define inputs and outputs to be shared between different governance levels
	Focus reporting on demonstrations on Gemba rather than extensive project documentation
	Focus on inclusion in solving hurdles instead of progress reporting to the hierarchy

(*continued*)

Table A2. Continued.

Stage	Derived sub-themes
	Decentralisation of responsibilities
	Initiate broad communication concerning progress (e.g. regular open reporting meetings in canteens)
	Invite champions or sponsors to demonstrate responsibilities regularly
Sustaining	Enable staff to rather introduce change instead of conducting change themselves to overcome increasing technological complexity
	Enable operational staff to remain responsible for realising adaptations, IT/OT function as support
	Install physical or digital Continuous Improvement boxes
	Install regular suggestion meetings with IT/OT on Shopfloor
	Utilise I4.0 practices as more reliable solutions for process standardisation (e.g. Augmented Reality)
Capabilities/ Resources	Centralise IT architecture capabilities and decentralise IT capabilities with an implementation focus
	Integrate OPEX and IT within one department
	Basic requirements concerning roles: hold at least one advanced OPEX expert, internal IT department, and one expert who is able to evaluate implementation capabilities concerning potential LM/I4.0 practices
	Basic requirements concerning skills: networks and databases, data analysis, low code, broad foundational understanding of LM and I4.0
	Constitute a core team based on influence and role-model capabilities
	Work with tandems of OPEX and IT resources (e.g. within one project team)
	Evaluate adaptive and digital capabilities to derive a development plan
	Develop deeper knowledge for voluntary and talented employees (e.g. key users or technical change facilitators)
	Train OPEX experts rather in applying instead of implementing I4.0 practices
	Train IT experts in the basics of OPEX
	Train key users within production staff as first-level support
	Involve external resources in the early stages of projects or programs to overcome lacking capabilities, capacity shortages or capability transfers