# Beyond lean production practices and Industry 4.0 technologies toward the human-centric Industry 5.0

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## Abstract

**Purpose** – Both technological and human-centric perspectives need to be acknowledged when combining lean production practices and Industry 4.0 (I4.0) technologies. This study aims to explore and explain how lean production practices and I4.0 technologies may coexist to enhance the human-centric perspective of manufacturing operations in the era of Industry 5.0 (I5.0).

**Design/methodology/approach** – The research approach is an explorative and longitudinal case study. The qualitative data collection encompasses respondents from different job functions and organizational levels to cover the entire organization. In total, 18 interviews with 19 interviewees and five focus groups with a total of 25 participants are included.

**Findings** – Identified challenges bring forth that manufacturing organizations must have the ability to see beyond lean production philosophy and I4.0 to meet the demand for a human-centric perspective in socially sustainable manufacturing in the era of Industry 5.0.

**Practical implications** – The study suggests that while lean production practices and I4.0 practices may be considered separately, they need to be integrated as complementary approaches. This underscores the complexity of managing simultaneous organizational changes and new digital initiatives.

**Social implications** – The research presented illuminates the elusive phenomena comprising the combined aspects of a human-centric perspective, specifically bringing forth implications for the co-existence of lean production practices and I4.0 technologies, in the transformation towards I5.0.

**Originality/value** – The study contributes to new avenues of research within the field of socially sustainable manufacturing. The study provides an in-depth analysis of the human-centric perspective when transforming organizations towards Industry 5.0.

**Keywords** Social sustainability, Lean production practices, Industry 4.0 technologies, Industry 5.0, Human-centric, Manufacturing management

**Paper type** Research paper

## 1. Introduction

There are calls for human-centric perspective in manufacturing research to better understand the complex systems in which humans and technology are paired in the digital transformation (Eriksson *et al.*, 2022; Lu *et al.*, 2022; Nahavandi, 2019). The socially sustainable challenges in contemporary manufacturing have been emphasized as a response



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to the technocratic understanding of digital transformation within the manufacturing industry. Humans are a core part of the lean philosophy, and lean practices are often considered to bring forward the importance of humans in manufacturing (Rother, 2010 p. XV). Managers and practitioners hence need to acknowledge the importance of employees' behaviors and managerial practices and during digital transformation (Alieva and Powell, 2022; Olsson *et al.*, 2024) and organizational concerns should be proactively arranged before adopting new technologies, rather than reactive responses (Marcon *et al.*, 2022).

The emphasis of human-centric perspective when implementing Industry 4.0 (I4.0) technologies are argued advantageous when moving forward in the analog designed Lean Production (LP) systems (Rossini *et al.*, 2021). Hence, the emerging concept of Industry 5.0 (I5.0) aims to complement the existing I4.0 approach by focusing on a sustainable, human-centric and resilient manufacturing industry (Breque *et al.*, 2021; Nahavandi, 2019). While the main concern in I4.0 is implementing new digital technologies, the research presented here brings forth the human-centric perspective of I5.0 focusing on the interconnection between humans and technology (Nahavandi, 2019). I5.0 accentuates operators and engineers in production processes and optimizing human work procedures, routines, decision support and information exchange (Eriksson *et al.*, 2022). Earlier research shows that production and operations management literature lacks research on the interplay between technology and work practice (Cagliano *et al.*, 2019) and that there is a linkage between technology competence and productivity (Masiko *et al.*, 2022). The field of I5.0 research is emerging and there are calls for further research to explain and exemplify socially sustainability and the human-centric perspective (Carlsson *et al.*, 2022; Eriksson *et al.*, 2022; Huang *et al.*, 2022; Zizic *et al.*, 2022).

As the I4.0 era evolves, the realization of addressing challenges of introducing novel digital technologies in existing LP systems. The LP philosophy with its practices originated in a different era (Womack *et al.*, 1990) and largely has dominated the manufacturing industry as the prevailing production system over the last decades (Janoski and Lepadatu, 2021; Åhlström *et al.*, 2021). However, it is argued that LP has not evolved despite changing and volatile markets (Hoellthaler *et al.*, 2018). An increasing awareness has gained ground emphasizing the importance of understanding the coexistence of LP practices and I4.0 technologies and simultaneously supporting digital transformation (Rossini *et al.*, 2021). Earlier research shows positive views of linking LP with I4.0 (Cifone *et al.*, 2021; Rossini *et al.*, 2021). However, the marriage between the two paradigms is not clear-cut and requires research into the interconnection between digital technologies and human skills and learning in existing manufacturing systems (Carlsson *et al.*, 2022; Cifone *et al.*, 2021; Eriksson *et al.*, 2022; Tortorella *et al.*, 2019). At the same time, it is recognized that LP alone has its difficulties for transformation and implementation in manufacturing, e.g. emphasizing organizational culture shifts and adaptive leadership (Maware and Parsley, 2022) and the importance of engagement from the management (Emiliani, 2018; Alieva and Powell, 2022). Though, it has been argued that the application of an iterative and continuous improvement LP approach when implementing I4.0 technologies may be beneficial (Rossini *et al.*, 2021; Sarro, 2020). Nevertheless, it is reasoned that LP practices and I4.0 have intrinsically distinctive characteristics, where LP focus on iterative continuous improvement and the involvement of humans, whereas I4.0 is characterized by disruptive technologies and radical change in large steps (Rossini *et al.*, 2021). This study contributes to bringing forth the complexity of managing simultaneous organizational changes in digital transformation towards I5.0. This addresses the need to acknowledge both technological and human-centric perspectives of combining LP and I4.0, highlighting the movement of analog production systems towards digital transformation. The study aims to explore and explain how LP practices and I4.0 technologies may coexist to enhance manufacturing operations in the era of I5.0. The study builds on previous work by (*Authors ND; Authors ND; Authors ND; Authors ND)* to

strengthen the emerging research on the human-centric perspective of I5.0 via a longitudinal case study, focusing on both digital technologies and socially sustainable human-centric perspective. Two research questions are posed:

*RQ1.* What challenges do manufacturing companies encounter when operating in the coexistence of lean production practices and I4.0 technologies?

*RQ2.* How are lean production practices and I4.0 perceived to be combined by employees being part of digital transformation approaching the human-centricity of I5.0?

In the following section, the research background is outlined focusing on lean production practices, the coexistence between I4.0 and lean production and I5.0 and the human-centric perspective. Thereafter follows the methodology section outlining the case description, qualitative method data collection and data analysis. This is followed by findings, discussion and conclusion.

## 2. Research streams – lean production, Industry 4.0 and Industry 5.0

The manufacturing industry is historically struggling to implement LP practices despite established principles and tools to reach ways of working and improving production efficiency (Janoski and Lepadatu, 2021). At the same time, a new manufacturing landscape is emerging facilitated by I4.0 technologies, creating a volatile environment in which the industry is expected to identify and adopt novel technologies (Sousa-Zomer *et al.*, 2020). Therefore, further understanding in both theory and practice of the complexity and challenges surrounding successful implementation of I4.0 technologies is called for (Alcácer and Cruz-Machado, 2019; Frank *et al.*, 2019), especially in the coexistence between LP and I4.0 (Rossini *et al.*, 2021; Sarro, 2020). The complementing paradigm of I5.0 highlights the creativity and intelligence of humans in interconnection with intelligent machines to obtain user-favored manufacturing solutions, striving towards trust and new competence to achieve socially sustainable manufacturing. As such, emphasis is put on acknowledging human strengths and competencies, including talents, skills, diversity and empowerment (Xu *et al.*, 2021). The emergence of I5.0 is argued to stem from a necessity to combine and frame both industry and societal trends and needs (Xu *et al.*, 2021).

### *2.1 Lean production practices*

The term "lean production" was first used in 1988 by John Krafcik to explain successful Japanese manufacturing methods (Krafcik, 1988). LP is described as a production system that focuses on reducing waste (muda), continuous improvement (kaizen) and focus on quality (Womack *et al.*, 1990). Characteristics of LP systems is the importance of pull practices as opposed to push practices, where pull practices means that the final process timely draws the required quantities from the previous process and this procedure is then repeated through all processes upstream (Ohno, 1988). Since the transmission of LP out of the Japanese automotive industry, specifically the Toyota Production System (TPS), by the 1990s, it has irrefutably diffused into the Western World manufacturing industry (Janoski and Lepadatu, 2021 p.5; Hoellthaler *et al.*, 2018). TPS and LP have over time diverged from each other, as LP attempts to attract more attention from a management point of view developing into Lean Management and later Lean Strategy (Emiliani, 2018). LP as a strategy for flow efficiency has gained and maintained its position in the manufacturing industry over the past decades (Modig and Åhlström, 2016) where LP has proven beneficial for, e.g. reduction of transportation times and increased efficiency throughout production processes (Ribeiro *et al.*, 2019). More recent research streams have raised that LP cannot continue to be efficient without I4.0 technologies (Cagnetti *et al.*, 2021) and there is the notion that LP have reached it

limits with the analog implementation in organization and production processes (Hoellthaler *et al.*, 2018). Thus, there is the ongoing involvement and anticipation in the research field of the coexistence of LP and I4.0 (Hines *et al.*, 2023).

### *2.2 The coexistence between Industry 4.0 and lean production*

I4.0 encompasses profound changes in manufacturing industries through the application and implementation of digital technologies, including, e.g. the Internet of Things (IoT), advanced robotics and big data analytics, additive manufacturing, augmented reality, often in relation to artificial intelligence (AI) (Alcácer and Cruz-Machado, 2019; Qu *et al.*, 2019). The digital advancement of I4.0 embraces a plurality of core technologies, methodologies and trends aided towards increased process efficiency, value creation and competitiveness (Matt *et al.*, 2023; Sousa-Zomer *et al.*, 2020). This research stream emphasis I4.0 being the defining moment to the end of the conventional centralized applications and disruptively impact manufacturing industry towards the smart manufacturing ecosystems (Alcácer and Cruz-Machado, 2019).

Seeing the possibilities with I4.0 technologies there are developments for the fusion between LP and I4.0 or applying both simultaneously for an efficient and flexible manufacturing industry (Deshmukh *et al.*, 2022; Jiang *et al.*, 2021; Sarro, 2020). This stresses the possibility of assessing and continually enhancing manufacturing processes to improve customer value, enable data-based decisions and facilitate continuous improvement (Javid and Haleem, 2020). Thus, LP practices cannot continue to be efficient if integration with I4.0 technologies and LP is neglected (Gallo *et al.*, 2021; Ghobakhloo *et al.*, 2022). Advantages of combining LP and I4.0 emphasize that the LP practices can be implemented digitally to further reduce waste on time, cost and quality (Hoellthaler *et al.*, 2018), I4.0 technologies can enhance pull systems in regards data collection throughout manufacturing processes and e-kanban for triggering automatic replenishment (Tortorella *et al.*, 2019) and digital solutions for Value Stream mapping (VSM) (Huang *et al.*, 2019) with agent-based approaches (de Paula Ferreira *et al.*, 2022). Furthermore, the characteristics of continuous process improvements of LP practices can play a role in guiding the implementation of I4.0 (Rossini *et al.*, 2021).

Recent research stresses the challenges of combining LP and I4.0 from different points of views (Dornelles *et al.*, 2022; Hoellthaler *et al.*, 2018; Rossini *et al.*, 2021; Tortorella *et al.*, 2019). The sole adoption of digital LP tools while not considering effective pull systems may result in the production remaining a push system (Tortorella *et al.*, 2019). A production system in the dual context of LP and I4.0 is emphasized as challenging as LP is based on continuous improvement, structure and sets of rules, whereas I4.0 development is considered to evolve dynamically when adopting disruptive technologies (Hoellthaler *et al.*, 2018; Rossini *et al.*, 2021). Another vital challenge is that LP is considered a human-centered production system, and this aspect is not acknowledged in the implementation of the I4.0 technologies which has a strong technocratic focus (Cagliano *et al.*, 2019; Dornelles *et al.*, 2022). Simultaneously combining LP practices and I4.0 technologies entails challenges to avoid focusing purely on digitalization (Frank *et al.*, 2019; Sousa-Zomer *et al.*, 2020), or solely on LP implementation (Emiliani, 2018; Maware and Parsley, 2022). Current research streams suggest that crucial factors for successful digital transformation are technology readiness, organizational strategy and organizational culture (Antony *et al.*, 2023a) along with a shared understanding of production characteristics (Eriksson *et al.*, 2022). Within this, it could be argued that the field has recognized that the human-centric perspective is important as the coexistence of a LP system and I4.0 technologies is characterized by applying advanced I4.0 technologies. While at the same time coordinating LP practices and acknowledging the company vision (Antony *et al.*, 2023a; Deshmukh *et al.*, 2022) alongside with the need for extended human skills and competences (Alieva and Powell, 2022; Carlsson *et al.*, 2022; Masiko *et al.*, 2022).

### 2.3 Industry 5.0 and the human-centric perspective

I5.0 has been raised over the past couple of years as an emerging value-driven concept complementing I4.0 (Breque *et al.*, 2021). I5.0 focuses on the organizational transformation to a sustainable, human-centric and resilient manufacturing industry in which talents, diversity and empowerment are emphasized for flexible and adaptable production processes (Breque *et al.*, 2021). Human interaction, critical thinking and interpretation are argued crucial when facing challenges in implementing I4.0 technologies (Nahavandi, 2019). Handling organizational changes such as digital transformation is argued to include social sustainability such as the involvement of all employees, strategic communication, innovation and leadership (Marcon *et al.*, 2022; Olsson *et al.*, 2024).

Lean production is recognized as a people-centered production system, by rigorously utilizing human capabilities (Rother, 2010 p. XV). However, critique has been raised that the LP production system ought to focus more strongly on the human-centric perspective (Janoski and Lepadatu, 2021 p. 6). As regards I4.0, such initiatives have been especially criticized for focusing solely on the technological aspects of implementing I4.0 and leaving the human-centric perspective to the side (Xu *et al.*, 2021). Hence, it is crucial to balance aspects of novel technology, but always keeping humans in the center (Zizic *et al.*, 2022). Thus, both LP and I4.0 benefit from an increased human-centric perspective as accentuated by I5.0. Emerging I5.0 research emphasizes the importance of balancing the one-sided emphasis on technology with the recognition of human strengths and competencies to achieve a socially sustainable digital transformation. This study aligns with emerging I5.0 research by contributing to explore the complexity of acknowledging both technological and human-centric perspectives when combining LP and I4.0.

## 3. Methodology and data analysis

The methodology and analytical approaches of this case study address the aim to explore and explain how LP practices and I4.0 technologies may coexist to enhance manufacturing operations in the era of I5.0. This section includes the case description and outlines the qualitative data collection from the longitudinal and explorative case study (2020–2023). The complexity of digital transformation and the coexistence of LP and I4.0 add further complexity, motivating a qualitative approach. The case study methodology, with qualitative data collection, was chosen to capture the elusiveness of both lean production practices and digital initiatives focusing on the employee perception of digital transformation. To enhance data richness focus groups and interviews were combined (Lambert and Loiselle, 2008) to give participants voice and opportunity to jointly reflect on the perceived understanding, in their real context, i.e. CC, as recommended by Yin (2018). Below are the details of the timeline, data collection and analysis regarding the interview informants and focus group participants.

### 3.1 Case description

One large Swedish manufacturing company, producing components for use in the energy sector was selected as the case, herein referred to as the Case Company (CC). CC manufactures and performs maintenance of large-sized, heavy, high-quality and cutting-edge components in a national and international supply chain of manufacturing units as part of a large global company. CC has a hierarchical organizational structure, operating at a centralized office level supported by the business functions. The digital transformation of the global company is scattered across manufacturing units, with early and late adopters of I4.0 technologies, which is an additional complexity as addressed by Antony *et al.* (2023b). The CC manufacturing unit selected for this case study has low levels of digitalization and

automation with a high degree of manual work, e.g. welding operations and previously LP has gained low interest. However, in the latter years, LP has gained attention at CC and initiatives of introducing LP principles and methods are ongoing in parallel with introducing digital initiatives. Thus, the case captures CC while simultaneously juggling implementing of LP practices and introducing novel digital technologies. This lends a suitable case for studying not only the coexistence of LP and I4.0, but also investigating the concurrent implementation and ambivalent use of analog and/or digital methods for production improvement and advancement.

### *3.2 Data collection*

The data collection was explorative and qualitative, focusing on understanding challenges and successes of the simultaneous implementation and coexistence of lean production and I4.0 digitalization. The case study design is focused on understanding the dynamics over time within a specific setting. The crafting instruments and protocols, here design of interviews and focus groups, are combined with multiple investigators contributing complementary insights and perspectives adding richness to the data (Eisenhardt, 1989). Furthermore, there is an argument that "to study change [digitalization], one needs longitudinal data" (Laaksonen and Peltoniemi, 2018, p. 187). Therefore, the longitudinal case study method was chosen with data collection through semi-structured interviews and focus groups with CC employees in its real context (Eisenhardt, 1989; Ekanem, 2007; Yin, 2018). The term employee is herein applied in a general sense to describe all co-workers at the company. The qualitative approach allowed the informants and participants to give voice to their understanding and interpretation (Bell *et al.*, 2019) of ongoing implementations of production improvements at CC.

*3.2.1 Interviews.* Purposive sampling was applied to select and reach interview informants engaged in initiatives for I4.0 digitalization and/or implementation of LP practices. This choice of sampling was strategically made to capture informants' perceptions and understanding of the phenomena studied (Bell *et al.*, 2019). To identify further informants and to reach saturation of the number of informants (Saunders *et al.*, 2018), snowball sampling (Bell *et al.*, 2019) was applied. Snowball sampling means that one informant recommends the second who refers to the third and so on as a dynamic social process conveyed over time (Olsson *et al.*, 2020). The phenomena investigated are elusive and can be difficult to grasp and thus require a sampling technique that allows the finding of hidden, hard-to-reach and conflicting groups of informants (Atkinson and Flint, 2001). All interviews followed a semi-structured interview guide including the themes of questions on analog and digital production planning and control; I4.0 technologies; organizational change, structure and leadership. All interview informants were given the same questions, though the semi-structured interview guide enabled capturing additional viewpoints. The interview study incorporates 18 interviews with 19 respondents. The main part of the interviews, i.e. the Informant IDs 1–14, were performed for nine months (October 2020–June 2021). However, an additional four interviews, i.e. the Informant IDs 15–18, took place in the beginning of the year (February 2023). The choice of additional interviews was made strategically from the methodological point of view to fill two purposes: collecting data on the most recent development at the company and as there have been a fluctuation of turnovers of employees it was important to capture new voices, thus adding four complementary interviews. The interview part of the case study comprises 18 in-depth interviews with management, production planners, production team leaders, quality control and corporate service functions such as human resources (HR) and business administration. The selection of informants aims to get an encompassing understanding from different functions. In one of the interviews, two informants took part (11a and 11b); thus, 19 informants were interviewed. All interviews were

recorded with informed consent, and they were digitally conducted both due to restrictions of the COVID-19 pandemic and for easy recording, storing and analyzing. Table 1 shows the total overview of interviews and informants.

*3.2.2 Focus groups.* The choice of focus group as complementary method meant that a large range of functions from CC could be included in the case study, and as such, the range of functions can give perspectives of different production improvements such as digitalization initiatives (Authors, ND; Authors, ND). Focus groups give voice to participants' views and offer rich opportunities to gather data as participants share, jointly reflect and build on their interpretations of a context or phenomenon (Rutledge *et al.*, 2021). All focus groups were planned with the same design to capture participants', here employees from different functions and levels at CC, interpretations of initiatives for LP and I4.0. CC supported sampling of participants from all functions, considering a range of gender, employed time and work tasks to reflect the distribution of the company. The participants were divided by function to limit power differences and restrictions to socially acceptable comments (Smithson, 2000). The focus groups explore the journey through implementing LP practices and digital initiatives to understand the handling of their coexistence in the manufacturing company CC. An essential strength of this approach is the possibility for participants to reflect and develop ideas together and construct individual and group opinions that may change and develop during the group's duration (Smithson, 2000).

The case incorporated five focus groups and was performed over 10 months (April 2022–January 2023), with 25 participants from different job functions to encompass the entire organization: shop floor team leaders, shop floor operators; support functions including. Supply Chain Manager (SCM), technical management and manufacturing engineers. Table 2 shows the total overview of focus groups and participants. In the focus groups Support functions including. SCM (F3) and Technical management (F4) there is a 100% overlap of participants that also have participated in interviews. However, the focus groups Shop floor team leaders (F1), Shop floor operators (F2) and Manufacturing engineers (F5) do not have any overlaps between participants from interviews. Some overlap between interview

| Function categorization | Number of interviews | Informant IDs | Duration (hours) |
|---|---|---|---|
| Technical management | 5 | 1, 2, 6, 12, 15 | 4.0 |
| Production planning and control | 3 | 5, 7, 8 | 2.5 |
| Production team leaders | 4 | 4, 9, 16, 18 | 3.6 |
| Quality management | 2 | 3, 17 | 1.7 |
| Business adm., controllers, HR | 4 | 10, 11a, 11b, 13, 14 | 3.0 |
| *Tot. 5 Function categories* | *Tot. 18 interviews* | *Tot. 19 informants* | *Tot. 14.8 h* |

**Source(s):** Authors' own creation

**Table 1.** Overview of interviews and informants

| Function categorization | Focus group name | Participants IDs | Duration (hours) |
|---|---|---|---|
| Shop floor team leaders | F1 | F1.1, F1.2, F1.3, F1.4, F1.5 | 1.7 |
| Shop floor operators | F2 | F2.1, F2.2, F2.3, F2.4 | 1.6 |
| Support functions incl. SCM | F3 | F3.1, F3.2, F3.3, F3.4, F3.5, F3.6 | 1.9 |
| Technical management | F4 | F4.1, F4.2, F4.3, F4.4 | 1.4 |
| Manufacturing engineers | F5 | F5.1, F5.2, F5.3, F5.4, F5.5, F5.6 | 1.5 |
| *Tot. 5 Function categories* | *Tot. 5 focus groups* | *Tot. 25 participants* | *Tot. 8.1 h* |

**Source(s):** Authors' own creation

**Table 2.** Overview of focus groups and participants

informants and focus group participants is viewed as advantageous as this allowed to follow how CC evolved over time.

Aiming to capture both present and retroactive perspectives, all focus groups were designed inspired by the history wall approach (Karanasios, 2018). The focus groups were run in a workshop format where participants together created a history wall, i.e. a visual representation of activities in the organization over time (Wheeler and Thomas, 2011). All participants were asked to consider what initiatives had occurred, either directed towards increased digitalization or towards lean production or organizational changes between the years 2015–2023. The reason for choosing the year 2015 as starting point was based on previous studies at CC (*Authors ND*; *Authors ND*), where results indicated that from 2015 and onwards, various digital initiatives, lean production practices, as well as organizational changes took place. During the 1.5-2-hour focus group sessions, participants sat in a half circle around a table and wrote activities on a long rolled-out paper that all participants could reach and write on, i.e. a history wall, overlooking participants' interpreted activities. The focus group leader, one of the researchers, circled the table and moderated the workshop to limit the risk of single participants dominating the discussions. The other researchers focused on notetaking and video and audio recording (with informed signed consent), occasionally breaking in with follow-up questions.

*3.2.3 Summary of data collection.* Figure 1 summarizes the data collection, including timeline, of the qualitative methodology longitudinal case study approach. The case study incorporates 14 interviews (Dec. 2020–Jun. 2021) with 15 informants, after that, followed the focus group study with 25 participants (Apr. 2022–Jan. 2023) and additionally four complementary interviews (Feb. 2023). Further, to the left side of Figure 1, the retrospective direction of the history wall approach stretching back to 2015 is shown.

### *3.3 Data analysis*

This section initially outlines the mind-map approach for conducting the data analysis and raising findings from both interviews and focus groups. Thereafter, the next level/in-depth analysis, incorporating excerpts from both interviews and focus groups, is described and the results of the aspects of the coexistence of LP and I4.0 are expressed.

*3.3.1 Data analysis and findings from the mind-map approach.* An explorative mind-mapping approach guided the analysis of the interview and focus group data sets. This analytical approach was appropriate to provide structures and mental models that support information understanding of the two data sets (Fearnley, 2022; Wheeldon and Faubert, 2009). Mind-mapping may further be applied as an interdisciplinary tool to identify, illustrate and analyze perspectives, relationships and differences across qualitative datasets (Fearnley, 2022). The visual representation provided extended ways of representing the data and, in

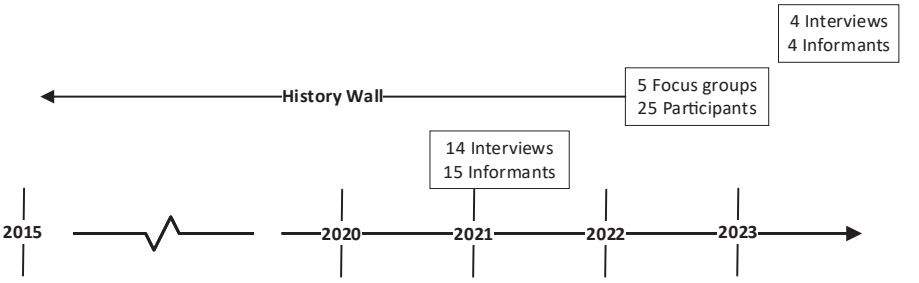


**Figure 1.**
Longitudinal case study data collection timeline

**Source(s):** Authors' own creation

turn, the categories and sub-categories that emerged from the data are visualized in mind-maps. The mind-mapping approach followed an analytical process of six steps: verbatim transcripts, familiarizing with data, coding scheme as mind-map analysis, selection of excerpts, analyzing and categorizing of excerpts, mind-map categories and sub-categories.

First, all collected data were transcribed verbatim. Then, the multi-disciplinary group of authors familiarized themselves with the transcripts, and after that, the data was analyzed in several rounds, jointly by all authors, in an iterative approach. The transcriptions from all 18 interviews and all 5 focus groups were read and scanned for excerpts concerning LP and digitalization initiatives. The excerpts were structured and analyzed further in several iterations using Excel software. The analysis resulted in the final number of 123 excerpts from the interviews and 81 excerpts from the focus groups, i.e. a total of 204 excerpts are included in the study. The two data sets were analyzed in parallel, creating two mind-maps, see Figure 3. Most of the interviews took place before the focus group, though four of the interviews complementing the study were done at the end of the study to follow up latest developments at CC and to incorporate more recent employees, see Figure 1. The advantages with the interviews are that the data collected goes deeper, informants may feel more trust, are allowed to act more personally and more easily owns the work and speak up, thus there may be more critical answers in the individual interviews (Bell *et al.*, 2019). On the other hand, the focus groups allowed joint reflection among participants, which may lead to further aspects being unveiled as discussions evolve (Rutledge *et al.*, 2021; Smithson, 2000). Further, the focus groups differ from the interviews as they were designed inspired by the history wall approach (Karanasios, 2018) and sought to capture both present and retroactive perspectives.

The categorization and the application of the mind-map approach supports the inductive stepwise thematic data analysis (Braun and Clarke, 2012) towards reaching a deeper understanding of what challenges that manufacturing companies encounter when searching for a coexistence between LP and I4.0, i.e. research question 1. The mind-map in Figure 2 represents the analysis of the interview study and the mind-map in Figure 3 represents the analysis of the focus groups. Both mind-maps are centered on *Initiatives*, which include all activities and changes that the employees bring forth as impacting the organization towards increased digitalization or implementation of LP practices. However, there is also a flora of other initiatives that take place continuously within CC, impacting organizational development. To summarize there are five sub-categories of Initiatives, *Digital coordination, Digital initiative, Lean coordination, Lean production practice and Organizational change*, are shared between the two mind-maps, in the focus groups the additional sub-category *New machinery* was identified. The next iteration of the inductive analysis generates two further sub-categories: areas of improvement, *Focus of improvement* and assess employees' interpretation of whether the initiatives were a success or resulted in implementation challenges, *Success or Challenge*. The numbers in the mind-maps in Figure 3 show the amount of the excerpt from the analysis representing each category or sub-category. The categories and sub-categories are described and discussed in further detail in section.

## 4. Findings and discussion

This study aims to explore and explain how LP practices and I4.0 technologies may coexist to enhance manufacturing operations in the era of I5.0. This qualitative case study draws on longitudinal data from CC, a manufacturing organization, that is juggling LP practice implementation in parallel with implementing I4.0 technologies. Two data sets of interviews and focus groups are integrated to advance the research field by contributing a deepened understanding of how manufacturing industries could move beyond LP practices and I4.0 technologies towards I5.0. The following section present findings and discussion related to

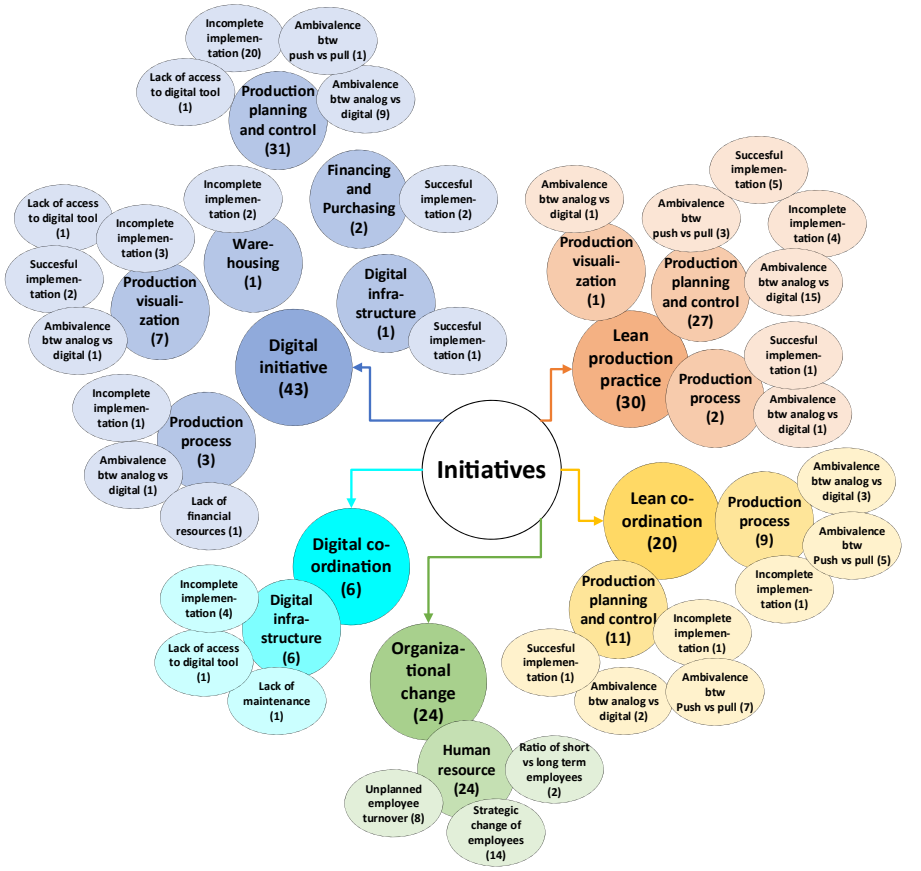


**Figure 2.**
Mind-map coding of findings from the interviews with categories and sub-categories

**Source(s):** Authors' own creation

the research questions: *Challenges when operating in the coexistence of LP practices and I4.0 technologies and Combinations* of *LP practices and I4.0 technologies in the organizational transformation towards I5.0.*

### *4.1 Challenges when operating in the coexistence of lean production practices and Industry 4.0 technologies*

Referring to RQ1, the interest was to understand and explain challenges in relation to these dual aspects of production systems. Findings are presented and discussed through three central categories: Initiative, Focus of Improvement, Success or Challenge.

*4.1.1 Initiative.* The central category, *Initiative*, captures activities or changes that have been introduced at CC including digital, LP practices and other initiatives related to production or organization. The scope includes initiatives related to production and other areas of the companies, giving an encompassing view of initiatives throughout the CC organization. Six sub-categories of initiatives have been surfaced during the analysis: *Digital coordination*, *Digital initiative*, *Lean coordination*, *Lean production practice*, *New machinery* and *Organizational change*.


**Source(s):** Authors' own creation

**Figure 3.**
Mind-map coding of findings from the focus groups with categories and sub-categories

The *digital coordination* category focuses on challenges between overarching digital infrastructure and shopfloor operators struggling with using and accessing shop-floor computers. That is, what kind of hardware currently exists within CC and what might be necessary to reach the desired object of either I4.0 or LP practices. When informants spoke of hardware, most discussions related to the need for Internet access and digital support functions. *Digital initiative* came to span between software applications for administrative tasks, such as Microsoft Teams and financing software, to digital warehouse technologies, advanced production planning systems and IoT solutions. Findings revealed a great span between technological applications due to the cross section of data sets displaying a combination of functions and, more importantly, interpretations of LP practices and I4.0 technologies. Acknowledging the broad variety of perceptions of what digital initiatives potentially encompass in relation to the manufacturing features is imperative. *Lean coordination* relates to a higher overarching practice guiding the philosophy of the company. Indicating that all employees of the company must engage and that lean principles permeate the whole organization. In the findings fragmented perceptions of lean initiatives are shown. This concurs with (Eriksson *et al.*, 2022; Sousa-Zomer *et al.*, 2020) stating that contradictory actions within the organization are common and sometimes hard to overcome. For example, CC management does not speak of a tuned strategic initiative or related actions. This also

means when *Lean production practice*s are initiated, employees lack a shared understanding of Lean, making it challenging to maintain lean initiatives such as lean production flow boards and 5S-principles. *New machinery* was a category unique to the focus groups, particularly the shop floor operators spoke of new machinery in relation to digital initiatives. Shop floor operators spoke fondly of implementing new machinery and wished for further development of machinery. *Organizational change* was a recurring topic across data sets. For example, informants/participants, speak of organizational change as both an opportunity and disturbance of balance within the company. The digital initiatives are closely related to each phase of the organizational changes. Especially in relation to changes of management, but also changes in the shop-floor operator turnovers including consultants/short-term staff. It could be argued that this affects the organizational ability to implement LP practice and I4.0 technologies as it adds additional parameters to the already complexity in organizational changes (Janoski and Lepadatu, 2021; Maware and Parsley, 2022; Tortorella *et al.*, 2019).

*4.1.2 Focus of Improvement.* This second category, *Focus of Improvement*, identifies what areas within CC that have been chosen for improvement related to the different initiatives in the category Initiative. The scope includes initiatives related to production and other areas of the companies, giving an encompassing view of initiatives throughout the CC organization. *Focus of Improvement* was analyzed to consist of eight sub-categories: *Communication*, *Digital infrastructure*, *Financing and Purchasing*, *Human resource*, *Production process*, *Production planning and control*, *Production visualization* and *Warehousing*.

*Communication* is critical for handling changes in organizations and findings specifically show the use/practice of video conferences with communication platforms as a reoccurring theme. There is also mention of an internal communication platform which borders social media and internal communication channels. In general, administrative staff are pleased with the usage of various communication platforms. Meanwhile, other functions find the usage and access of communication platforms challenging to prioritize as it is interpreted to be time-consuming and interfering with their workflow. Hence, platforms and channels must be suitable with the intent of communication. In other words, the *Digital infrastructure* must match both the intended communication and employees' access to digital technologies. This shows that a functional digital infrastructure is required, linking both the structuring of hardware and software. Regarding *Financing and purchasing*, there are few examples of digital initiatives related to the topic. However, there are two cases related to digital payment solutions which both were successfully implemented. *Human resource* relates to a high degree of turnovers either planned, part of an overarching strategy, or unplanned. In discussions it becomes clear that CC has a high degree of consultants on both administrative tasks and in the various shop floor related tasks. There is a consensus among informants and focus group participants that CC has undergone multiple organizational changes to structure responsibility and management. The organizational changes combined with a high degree of consultants in various functions throughout CC has created a challenging environment for long-term strategic planning. As informants and focus group participants highlight, consultants come and go and act as a safety net for full-time employees and full-time employees change positions. This is a way of dealing with the fluctuating environment, but it also leads to uncertainty in the strategic work as human resources are continuously adjusting to new employee constellations and adjusting competence gaps (Alieva and Powell, 2022; Antony *et al.*, 2023a; Carlsson *et al.*, 2022). *Production process* holds a broader perspective of production development beyond I4.0 technologies and lean practices such as new machinery, strategic recruitments for shopfloor and implementations of off-the-shelf software. *Production planning and control* focuses on digital initiatives and Lean practices focused implementation to improve the production flows. Tortorella *et al.* (2019) describe that it is advantageous to dually work with I4.0 technologies and LP practices if the organization already has an implemented lean production practice. Informants and focus group

participants witness the challenges of simultaneously introducing lean production practices and digital initiatives. It could be argued that LP practices are more static in nature in contrast to the fast-paced changes that digital initiatives are argued to respond towards (Hoellthaler *et al.*, 2018; Rossini *et al.*, 2021). *Production visualization* relates to digital and LP practice implementation in the sense of visualizing the work for coordinating and planning. Informants and focus group participants give examples of visualizing the production and production orders, warehousing and blueprints through various digital solutions. Various forms of visualization are discussed: digital and non-digital flow boards, TV-screens and padlets. The focus is on visualizing the production rather than *how* to improve the production efficiency. When informants and focus group participants speak of *Warehousing, they relate it to the wish for an improved procedure for storage space including a digital warehouse solution* to avoid manually searching for material and components.

*4.1.3 Success or challenge.* This category explains, either the success of initiatives or the challenges occurring in relation to the different initiatives, weather related to digital initiatives, LP practices or other areas of improvement. The analysis of this category resulted in the identification of nine sub-categories: *Successful implementation*, *Incomplete implementation*, *Ambivalence btw analog vs digital*, *Ambivalence btw push vs pull*, *Lack of access to digital tool*, *Lack of financial resources*, *Lack of maintenance*, *Ratio of short vs long-term employees*, *Strategic change of employees* and *Unplanned employee turnover*.

The in-depth data analysis, findings and discussion of the sub-categories within the third category Success or Challenge is presented in Tables 3–5. The sub-categories are explained and exemplified with excerpts from both the interviews and focus groups. The sub-categories are divided into three tables. In total Tables 3–5 incorporates 34 excerpts from either the interview or the focus groups, selected excerpts have been chosen to illustrate and exemplify the success factors or challenges occurring when moving forward with LP and I4.0 in organizations going through changes.

Table 3 addresses the wide-ranging sub-categories successful implementation and incomplete implementation. The excerpts about successful implementation demonstrate that certain initiatives have been successfully implemented at CC. However, there are no examples of successful implementations of typical I4.0 technologies, e.g. IoT or digital twins. Instead, the excerpts identified relates to digital infrastructure (laptop computers), communication tools (Teams) and financing software, or being forces to change system because of a coincidental accident. Further, it should be noted that the LP tool Value Stream Mapping (VSM) is considered implemented and continuously used. The excerpts about implementation bring out initiatives of LP practices and I4.0 technologies that have not been followed through. This shows the difficulties in reaching full application of initiatives.

Table 4 focuses on the ambivalence between analog and digital and the ambivalence between push and pull, specifically highlighting challenges occurring when navigating among and searching for a coexistence of LP practices and I4.0 technologies. The excerpts regarding ambivalence show the perceived struggle between traditional analog LP practices and digital options. Analog approaches are also mentioned as being more reliable, though it is emphasized that physical boards need human intervention. Traditional analog VSMs have the advantage of facilitating teambuilding, whereas digital approaches are not viewed as appropriate for teambuilding. The excerpts demonstrate that CC struggles with the push versus pull principles. The importance of this lean characteristic is realized but viewed as difficult to turn the situation around.

Table 5 illustrates and exemplifies other challenges relating to informants and participants perceptions of what may affect novel initiatives, whether LP practices or I4.0 technologies. Table 5 thus includes the sub-categories lack of access to digital tool, lack of financial resources, lack of maintenance, ratio of short vs long-term employees, strategic change of employees, unplanned employee turnover. Excerpts show that CC employees are searching for digital

| | |
|---|---|
| *Successful implementation* (Tot. 23 excerpts) | *"Another thing that I think has had an impact is when we went from desktops to laptops. It was a large digitization and then you could take your computer with you and take the digital with you . . . it was 2012–2013 maybe?"* [F5.4]<br>See Figure 3: Digital initiative/Digital infrastructure/Successful implementation<br>*"Something else that was a large thing (change) was when we got Teams."* [F5.6]<br>See Figure 3: Digital initiative/Communication/Successful implementation<br>*"We should also include the grant request (financing). It's digital, we had it on a (paper based) form before."* [F5.4]<br>See Figure 3: Digital initiative/Financing/Successful implementation<br>*"We had two systems at the same time, because in the old one we had everything ready. But then a guy happened to drop it (the old system) and then we had to start using the new one."* [F2.3]<br>See Figure 3: Digital initiative/Production process/Successful implementation<br>*"VSMs, we work a lot with those and have done so for many years."* [12]<br>See Figure 2: Lean production practice/Production planning and control/Successful implementation |
| *Incomplete implementation* (Tot. 59 excerpts) | *"The production (employees) lost faith in the Advanced Planning and Scheduling (APS) system, so they didn't want to work with it anymore. They wanted a different system that was more visual so that everyone could understand. They thought it was too complicated to understand."* [5]<br>See Figure 2: Digital initiative/Production planning and control/Incomplete implementation<br>*"We've had flow boards a little before . . . this has somewhat deteriorated because it takes care of itself quite naturally as it is today . . . That's why we haven't used them for a while."* [17]<br>See Figure 2: Lean production practice/Production planning and control/Incomplete implementation<br>*"The difficulty with lean is actually following it and getting the whole business to follow it. We are good at using the tools, but if you look at what our production flow looks like, it is not lean."* [12]<br>See Figure 2: Lean coordination/Production planning and control/Incomplete implementation<br>*"We don't have computers beyond workplaces where we could easily stamp the production with electronic stamping, but they really do this physically on a piece of paper with a stamp."* [16]<br>See Figure 2: Digital coordination/Digital infrastructure/Incomplete implementation |

**Source(s):** Authors' own creation

**Table 3.** Illustrations of successful implementation and incomplete implementation

solutions to improve work practice. Financing and resources are brought forward as obstacles. The difficulties of keeping technology up to date and maintaining it for continuous use are mentioned. Further, infrastructure and support for IT- and digital solutions are imperative. There is an added complexity of old technique/machinery still being in use. Short-term employee contracts impact the organization and further, knowledge and competence are important.

### *4.2 Combinations of lean production practices and Industry 4.0 technologies in the organizational transformation towards Industry 5.0*

The second part of the study was related to RQ2, focusing on how LP practices and I4.0 technologies can be combined when manufacturing industries move towards I5.0,

| | |
|---|---|
| *Ambivalence btw analog vs digital* (Tot. 42 excerpts) | *"We have probably tried to drive this three times and try to digitalize the production order parts in particular. Without any major successes really."* [F3.1]<br>See Figure 3: Digital initiative/Production planning and control/Ambivalence btw analog vs digital<br>*" . . . had started the (lean flow) boards earlier and in about three months we had the flows up, but when the APS system was to be implemented, the planning department said that "we can't have the (lean) flow boards because they will break the APS system."* [1]<br>See Figure 2: Lean production practice/Production planning and control/Ambivalence btw analog vs digital<br>*"Then it became easier and clearer when it became manual via (lean flow) boards and so on . . . because it was (felt) safer."* [2]<br>See Figure 2: Lean production practice/Production planning and control/Ambivalence btw analog vs digital<br>*"The lean flow board is so static, if it had retrieved information from the ERP system in real time it would have been digital. But since it requires human intervention, I'd say it's not."* [16]<br>See Figure 2: Lean production practice/Production planning and control/Ambivalence btw analog vs digital<br>*"One disadvantage of production flow simulation is precisely, that if you run VSMs, it is a very teambuilding function and you see the same thing from similar functions in the business (whereas in simulation you lack the teambuilding)."* [1]<br>See Figure 2: Digital initiative /Production visualization/Ambivalence btw analog vs digital<br>*"We have worked a lot with VMSs and 5Ss and with more traditional methods, but I don't know how you could do it digitally. I do not know! I dare not say anything."* [9]<br>See Figure 2: Lean production practice/Production process/Ambivalence btw analog vs digital |
| *Ambivalence btw push vs pull* (Tot. 20 excerpts) | *"We are working more with products than with processes at the moment – that is very clear! Everyone focuses on products!"* [4]<br>See Figure 2: Lean coordination/Production process/Ambivalence btw push and pull<br>*"Now we have been able to expand the outdoor storage areas to accommodate everything. I last heard this morning that part of the parking lot has been used. So we can do a lot there!"* [2]<br>See Figure 2: Lean coordination/Production process/Ambivalence btw push and pull<br>*"Instead of having the pull flow as intended, for which we have system support, we have created a push system as we only keep feeding."* [12]<br>See Figure 2: Lean coordination/Production planning and control/Ambivalence btw push and pull<br>*"So, people have been batching and not understanding the (lean) flow boards, but more and more (people) are starting to get an understanding of it (the lean principles)."* [6]<br>See Figure 2: Lean coordination/Production planning and control/Ambivalence btw push and pull<br>*"Now they have the (lean) flow boards and when they know which operations to run in which order and at what pace. So, I notice a large difference in our production managers and team leaders that they feel they have control over their flow."* [1]<br>See Figure 2: Lean production practice/Production planning and control/Ambivalence btw push and pull |

**Source(s):** Authors' own creation

**Table 4.** Illustrations of Ambivalence btw analog vs digital and Ambivalence btw push vs pull

| | |
|---|---|
| *Lack of access to digital tool* (Tot. 5 excerpts) | *"Yes, padlets, yes we had those (in production) and then it stopped."* [F1.2] *"Yes, we did get some padlets, but we haven't had them in so many years. Say three to four years."* [F1.3]<br>See Figure 3: Digital initiative/Production visualization/Lack of access to digital tool<br>*"Therefore, it would have been nice to have a tool. What I think is difficult about the (production) flow we have (at our factory site) is that it is so complicated with quality deviations, varying and intersecting flows and operation times that I have difficulty seeing how we can get a system that can direct us right."* [7]<br>See Figure 2: Digital initiative/Production planning and control/Lack of access to digital tool |
| *Lack of financial resources* (Tot. 4 excerpts) | *"The padlets are not financially justifiable at the moment."* [F4.3]<br>See Figure 3: Digital initiative/Production visualization/Lack of financial resources<br>*"You have some thoughts and ideas (about digitization) . . ., but it ebbs out and dies in some way. It does. Always. It's probably also such things as resources and everything."* [9]<br>See Figure 2: Digital initiative/Production process/Lack of financial resources |
| *Lack of maintenance* (Tot. 10 excerpts) | *"The 50 inch flat screen TVs are not used much – only this that we got the computers for them six months later and they are still not connected."* [F1.3]<br>See Figure 3: Digital initiative/Production visualization/Lack of maintenance<br>*"Because now it's down (e-drawing system) and there's no one that take care of it (the situation) and then there's no computer and then we have to call (another department) and ask them to print out E-drawings."* [F2.2]<br>See Figure 3: Digital coordination/Digital infrastructure/Lack of maintenance<br>*"I can't access my computer, not my email, I can't stamp time - everything is locked."* [F2.2] *"Neither can I."* [F2.1] See Figure 3: Digital coordination/Production visualization/Lack of maintenance<br>*"The infrastructure is not in place either. If you really want to get to industry 4.0, then it's into machines and such with direct feedback (sensors), I think. We have a lathe from 1952, it feels like, maybe an exaggeration, maybe from the 60s, what do I know. But there is also a challenge there (about old machinery and maintenance)."* [5]<br>See Figure 2: Digital coordination/Digital infrastructure/Lack of maintenance |
| *Ratio of short vs long-term employees* (Tot. 5 excerpts) | *"There was a lot of change of consultants, but that could be for various reasons."* [10]<br>See Figure 2: Organizational change/Human resource/Ratio of short vs long-term employees<br>*"But they (some consultant operators) don't know English, so they don't understand what it says (the production instructions)."* [F2.1]<br>See Figure 3: Organizational change/Human resource/Ratio of short vs long-term employees |

**Table 5.**
Illustrations of lack of access to digital tool, lack of financial resources, lack of maintenance, ratio of short vs long-term employees, strategic change of employees, unplanned employee turnover

(*continued*)

| | |
|---|---|
| *Strategic change of employees* (Tot. 24 excerpts) | *"I think there are a lot of things (reorganizations and management changes) that mean that there will be no structure in this (digitization)."* [F3.2]<br>See Figure 3: Organizational change/Human resource/Strategic change of employees<br>*"We have just had a very large reorganization . . . It spread an incredible amount of anxiety here."* [15]<br>See Figure 2: Organizational change/Human resource/Strategic change of employees |
| *Unplanned employee turnover* (Tot. 12 excerpts) | *"We lack people and knowledge. After all, knowledge is lost all the time."* [F5.1] *"Yes all the time. We are drained of knowledge from the reorganization and forward until today."* [F5.3]<br>See Figure 3: Organizational change/Human resource/Unplanned employee turnover<br>*"They change technicians every month. It changes all the time. Just when a new technician comes to help us and then he quits - it's like that month after month."* [F1.2]<br>See Figure 3: Organizational change/Human resource/Unplanned employee turnover |

**Source(s):** Authors' own creation

**Table 5.**

highlighting technology and the human-centric perspective of juggling LP practices simultaneously with I4.0 technologies.

Encompassing the respective challenges of LP implementation and the introduction of I4.0 technologies and moving towards the coexistence or merging of LP and I4.0 entails additional complexity and further challenges for manufacturing organizations. The case study includes the added complexity that the CC case company is not aiming solely to merge I4.0 with a fully implemented LP system, but simultaneously continuing with their LP practice implementation in parallel with introducing I4.0 technologies. The CC case shows that the combination of LP practices and I4.0 technologies is by no means a self-explanatory set-up for manufacturing production, as sometimes argued (Gallo *et al.*, 2021; Jiang *et al.*, 2021). Instead, throughout the data sets and analyses, discrepancies are shown both in the technological aspects and in the organizational aspects when trying to combine LP practices and I4.0 technologies. The existence of immatureness surrounding LP practices and I4.0 technologies may lead to ambiguities of different viewpoints and the simultaneous implementation of the two manufacturing paradigms necessities for effectively dealing with changes to the organization, work tasks and practices.

It could be argued that one of the key aspects of combining I4.0 technologies and LP practices is acknowledging the human perspective when transforming organizations. Further, it is brought forward that it is crucial to consider nontechnical (Marcon *et al.*, 2022) and incremental (Eriksson *et al.*, 2022) steps when adopting new technologies and/or LP practices (Sarro, 2020). Aligned with arguments that successful LP implementation brings out the capabilities of people (Rother, 2010) and the realization in later years that introduction of I4.0 technologies requires a human-centric perspective towards reaching I5.0 (Breque *et al.*, 2021; Nahavandi, 2019). The CC case shows the importance of not leaving the human-centric perspective to the side. Throughout the dataset the hardship of balancing aspects of always implementing LP practices and/or novel technology while keeping human-in-the-loop. This is in line with LP's teambuilding aspect acknowledged by Rother (2010) and accordingly it could be argued that organizations seem to cling to LP practices due to their strong focus on people. Further, in the era of I4.0, the importance of human-centricity has been recognized moving towards I5.0. In contrast to previous research, the case shows that combining lean

production practices and I4.0 technologies is challenging and hence may appear unreachable. The study indicates that when introducing LP and I4.0 practices that they are perceived as two separate practices, though must be dealt with as coexisting approaches in the company. This is part of a change process in digital transformation bringing forth the added complexity of handling simultaneous changes and novel initiatives, which is crucial for management to acknowledge and address. However, the human-centric perspective in I5.0 is here viewed to support the coexistence of LP practices and I4.0 technologies when introducing novel activities and changes into organizations.

## 5. Conclusion

This study aims to explore and explain how LP practices and I4.0 technologies may coexist to enhance manufacturing operations in the era of I5.0 based on a longitudinal case study. The findings highlight the challenges that manufacturing companies encounter when operating in coexistence or in parallel with implementing LP practices and I4.0 technologies. Findings show that juggling and/or combining the two manufacturing paradigms result in ambiguities which challenge how to successfully handle organizational changes, new work tasks and practices, in a socially sustainable way. The study also presents how LP practices and I4.0 technologies simultaneously are addressed in organizational transformation towards the human-centric perspective of I5.0.

Challenges which manufacturing organizations encounter when operating in the coexistence of LP practices and I4.0 technologies range from successful implementations vs. incomplete implementations; ambivalence between analog vs. digital practices; ambivalence between push vs. pull systems; lack of access to digital tools; lack of financial resources; lack of technology maintenance; ratio of short vs. long-term employees; strategic change of employees; unplanned employee turnover.

The study suggests that while LP and I4.0 practices are initially seen as separate, they need to be integrated as complementary approaches within the company. This underscores the complexity of managing simultaneous organizational changes during digital transformation. Thus, it is a crucial managerial implication to acknowledge and address this complexity from a human-centric perspective when combining LP practices and I4.0 technologies. For manufacturing organizations to be able to combine LP practices and I4.0 technologies in the transformation towards I5.0 it is argued necessary keeping a human-centric perspective when introducing novel organizational activities and changes. The case study shows that manufacturing organizations ought to recognize and handle identified challenges for LP practices and I4.0 technologies to coexist. To conclude, manufacturing organizations must have the ability to see beyond the two separate production systems, i.e. the LP philosophy, that emphasizes production flow efficiency and low waste and I4.0 that focus on digital technology, to meet the demand for the human-centric perspective in socially sustainable manufacturing in the era of Industry 5.0.

### *5.1 Limitations and future research*

The intention was to obtain an in-depth analysis based on a longitudinal research study combining a mix of qualitative methods, i.e. interviews and focus groups, to explore and explain evidence from manufacturing practice over time. Thus, the limitations due to the single case study approach are outweighed by the rich data collection gathered over time. The qualitative approach combines the strengths of the plentiful in-depth interviews with focus groups where participants are given the possibilities to reflect and develop ideas jointly and the interviews compensate for the limitations of focus groups that may cover merely socially acceptable opinions, power differences among participants, or that a participant may

dominate the discussions. Therefore, the mix of participants and the researcher's moderating role was important and adhered to. The study contributes and provides new avenues of research within the field of socially sustainable manufacturing. Thus, future research is encouraged to cover multiple cases and/or different manufacturing sectors, as well as quantitative methods to draw on the strengths of both qualitative and quantitative methods, to elucidate the challenges and thus expand the frontier of the coexistence of lean production practices and I4.0 technologies. Furthermore, research is endorsed that contributes interdisciplinary perspectives, e.g. incorporating both social and engineering sciences, to understand the elusive phenomena of enfolding technology and human-centric perspectives in line with the Industry 5.0 paradigm.

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