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Empowering Factory Employees Through Low-Cost Automation in IoT Adoption

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Abstract:

Purpose: This study aims to understand the potential and challenges of incorporating low-cost automation (LCA) in the adoption of the Internet of Things (IoT) within the context of Industry 4.0 implementation and to examine their implications for factory employee empowerment.

Design/methodology/approach: Multiple case studies were conducted with industrial companies located in Sweden. Relevant empirical evidence was collected from the workshops where factory employees explored and prototyped simple IoT solutions to improve their work environments.

Findings: The study revealed multiple benefits of LCA incorporation, including enhancing factory employees' knowledge, skills, and motivation for improvement. The compatibility of LCA with Lean production was also found to be positive for the employees. However, the study also identified several challenges, mainly concerning establishing organisational preconditions that enable or facilitate the incorporation, such as its strategic alignment and securing managers' understanding and support. The study identified tensions between simple IoT solutions and large integrated solutions, which affect empowerment. Managing these tensions was found particularly challenging.

Originality/value: This paper provides deeper understanding of the potential and limitations of incorporating LCA into IoT adoption than previous studies. It highlights the potential of a bottom-up approach to IoT adoption, which is currently dominated by top-down, engineering-driven approaches.

Keywords: employee empowerment, industry 4.0, internet of things, low-cost automation, lean production, co-design

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1. Introduction

The proliferation of the industrial Internet of Things (IoT)—a cornerstone of Industry 4.0 (I4.0) that envisions every object possessing a digital identity and connecting to a data network (Tu et al., 2018)—enables manufacturing companies to transition towards information-intensive operations (Cañizares & Alarcón-Valero, 2018). Integration and sharing of extensive, timely and accurate information in production reduces data latency, analysis latency, and decision latency, which leads to higher responsiveness and agility in the operations (Schuh et al., 2017; Tu et al., 2018).

Despite its acknowledged potential, IoT adoption is often viewed as expensive due to the required hardware and software investments, complexity, and expertise needed for its design, implementation, and maintenance (Müller, 2019; Obiso et al., 2019). Moreover, the significance of socio-technical factors in the adoption process has gained increasing recognition (Hannola et al., 2020; Rožanec et al., 2022). As part of this digital transition, the quality of work, empowerment, learning, and participation of factory employees—defined here as workers, their leaders, and technicians working closely with shop floor operations—have been identified as crucial for utilising the full potential of technology adoption and ensuring sustainable changes towards high-performance operations (Davies et al., 2017; Marcon et al., 2022; Vereycken et al., 2021). In this context, empowering factory employees means enhancing their strengths, competencies, performance, and satisfaction, enabling them to contribute actively to the organisation's objectives using their creativity and domain knowledge (Sievers et al., 2021).

Empowering factory employees in adopting IoT and other I4.0 technologies remains a significant challenge. Various studies highlighting socio-technical factors, such as those focusing on Operator 4.0 (Kaasinen et al., 2020; Rabelo et al., 2021) and the integration of Lean and I4.0 (Ghobakhloo & Fathi, 2020; Rossini et al., 2021), argue that technology adoption can empower factory employees by providing them with more timely information, thereby increasing their decision-making autonomy. Yet, these studies often portray factory employees as passive recipients of technological changes with limited influence over the adoption process (Di-Pasquale et al., 2022). This top-down, engineering-driven approach to change limits employee empowerment, as participation and influence over the change process have been widely recognised as key drivers of employee empowerment (Bessant, 2003; Kesting & Ulhoi, 2010).

This paper focuses on the adoption of IoT within the context of I4.0 implementation. It examines how the integration of low-cost automation (LCA) in the IoT adoption process can influence factory employee empowerment.

LCA primarily focuses on mechanical automation and has been practised widely since 1990 (Erbe, 2002; Gamberini et al., 2009). It seeks simplicity and transparency in automation and enables incremental improvement of the operations and employee participation and autonomy in the problem-solving process (Takeda, 2007). Due to the bottom-up nature of the approach, LCA has been practised as part of organisations' Lean production initiatives (Gamberini et al., 2009; Takeda, 2007).

While it is a niche area, a few studies argue that IoT-enabled solutions are not necessarily complex, large, and expensive and that an uncomplex and low-cost system can still effectively support the factory's day-to-day operations (Fast-Berglund et al., 2020; Kolberg & Zühlke, 2015; Mokudai et al., 2021; Müller-Polyzou et al., 2020). For instance, a low-cost device connected to machining equipment can monitor abnormal behaviours and raise alarms to the operators (Mokudai et al., 2021). Such solutions are easy to customise to fit the employees' specific needs and enable gradual change toward a digital factory (Müller-Polyzou et al., 2020; Semwal et al., 2020). By seeking simple solutions, the problem-solving activities can stay close to the shop floor operations (Mokudai et al., 2021)

Although previous studies have implied the potential of incorporating LCA in IoT adoption, its impact on factory employee empowerment and the associated challenges remain insufficiently explored. Previous studies primarily focus on describing instances of simple IoT solutions from a technical standpoint without exploring those questions in detail. A deeper and more comprehensive understanding of these issues is critical to properly assessing the potential and risks of incorporating LCA in IoT adoption. Such insights could offer a valuable counterbalance to the prevailing top-down, engineering-driven approaches that currently dominate IoT adoption (Dieste et al., 2022).

The purpose of the present study is to better understand the above questions. To this end, multiple case studies were conducted, adopting design science (Holmström et al., 2009) as a research approach. In the case studies, the researchers organised workshops where factory employees could explore and prototype simple IoT solutions to improve their work environments. The workshops provided participants a platform to express both the potential benefits and concerns associated with the LCA incorporation, while also allowing the researchers to observe and analyse the impact on employee empowerment. In total, 214 industry professionals from 35 companies located in Sweden participated in the case studies.

The findings indicate that the potential of the LCA incorporation into IoT adoption mirrors benefits previously identified in traditional mechanical-based LCA. For instance, employees found it easier to engage in the problem-solving process, which in turn fostered a greater sense of ownership over the solutions. The study also identified several concerns, some of which are unique to IoT adoption. For example, it identifies a dilemma between simple, local, and stand-alone solutions versus complex but more vertically and horizontally integrated solutions. Inadequately addressing the dilemma may adversely affect employee empowerment.

The remainder of this paper is structured as follows: The next section discusses previous research related to the main topic of this paper. Section 3 presents the case study method. Section 4 presents examples of ideas and prototypes of simple IoT solutions generated in the case studies. Section 5 analyses the potential of and concerns about LCA incorporation in IoT adoption and how they affect empowerment. Finally, Section 6 discusses this paper's contribution and avenues for future research.

2. Related Research

The adoption of IoT in manufacturing is often discussed in the context of I4.0 implementation. This section discusses previous research related to two themes: 1) factory employee empowerment in implementing I4.0 technologies and 2) the potential of LCA to facilitate employee empowerment in the implementation.

2.1. Factory Employee Empowerment in Adopting I4.0 Technologies

Kanter (2008) and Michael, Alexander and Melanie (2019) discuss that individuals are empowered if they have access to four dimensions: (1) access to information and knowledge necessary to perform tasks, (2) access to resources in terms of money, material and working time, (3) access to support such as receiving guidance and feedback from colleagues, supervisors, and other sources, and (4) access to opportunities for learning and skills growth. This paper understands those four dimensions as key sources of employee empowerment.

The literature discussing factory employee empowerment in I4.0 implementation seems to suggest two approaches to establishing those four dimensions of access: a) they emerge as a consequence of implementing I4.0 technologies, and b) they are fostered through employees' active participation in the technology adoption process, wherein they exert influence over decisions regarding the utilisation and intended purpose of the technologies.

The literature provides numerous examples of the former approach. For instance, by connecting pieces of equipment to the factory's information network, employees gain increased access to real-time information and make informed decisions regarding the operations and their improvement (Onizawa et al., 2016). Work introductions enhanced by Augmented Reality technologies provide context-sensitive guidance, facilitating efficient quality control procedures and maintenance tasks (Kaasinen et al., 2020). Several such examples are discussed under Operator 4.0 (Mattsson et al., 2020; Rabelo et al., 2021; Salvatore & Stefano, 2021), which envisions the application of I4.0 technologies to augment the operators' physical or cognitive abilities in operations (Romero et al., 2016).

These studies argue that factory employee empowerment occurs because the technologies enable the employees' increased access to information, knowledge, guidance, and feedback. In those studies, however, factory employees are often positioned as passive recipients of technological changes. Such changes are typically top-down and engineering-driven (Di-Pasquale et al., 2022). The prevailing mental model in this approach is "what technologies can do to factory employees".

The second approach to empowerment emphasises employee agency and active participation in the technology adoption process. The dominant mental model in this approach shifts to "what factory employees can do with the technologies". Outside the specific context of I4.0, employee participation in decision-making in change processes has been recognised as a critical factor for empowerment and improved performance (von Hippel, 2005). The highest levels of empowerment are achieved when problem owners, with a high degree of autonomy, actively engage in identifying and solving problems using their creativity, domain knowledge, and experience (Bessant, 2003; Hoyrup, 2010). While individual contribution may be modest, their cumulative tangible and intangible impact on organisational capability in operations and improvements can be substantial (Tidd et al., 2005).

Within the I4.0 literature, the knowledge of practising this participatory approach is limited, despite its acknowledged importance. For instance, this issue has been an active topic in the research stream of integrating Lean production and I4.0 (Chiarini & Kumar, 2021; Sodhi, 2020; Sordan et al., 2022; Tortorella et al., 2019). In this stream, there is a consensus that these two initiatives are generally compatible (Sanders et al., 2016). Preserving the improvement capacity developed under Lean production is considered crucial, as it provides a solid foundation for introducing digital technologies into manufacturing operations (Bittencourt et al., 2021; Demeter et al., 2021; Tortorella et al., 2019). Studies by Rossini et al. (2021) and Demeter et al. (2021) indicate that Lean organisations tend to prefer gradual and sustaining changes to infrequent but large and disruptive changes when adopting I4.0 technologies.

Despite this alignment, researchers still struggle to find an effective means to integrate the top-down and complex nature of I4.0 technology applications with the human-centred and simplicity-focused bottom-up improvements practised in Lean production (Buer et al., 2018; Tortorella et al., 2019). Kaasinen et al. (2020) suggest that adopting participatory design—a design practice involving non-technical stakeholders in co-design activities (Sanders, 2002) —holds promise for enabling workers to be active agents in I4.0 technology adoption. However, their study did not provide concrete guidance on how to implement such practices.

2.2. LCA to Facilitate Factory Employee Empowerment

The study presented in this paper hypothesises that incorporating LCA in the adoption of IoT represents a viable pathway to operationalise the second approach discussed in the previous subsection.

LCA has traditionally been associated with mechanical automation. It seeks to deliver only the essential functionalities required to support operations using standard components available on the market. It is characterised by minimal training and workload to implement, flexibility for future uses, and compatibility with existing systems and methods (Gamberini et al., 2009; Seifermann et al., 2014). Proponents of LCA argue that large systems are not always cost-effective, particularly when the maintenance cost is high and the systems lack responsiveness to the accelerating pace of market changes (Erbe, 2002; Gamberini et al., 2009).

Critical characteristics of LCA are not only simplicity and cost-efficiency in solutions but also the facilitation of active participation and autonomy among factory employees in the problem-solving process (Erbe, 2002). Due to its inherent simplicity and transparency, LCA enables factory employees to comprehend the structures and functions of LCA solutions, thereby empowering them to conceptualise, configure, and maintain these solutions (Erbe, 2002; Takeda, 2007). Such engagement fosters enhanced domain knowledge and creativity and cultivates a sense of ownership over the solutions (Müller-Polyzou et al., 2020). Ensuring that employees play a meaningful role in technological advancement is fundamental to establishing an effective work organisation (Adeleye et al., 2001).

Previous studies on LCA also find that LCA and Lean production are compatible (Gamberini et al., 2009; Takeda, 2007). They share the same application environment and aims, including employee involvement, application of gradual changes, and a preference for solution simplicity (Gamberini et al., 2009; Takeda, 2007).

Although the term LCA may not be used as explicitly as the traditional mechanical-oriented LCA, the literature provides a limited number of examples demonstrating the simple use of IoT and other I4.0 technologies. The scarcity of such examples suggests that the LCA incorporation in I4.0 technologies remains a niche area of study and practice.

Semwal et al. (2020) reported a use case of deploying a simple IoT system using inexpensive system-on-a-chip devices to monitor industrial assets at a large industrial site. Kolberg and Zühlke (2015) report an example of a simple IoT system enabling operators to remotely monitor CNC machine status via mobile devices. Fast-Berglund et al. (2020) present an instance where an affordable collaborative robot supports manual assembly tasks.

The authors of these studies recognise several advantages associated with the simplified application of I4.0 technologies. They include; a simple solution is easy to customise to suit specific operational contexts (Semwal et al., 2020); implementing simple solutions offers opportunities for a gradual transition towards a digital factory (Müller-Polyzou et al., 2020); the return on investment would no longer be the most crucial parameter in the project (Fast-Berglund et al., 2020); problem-solving activities can stay close to the shop floor operations (Mokudai et al., 2021); it has affinities with Lean production due to their shared approach of employee involvement and bottom-up orientation (Kolberg & Zühlke, 2015; Mokudai et al., 2021). However, Mokudai et al. (2021) also raise the uncertainty of how much the simple use of digital technologies impacts organisational performance, as individual use cases often yield only marginal improvements.

To our knowledge, there is no comprehensive understanding of the potential and limitations of incorporating LCA into IoT adoption beyond those studies. These studies have primarily focused on technical descriptions of simple solutions and do not explore in detail how such approaches might influence factory employee empowerment. Moreover, discussions on the potential and limitations of these approaches in the literature have mainly been based on researchers' interpretations or statements from managers at manufacturing sites, lacking direct input from factory employees.

3. Case Study Method

The study in this paper aims to gain a deeper understanding of the potential and challenges associated with incorporating LCA in IoT adoption in manufacturing, especially regarding its impact on factory employee empowerment. This can be optimally achieved by gathering empirical evidence grounded in practitioners' real-world experience with the target phenomena. However, at the time of the study, many manufacturing companies were still on the verge of adopting IoT on the shop floors, and the application of LCA in IoT was even less practised.

The researchers, who conducted the case studies and are authors of this paper, strategised that empirical evidence could be generated through research by adopting design science (Holmström et al., 2009). Design science is a variation of action research wherein researchers develop and test solutions in collaboration with case companies to extract empirical evidence (Holmström et al., 2009). It is a suitable research approach to address an ill-structured problem—a solution to a problem is not known to decision-makers or does not even exist (Simon, 1973). LCA incorporation in IoT adoption was an ill-structured problem for most industrial companies.

The research approach was implemented by the same researchers devising a collaborative design method inspired by participatory design practices (Broberg, 2011; Sanders, 2002). This method was intended to enable factory employees to actively engage in the early phases of problem-solving, using IoT as an enabler of solutions. The rationale for focusing on the early phases of problem solving and the limitations incurred by this focus are discussed later in this section.

The method consists of three steps. In Step 1, factory employees identify improvement opportunities on the shop floor that could be addressed through IoT-enabled solutions. This is facilitated through a brainstorming session where participants are informed that the proposed solutions do not need to be complex or costly. Participants select a few improvement opportunities for the next step. Step 2 involves the generation of conceptual solutions for the selected improvement opportunities. To support this process, an IoT card deck and an IoT business origami kit (Aranda-Muñoz et al., 2021) are utilised, as shown in Figure 1. The card deck includes 28 cards representing various physical, digital, and functional components of IoT solutions, such as different types of sensors, actuators, and displays for visualising digital information. The IoT business origami kit serves the same purpose as the card deck but is used in different workspaces. The card deck is used on a whiteboard, and the other on an A3 sheet. In Step 3, practitioners create low-fidelity prototypes to demonstrate and assess the practical viability of the conceptual solutions developed in Step 2. This is achieved using a modular IoT prototyping kit (MESH, 2022), which requires no prior knowledge of coding or electronics.

The method was applied at manufacturing companies through workshops facilitated by the authors of this paper. Each of the three steps required approximately one hour to complete. Depending on the participants' availability, these steps were conducted on one or a few separate days.

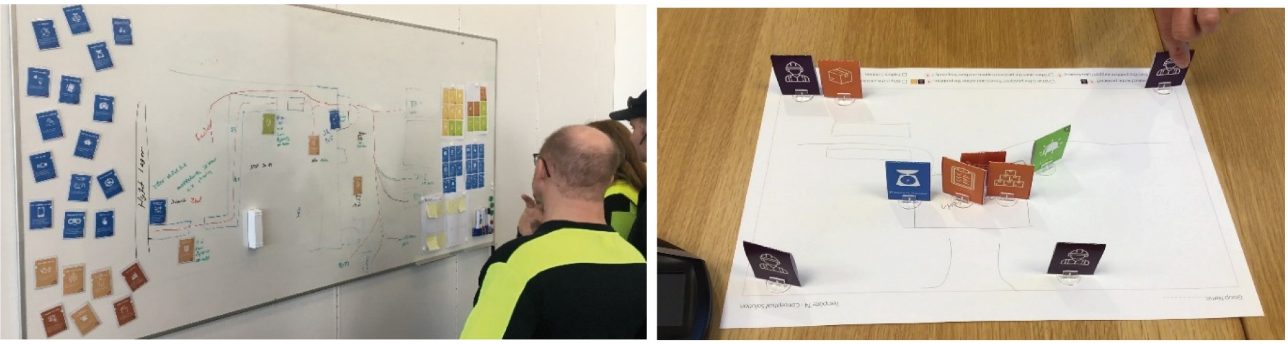

Figure 1. The scenes photographed during Step 2. The left image shows the IoT card deck in use, and the right image shows the IoT origami kit

During the study between 2018 and 2022, a total of 35 industrial companies participated in the workshops, involving 214 practitioners. The workshops were conducted either at the companies' manufacturing sites or online, particularly during the COVID-19 pandemic. While the majority of the participants were factory employees, some workshops also included individuals in other roles, such as managers, IT engineers, and Lean coaches. The number of participants at each workshop ranged from six to 35. The researchers recommended that companies strive for age and gender diversity among participants, as such diversity was found to foster more dynamic and inclusive discussions. These companies selected participants based on this recommendation and employees' availability and interest.

Empirical data were collected during the workshops and post-workshop reflections. Participants documented improvement ideas and design outcomes in the workshops in sticky notes, storyboards, photos, or videos. Except on a few occasions, more than one researcher attended the workshops. While one researcher led the workshops, the other researchers remained close to the participants to observe their discussions and behaviours. The researchers took notes on these discussions and behaviours. Some workshops were audio-recorded if allowed. In post-workshop reflections, participants or their representatives communicated their experiences and opinions about the workshops, potentials and limitations of LCA incorporation in adopting IoT, and their perceptions about the company's ongoing digitalisation effort. After the data collection, the content analysis (Kohlbacher, 2006) was conducted to extract and organise the data relevant to the study's purpose.

A key limitation of the research method lies in its focus on the early stages of the problem-solving process, from ideation to low-fidelity prototyping. The later stages, such as detailed design and implementation, were excluded. This exclusion was due to two primary reasons. Firstly, the researchers in the study considered that factory employees would have a greater and more critical influence on decision-making about desired solutions in the early stage (Hattinger et al., 2021; Kaasinen et al., 2020). Second, the onset of the pandemic restricted the researchers' access to the shop floors, making it impractical to support implementation activities. As a result, the study focused on enriching empirical data across a broader range of companies and participants. The researchers believe that the large number of industrial participants compensates for the limitation, as discussions during the workshops often extended into considerations relevant to later stages of the improvement process. The study contends that it has gathered sufficiently rich and diverse data to formulate an initial proposition regarding the research objective, which warrants further validation in future investigations.

4. Ideas and Low-Fidelity Prototypes Generated from the Case Studies

In Step 1 of the collaborative design method described in Section 3, the case study participants generated a total of 141 improvement ideas. An overview of those ideas is presented in Table 1. As shown in the table, a substantial portion of ideas fall under three categories: “Show the current status of a certain object”, “Notify when something happens”, and “Know where things or people are”. Most of the issues addressed were not complex but recurrent in the participants’ immediate work environments. The participants expressed that the repetitive nature of these problems contributed to their frustration, often resulting in unnecessary physical or cognitive strain.

Categories of the identified improvement opportunities	Examples of the identified improvement opportunities
Show the current status of things (51)	Know the status of the robot gripper. Know the current status of the previous production process in a separate building. Know the humidity and temperature at the warehouse.
Notify when something happens (34)	Notify forklift drivers to fetch certain materials when there is a shortage. Notify the machine operator when the process in the machine has finished.
Know where things or people are (15)	Immediately find the right material in the buffer area. Reduce time spent locating an empty cart for material transportation. Reduce time spent finding the appropriate person for problem-solving.
Record operational information (14)	Automatically log tolerance measurements. Log the results of autonomous maintenance. Eliminate manual logging of overall equipment effectiveness.
Digital work orders, instructions, and quality deviation reports (9)	Avoid printing work instructions. Display the torque value needed for the fastening operation. Prevent forgetting to report quality deviations.
Others (9)	Have an automatic adjustment of working height. Have a simple way to report quality deviations.

Table 1. The categories of improvement opportunities identified in Step 1. The figures in parentheses indicate the number of ideas associated with each category

During Steps 2 and 3 of the collaborative method, the participants generated low-fidelity prototype solutions. While detailing each solution is not the scope of this paper, a few illustrative examples are provided below:

Example I: At a factory manufacturing automobile components, material supply vehicle drivers drove through different automated production cells. They found it bothersome to stop and step out of the vehicle at each cell to check the status of the cell’s inbound and outbound materials and some of the machine conditions. The participants suggested a solution resembling a pit board on a race track. At each cell, the information necessary for the routine check would be collected and displayed on a screen so that the drivers could see it while driving, preventing an unnecessary stop at each cell.

Example II: In a factory manufacturing components for construction equipment, forklift drivers at the yard outside of the factory had limited communication with the operators at the adjustment division located after the end of the main assembly line. There, operators adjust some of the finished components to meet the customers’ specific requirements. The forklift driver often drove into the division to check if there were any finished components to be transported outside, only to find none, resulting in wasted effort. Two solutions were suggested. The forklift drivers suggested that the operators at the adjustment division press a button to notify the drivers to transport the materials via a light signal placed on the forklifts. Another solution suggested by production engineers was making the location of any components in the factory trackable via RFID, and this tracking system would inform the drivers about the transportation timing.

Example III: At a company manufacturing drivetrain components of heavy-duty vehicles, a project was underway to design and implement a new automation cell. The project members created a basic cell design and wanted to explore opportunities for utilising IoT in the new cell. One of the generated solutions was to monitor the amount of metal scrap in the scrap bins so that operators could plan the timing of replacing the bins without unnecessarily stopping the cell operation. The amount of metal scrap would be detected by an object detection sensor and displayed through a visualisation function of the IoT platform the company was using.

Example IV: At a company's CNC machine shop specialising in producing high-precision metal equipment, employees and managers discussed a light indication system for the machine shop. This system was designed to keep all shop floor operators informed about the ongoing work status at each machine. It would facilitate the sharing of real-time updates such as "operation proceeding smoothly", "setup in progress", "assistance required for measurement", and "measurement room currently in use". This allowed operators to adapt their work and foster collaboration dynamically. To indicate their work status, operators would press buttons located next to their respective machines.

5. Positive Aspects and Concerns of Incorporating LCA in the Adoption of IoT and their Impact on Factory Employee Empowerment

The case studies provided participants with the opportunity to articulate or imply their perspectives regarding the benefits and concerns associated with incorporating LCA in adopting IoT on the shop floors. These perspectives are summarised in Table 2, which also outlines their implications for factory employee empowerment.

Positive aspects and concerns	Influence on factory employee empowerment
Positive aspects:	
P1: Addressing minor but persistent issues often unaddressed in large-scale information system implementations.	P1-P6 positively affect one or more of the four sources of empowerment introduced in Section 2. For instance, employees' active participation (P2) enhances their perception of access to information, knowledge, support, resources, and learning opportunities.
P2: Facilitating factory employees' active participation in the technology adoption, fostering a sense of agency in the process and ownership of the solutions.	
P3: Allowing experimentation and learning with new technology without overwhelming employees or inducing fear of failure.	
P4: Potentially reducing implementation lead time, aligning with continuous improvement initiatives.	
P5: Concretising the I4.0 initiative by providing hands-on experience with the technology.	
P6: Facilitating integration of the I4.0 initiative with the existing Lean production initiatives.	
Concerns:	
C1: Uncertainty in managing tensions between simple and vertically and horizontally more integrated solutions.	C1-C2 may negatively affect empowerment if not properly managed.
C2: Ambiguity regarding post-implementation and maintenance ownership.	
C3: Necessity of ensuring functional reliability and cybersecurity of solutions.	C3-C6 are considered hygiene factors; without addressing them, the incorporation may not proceed.
C4: Limited capacity of IT departments to support simple solutions.	
C5: Need for alignment with the organisation's I4.0 strategy and securing managerial understanding and support.	
C6: Need for a systematic method to facilitate the LCA incorporation.	

Table 2. Overview of positive aspects and concerns regarding LCA incorporation in IoT adoption and their influence on factory employee empowerment

5.1. Positive Aspects

The analysis of empirical material reveals several benefits of incorporating LCA in adopting IoT. It encourages addressing minor but persistent issues that are often neglected in large-scale information system implementations (P1 in Table 2). Participants expressed that resolving these issues was important for factory employees, although it may not drastically enhance performance metrics. Their recurrence contributes to employee frustration and a sense of being unheard.

A participant, a shop floor group leader, voiced this sentiment during discussions on Example III:

> "*We need a simpler material replenishment order system for the new production cell because the current one was tremendously inconvenient. In each order, we have to walk to the computer terminal, log onto it, which is usually logged off, and navigate it through several mouse clicks to locate and order the required material.*"

Another benefit is the facilitation of employee involvement in problem-solving (P2). Participants noted that factory employees were often not deeply involved in implementing information systems, and even if they were, their involvement was often too late to propose meaningful alternatives. When problems are familiar and solutions are straightforward, employees are more likely to articulate needs and contribute ideas. This sense of ownership was reflected in a participant's remark:

> "*This is what we need. Usually, it's the opposite. It's managers that tell us, 'This is what you need'.*"

Further, the participants expressed that pursuing simple solutions was beneficial as it allowed experimentation and learning about new technology without feeling overwhelmed (P3). They also perceived that simple solutions could accelerate implementation timelines (P4), as several participants noted:

> "*The improvement cycle tends to be too lengthy when the IT department is involved. We want to see continuous progress on the shop floor when managers discuss digitalisation and the importance of our participation. Otherwise, our interest and engagement wane over time, as we feel that our willingness to contribute is neglected.*"

The other positive feedback about the LCA incorporation includes its ability to help factory employees to concretise the organisation's I4.0 initiative through hands-on experience (P5) and its alignment with the ongoing Lean production initiatives (P6). Participants expressed that they initially perceived IoT as an abstract and complex concept handled primarily by technology experts. They recognised that the LCA incorporation could make IoT adoption more accessible and closer to a bottom-up approach, which would resonate with Lean practices.

5.2. Concerns

The case studies also identified several concerns about incorporating LCA in IoT adoption. A primary issue is uncertainty about managing the tensions between simple IoT solutions and larger, more horizontally and vertically integrated solutions (C1). For instance, the simple solution proposed in Example II involved an operator at the adjustment division pressing a button to notify the forklift driver of material collection, while the more horizontally integrated alternative proposed the notification by implementing a factory-level material tracking system using RFID. The forklift driver expressed indifference to the method, provided he received the notification, but showed less engagement when the discussion shifted towards using RFID.

In Example IV, employees and managers discussed whether the light indication system should be integrated into their Enterprise Resource Planning system. The manager, however, commented:

> "*Surely, the higher degree of integration has its benefits, but the system can become over-complicated. And in my experience, when things become complicated, the operators stop using them.*"

The case studies revealed that tensions between simple and large integrated solutions exist across various dimensions, including operational impact, cost, implementation timelines, employee engagement and ownership, and standardisation. While simple solutions may offer limited improvements in performance metrics, they are potentially inexpensive, easier to implement, and associated with shorter deployment periods. Additionally, such solutions can afford factory employees greater autonomy and influence over the design and operation. However, simple solutions may lack standardisation, as they entail the risk of disparate use of software applications, data structures, and communication protocols. In contrast, large integrated solutions may offer coherent systems with broader operational impact, but are likely to be expensive, complex, engineering-driven, and time-intensive to implement.

Another concern involves the post-implementation ownership (C2). Assigning maintenance responsibility to factory employees may enhance their understanding of the solutions and underlying technologies, potentially reducing repair times. Conversely, technical expert ownership may improve the solution reliability but negatively affect employee engagement and learning. Several participants commented that IT department personnel often prefer extensive control over information systems.

Cybersecurity (C3) was universally acknowledged as a critical issue, necessitating IT department involvement regardless of solution complexity. This concern may influence the issue of post-implementation ownership. The cybersecurity requirement raised concerns about the IT department's capacity to support employee-led initiatives (C4). One participant questioned:

"*With the IT department already overwhelmed and resource-limited, how can they assist us or accept our ideas?*"

Alignment with the company's I4.0 strategies and managerial understanding and support were significant concerns for many participants (C5). Participants noted that managers often favour high-profile projects over simple solutions. The importance of strategic alignment was evident in one case. During a workshop, participants appeared disengaged and confused. It was found later that they attended the workshop without managers explaining its relevance to the organisation's goals. Engagement significantly improved after the relevance was clarified.

Finally, the need for a systematic methodology (C6) was identified. Although not explicitly voiced by participants, the collaborative design method used in the workshops facilitated participation and contributed to making the technology adoption less overwhelming. Without such assistance, the participants might not have perceived the positive aspects of the LCA incorporation.

5.3. Impact on Factory Employee Empowerment

The study analyses how the identified benefits and concerns influence factory employee empowerment, based on the four sources of empowerment introduced in Section 2. According to Kanter (2008) and Michael et al. (2019), employees experience empowerment when they have access to information and knowledge (S1), resources (S2), support (S3), and learning opportunities (S4). It should be noted that these sources are interdependent; for example, access to learning opportunities may require access to resources and support. The following discussion associates the identified benefits and concerns with these sources, but this association is only indicative.

The benefits of the LCA incorporation positively affect these sources. For instance, P1 (addressing minor yet persistent issues) enhances perceived support (S3) by addressing employee frustration and the issue of their voices being unheard. P2 (facilitation of employee engagement in problem-solving) enables or necessitates access to all four sources (S1-S4), underscoring the close relevance of participation to empowerment. P6 (alignment with Lean production) reinforce access to resources (S2) and support (S3), as a continuous improvement approach has already been legitimised by management.

Conversely, the concerns of LCA incorporation may hinder empowerment if not adequately addressed. Interestingly, these concerns pertain to strategic, organisational, and managerial issues that are often beyond the control of factory employees. For example, C1 (the tensions between simple and large integrated solutions) can either support or obstruct empowerment depending on how they are managed. As discussed in Section 5.2, supporting simple solutions may enhance empowerment, but potential disadvantages such as the risk of standardisation should be managed. Orientation towards large complex solutions may hinder empowerment. Finding a proper balance between these two orientations can be a challenging task for managers. Intangible benefits of LCA incorporation, such as employees' learning, motivation, and job satisfaction, are difficult to quantify and foresee.

Concerns C3 to C6 are considered hygiene factors; without addressing them, LCA incorporation may not proceed. The case studies indicate that C5 (securing managerial understanding and support) is particularly critical. While managers involved in the studies generally viewed the approach positively, they struggled to assess its overall and long-term impact on the organisation. The lack of antecedents also contributes to the difficulty of assessment. This dilemma may be a factor of the approach's limited adoption in industry.

6. Conclusions and Discussions

The present study's purpose is to explore the potential and challenges associated with incorporating LCA in IoT adoption in manufacturing environments and to examine its implications for factory employee empowerment. For this purpose, multiple case studies were conducted using the design science approach. Practitioners' voices relevant to the study's purpose were collected and analysed.

The study reveals multiple benefits of LCA incorporation and its potential to contribute to factory employee empowerment. However, it also presents several challenges, mainly concerning preparing organisational preconditions that enable or facilitate the incorporation, such as its strategic alignment and securing managers' understanding and support. The study finds that establishing those preconditions is a significant managerial challenge because of the lack of prior knowledge and antecedents, and the tangible benefits of the incorporation. This partially explains the limited practical application of LCA in IoT adoption, despite practitioners recognising its significant potential for empowering factory employees.

The key theoretical contributions of this study are two-fold. Firstly, the study advances research on I4.0 implementation, especially its implications for factory employee empowerment. It offers deeper insights into participatory-induced empowerment, a dimension that has received limited attention in existing literature.

As discussed in Section 2, the current body of research addresses two types of empowerments: technology-induced empowerment and participatory-induced empowerment. Previous studies are mostly devoted to the former type, arguing that implementing I4.0 technologies increases employees' access to operational information, resulting in empowerment (Hannola et al., 2018; Kaasinen et al., 2020; Michael et al., 2019; Romero et al., 2016; Salvatore & Stefano, 2021; Sievers et al., 2021). The latter posits that empowerment arises when they actively participate in the decision-making related to technology adoption, influencing its implementation and purpose.

The present study details how the LCA incorporation affects participatory-induced empowerment. Previous studies have only fragmentarily discussed the link between LCA incorporation and empowerment, often relying on the view of researchers or industrial managers (Fast-Berglund et al., 2020; Kolberg & Zühlke, 2015; Mokudai et al., 2021; Müller-Polyzou et al., 2020; Tortorella et al., 2021). In contrast, the present study offers granularity and comprehensiveness, drawing primarily on the voices of factory employees.

Secondly, the study contributes to the broader discourse on LCA by identifying unique challenges in the context of IoT adoption. The observed benefits—such as addressing minor but recurrent issues, enabling employee participation, fostering experimentation and learning, and affinity to Lean production—are consistent with those reported in the traditional mechanical-based LCA (Erbe, 2002; Gamberini et al., 2009; Seifermann et al., 2014; Takeda, 2007). Concerns, such as the necessity of strategic alignment, management support, and structured methodologies, are also echoed in the traditional LCA (Erbe, 2002; Gamberini et al., 2009; Takeda, 2007).

However, tensions between simple and large-scale integrated solutions and cybersecurity are concerns unique to IoT adoption. The present study highlighted a gap in understanding how to manage these tensions. This challenge in the context of IoT adoption mirrors the difficulties in Lean-I4.0 integration, where researchers and practitioners struggle to find a viable way to combine top-down and bottom-up approaches in I4.0 implementations, a combination that has been more successfully realised in Lean initiatives. (Demeter et al., 2021; Rossini et al., 2021; Tortorella et al., 2019).

The study offers two practical contributions. Firstly, the main study results—identifying the benefits and concerns of LCA incorporation in IoT adoption and their implications for employee empowerment—provide managers with a broader view of the incorporation. While the findings may not enable operationalisation, they help managers to anticipate the potential of LCA incorporation and organisational conditions necessary to realise it.

Secondly, the collaborative design method developed and applied in the case studies is a practical contribution to industry. Although limited to ideation and low-fidelity prototyping phases, the method underwent multiple iterations of refinement and was validated through applications across multiple case companies.

Finally, the study's limitations and avenues for future study are discussed. As discussed in Section 3, a notable limitation is that the empirical data were derived from workshops focusing on the early stages of the problem-solving process. Although this limitation was mitigated by conducting a large number of case studies, where participants discussed issues beyond the initial stages, it remains possible that further benefits and concerns could be identified through studies encompassing the full implementation process.

Future research could extend understanding by examining the long-term impact of LCA incorporation in IoT adoption; specifically, how implementations of simple IoT solutions contribute to operational performance and enhance employees' knowledge, skills, and motivation for improvement over time. This longitudinal aspect is not included in the present study and represents an opportunity for further investigation.

Notably, the researchers observed that the solution in Example IV was implemented and appreciated by the employees. The manager remarked, "*The solution was implemented during the weekend, and on Monday morning, operators started to use the system even before I explained it. This is a sign that the solution really captures their needs*". The prevalence of such outcomes remains unknown. Follow-up studies could provide deeper insights into the impact, enablers, and barriers of LCA incorporation.

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Authors' contributions

Yuji Yamamoto: Conceptualisation, Methodology, Data Curation, Formal Analysis, Funding Acquisition, Writing – Original Draft.

Alvaro Munoz-Aranda: Conceptualisation, Methodology, Writing – Review & Editing.

Kristian Sandström: Conceptualisation, Methodology, Funding Acquisition, Writing – Review & Editing.

Data availability

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References

Adeleye, E., Yusuf, Y., Sivayoganathan, K., & Al-Dabass, D. (2001). An Exploratory study of the impact of process automation and employee empowerment on competitive capabilities and performance. *16th International Conference of Production Research (ICPR)* (29).

Aranda-Muñoz, Á., Eriksson, Y., Yamamoto, Y., Florin, U., & Sandström, K. (2021). To support IoT collaborative expressiveness on the shop floor. *Proceedings of the Design Society*, 1, 3149-3158. https://doi.org/10.1017/pds.2021.576

Bessant, J.R. (2003). *High-Involvement Innovation: Building and Sustaining Competitive Advantage Through Continuous Change*. Chichester, England: Wiley.

Bittencourt, V.L., Alves, A.C., & Leão, C.P. (2021). Industry 4.0 triggered by Lean Thinking: insights from a systematic literature review. *International Journal of Production Research*, 59(5), 1496-1510. https://doi.org/10.1080/00207543.2020.1832274

Broberg, O. (2011). Enabling objects for participatory design of socio-technical systems. *DS 68-7: Proceedings of the 18th International Conference on Engineering Design (ICED 11), Impacting Society through Engineering Design (7): Human Behaviour in Design, Lyngby/Copenhagen, Denmark* (64-73).

Buer, S.V., Strandhagen, J.O., & Chan, F.T.S. (2018). The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda. *International Journal of Production Research*, 56(8), 2924-2940. https://doi.org/10.1080/00207543.2018.1442945

Cañizares, E., & Alarcón-Valero, F. (2018). Analyzing the effects of applying IoT to a metal-mechanical company. *Journal of Industrial Engineering and Management (JIEM)*, 11(2), 308-317. https://doi.org/10.3926/jiem.2526

Chiarini, A., & Kumar, M. (2021). Lean Six Sigma and Industry 4.0 integration for Operational Excellence: evidence from Italian manufacturing companies. *Production Planning & Control*, 32(13), 1084-1101. https://doi.org/10.1080/09537287.2020.1784485

Davies, R., Coole, T., & Smith, A. (2017). Review of Socio-technical Considerations to Ensure Successful Implementation of Industry 4.0. *Procedia Manufacturing*, 11, 1288-1295. https://doi.org/10.1016/j.promfg.2017.07.256

Demeter, K., Losonci, D., & Nagy, J. (2021). Road to digital manufacturing-a longitudinal case-based analysis. *Journal of Manufacturing Technology Management*, 32(2), 820-839. https://doi.org/10.1108/JMTM-06-2019-0226

Di-Pasquale, V., De-Simone, V., Miranda, S., & Riemma, S. (2022). Smart operators: How augmented and virtual technologies are affecting the worker's performance in manufacturing contexts. *Journal of Industrial Engineering and Management*, 15(2), 233-255. https://doi.org/10.3926/jiem.3607

Dieste, M., Sauer, P.C., & Orzes, G. (2022). Organizational tensions in industry 4.0 implementation: A paradox theory approach. *International Journal of Production Economics*, 251, 108532. https://doi.org/10.1016/j.ijpe.2022.108532

Erbe, H. (2002). Low cost intelligent automation in manufacturing. *IFAC Proceedings Volumes*, 35(1), 373-378. https://doi.org/10.3182/20020721-6-ES-1901.00064

Fast-Berglund, Å., Salunkhe, O., & Åkerman, M. (2020). Low-cost Automation-changing the traditional view on automation strategies using collaborative applications. *IFAC-PapersOnLine*, 53(2), 10285-10290. https://doi.org/10.1016/j.ifacol.2020.12.2762

Gamberini, R., Gebennini, E., Rimini, B., Spadaccini, E., & Zilocchi, D. (2009). Low cost automation and poka yoke devices: tools for optimising production processes. *International Journal of Productivity and Quality Management*, 4(5-6), 590-612. https://doi.org/10.1504/IJPQM.2009.025187

Ghobakhloo, M., & Fathi, M. (2020). Corporate survival in Industry 4.0 era: the enabling role of lean-digitized manufacturing. *Journal of Manufacturing Technology Management*, 31(1), 1-30. https://doi.org/10.1108/JMTM-11-2018-0417

Hannola, L., Lacueva-Pérez, F., Pretto, P., Richter, A., Schafler, M., & Steinhüser, M. (2020). Assessing the impact of socio-technical interventions on shop floor work practices. *International Journal of Computer Integrated Manufacturing*, 33(6), 550-571. https://doi.org/10.1080/0951192X.2020.1775296

Hannola, L., Richter, A., Richter, S., & Stocker, A. (2018). Empowering production workers with digitally facilitated knowledge processes – a conceptual framework. *International Journal of Production Research*, 56(14), 4729-4743. https://doi.org/10.1080/00207543.2018.1445877

Hattinger, M., Lundh-Snis, U., & Islind, A.S. (2021). Real-time analytics through industrial internet of things: Lessons learned from data-driven industry. *27th Annual Americas Conference on Information Systems (AMCIS), Electr Network*.

Holmström, J., Ketokivi, M., & Hameri, A.P. (2009). Bridging practice and theory: A design science approach. *Decision Sciences*, 40(1). https://doi.org/10.1111/j.1540-5915.2008.00221.x

Høyrup, S. (2010). Employee-driven innovation and workplace learning: basic concepts, approaches and themes *Transfer: European Review of Labour and Research, 16*(2), 143–154. SAGE Publications, London, England. https://doi.org/10.1177/1024258910364102

Kaasinen, E., Schmalfuß, F., Özturk, C., Aromaa, S., Boubekeur, M., Heilala, J. et al. (2020). Empowering and engaging industrial workers with Operator 4.0 solutions. *Computers & Industrial Engineering*, 139, 105678. https://doi.org/10.1016/j.cie.2019.01.052

Kanter, R. M. (2008). *Men and women of the corporation: New edition*. Basic books.

Kesting, P., & Ulhoi, J.P. (2010). Employee-driven innovation: extending the license to foster innovation. *Management Decision*, 48(1), 65-84. https://doi.org/10.1108/00251741011014463

Kohlbacher, F. (2006). The use of qualitative content analysis in case study research. *Forum Qualitative Sozialforschung/Forum: Qualitative Social Research*, 7(1), 1-30.

Kolberg, D., & Zühlke, D. (2015). Lean Automation enabled by Industry 4.0 Technologies. *IFAC Proceedings Volumes (IFAC-PapersOnline)*, 48(3), 1870-1875. https://doi.org/10.1016/j.ifacol.2015.06.359

Marcon, É., Soliman, M., Gerstlberger, W., & Frank, A.G. (2022). Sociotechnical factors and Industry 4.0: an integrative perspective for the adoption of smart manufacturing technologies. *Journal of Manufacturing Technology Management*, 33(2), 259-286. https://doi.org/10.1108/JMTM-01-2021-0017

Mattsson, S., Fast-Berglund, Å., Li, D., & Thorvald, P. (2020). Forming a cognitive automation strategy for Operator 4.0 in complex assembly. *Computers & Industrial Engineering*, 139, 105360. https://doi.org/10.1016/j.cie.2018.08.011

MESH (2022). *MESH*. Available at: https://meshprj.com/en/

Michael, L., Alexander, R., & Melanie, S. (2019). "Power to the workers": Empowering shop floor workers with worker-centric digital designs. *International Journal of Operations & Production Management*, 39(1), 24-42. https://doi.org/10.1108/IJOPM-05-2017-0294

Mokudai, T., Schröder, M., Müller, M., Schaede, C., Holst, H., Sinopoli, R. et al. (2021). Digital technologies as lean augmentation: a preliminary study of Japanese automotive manufacturers. *International Journal of Automotive Technology and Management*, 21(3), 228-249. https://doi.org/10.1504/IJATM.2021.116607

Müller, J.M. (2019). Assessing the barriers to Industry 4.0 implementation from a workers' perspective. *IFAC-PapersOnLine*, 52(13), 2189-2194. https://doi.org/10.1016/j.ifacol.2019.11.530

Müller-Polyzou, R., Meier, N., & Georgiadis, A. (2020). Case study analysis of laser-assisted Low-Cost Automation assembly. *IFAC-PapersOnLine*, 53(2), 10403-10410. https://doi.org/10.1016/j.ifacol.2020.12.2780

Obiso, J.J.A., Himang, C.M., Ocampo, L.A., Bongo, M.F., Caballes, S.A.A., Abellana, D.P.M. et al. (2019). Management of Industry 4.0 – reviewing intrinsic and extrinsic adoption drivers and barriers. *International Journal of Technology Management*, 81(3-4), 210. https://doi.org/10.1504/IJTM.2019.105310

Onizawa, R., Takamura, T., Tanaka, M., & Motohashi, S. (2016). Next-generation IoT-based Production System for High-mix Low-volume Products in an Era of Globalization. *Hitachi Review*, 65(5), 58-63.

Rabelo, R.J., Romero, D., Zambiasi, S.P., & Magalhães, L.C. (2021). When Softbots Meet Digital Twins: Towards Supporting the Cognitive Operator 4.0. *IFIP International Conference on Advances in Production Management Systems* (37-47). https://doi.org/10.1007/978-3-030-85914-5_5

Romero, D., Stahre, J., Wuest, T., Noran, O., Bernus, P., Fasth-Åsa, F.B. et al. (2016). Towards an Operator 4.0 Typology: A Human-Centric Perspective on the Fourth Industrial Revolution Technologies. In *International Conference on Computers & Industrial Engineering (CIE46)* (1-11).

Rossini, M., Cifone, F.D., Kassem, B., Costa, F., & Portioli-Staudacher, A. (2021). Being lean: how to shape digital transformation in the manufacturing sector. *Journal of Manufacturing Technology Management*, 32(9), 239-259. https://doi.org/10.1108/JMTM-12-2020-0467

Rožanec, J.M., Novalija, I., Zajec, P., Kenda, K., Tavakoli-Ghinani, H., Suh, S. et al. (2022). Human-centric artificial intelligence architecture for industry 5.0 applications. *International Journal of Production Research,* 61(20), 6847-6872. https://doi.org/10.1080/00207543.2022.2138611

Salvatore, M., & Stefano, R. (2021). Smart operators: How Industry 4.0 is affecting the worker's performance in manufacturing contexts. *Procedia Computer Science*, 180, 958-967. https://doi.org/10.1016/j.procs.2021.01.347

Sanders, A., Elangeswaran, C., & Wulfsberg, J.P. (2016). Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function as enablers for lean manufacturing. *Journal of Industrial Engineering and Management (JIEM)*, 9(3), 811-833. https://doi.org/10.3926/jiem.1940

Sanders, E.B.N. (2002). From user-centered to participatory design approaches. In Frascara, J. (Ed.), *Design and the social sciences* (1-7). Taylor & Francis. https://doi.org/10.1201/9780203301302.ch1

Schuh, G., Anderl, R., Gausemeier, J., ten-Hompel, M., & Wahlster, W. (2017). *Industrie 4.0 Maturity Index: Managing the digital transformation of companies*. Acatech Study.

Seifermann, S., Böllhoff, J., Metternich, J., & Bellaghnach, A. (2014). Evaluation of work measurement concepts for a cellular manufacturing reference line to enable low cost automation for lean machining. *Procedia CIRP*, 17, 588-593. https://doi.org/10.1016/j.procir.2014.01.065

Semwal, T., Aracri, S., McConnell, A.C., Sayed, M.E., & Stokes, A.A. (2020). A Systems Approach to Real-World Deployment of Industrial Internet of Things. *2020 IEEE Congress on Evolutionary Computation (CEC)* (1-8). https://doi.org/10.1109/CEC48606.2020.9185790

Sievers, F., Reil, H., Rimbeck, M., Stumpf-Wollersheim, J., & Leyer, M. (2021). Empowering employees in industrial organizations with IoT in their daily operations. *Computers in Industry*, 129, 103445. https://doi.org/10.1016/j.compind.2021.103445

Simon, H.A. (1973). Does scientific discovery have a logic? *Philosophy of Science*, 40(4), 471-480. https://doi.org/10.1086/288559

Sodhi, H. (2020). When Industry 4.0 meets lean six sigma: a review. *Industrial Engineering Journal*, 13(1), 1-12. https://doi.org/10.26488/IEJ.13.1.1214

Sordan, J.E., Oprime, P.C., Pimenta, M.L., da-Silva, S.L., & González, M.O.A. (2022). Contact points between Lean Six Sigma and Industry 4.0: a systematic review and conceptual framework. *International Journal of Quality & Reliability Management*, 39(9), 2155-2183. https://doi.org/10.1108/IJQRM-12-2020-0396

Takeda, H. (2007). *Toyota shiki kanben jidoka*. Nikkan kogyo shimbun (in Japanese).

Tidd, J., Bessant, J., & Pavitt, K. (2005). *Managing innovation: Integrating technological, market and organizational change*. Chichester, England: John Wiley & Sons.

Tortorella, G.L., Giglio, R., & Van-Dun, D.H. (2019). Industry 4.0 adoption as a moderator of the impact of lean production practices on operational performance improvement. *International Journal of Operations & Production Management*, 39(6/7/8), 860-886. https://doi.org/10.1108/IJOPM-01-2019-0005

Tortorella, G.L., Narayanamurthy, G., & Thurer, M. (2021). Identifying pathways to a high-performing lean automation implementation: An empirical study in the manufacturing industry. *International Journal of Production Economics*, 231, 107918. https://doi.org/10.1016/j.ijpe.2020.107918

Tu, M., Lim, M.K., & Yang, M.F. (2018). IoT-based production logistics and supply chain system – Part 1. *Industrial Management & Data Systems*, 118(1), 65-95. https://doi.org/10.1108/IMDS-11-2016-0503

Vereycken, Y., Ramioul, M., Desiere, S., & Bal, M. (2021). Human resource practices accompanying industry 4.0 in European manufacturing industry. *Journal of Manufacturing Technology Management*, 32(5), 1016-1036. https://doi.org/10.1108/JMTM-08-2020-0331

von-Hippel, E. (2005). *Democratizing innovation*. MIT Press. https://doi.org/10.7551/mitpress/2333.001.0001

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