Production Planning & Control
The Management of Operations

ISSN: 0953-7287 (Print) 1366-5871 (Online) Journal homepage: www.tandfonline.com/journals/tppc20

A global industrial perspective on lean industry 4.0: a qualitative wide-angle lens approach

Peter Hines, Guilherme Luz Tortorella, Jiju Antony, David Romero, Aidan Walsh, Darrin Taylor, Anabela Carvalho Alves, Massimo Bertolini, Rodrigo Caiado, Krisztina Demeterj, José Dinis-Carvalho, Luís Pinto Ferreira, Diego Fettermann, Moacir Godinho Filho, Paolo Gaiardelli, Graham Howe, Guven Gurkan Inan, Maneesh Kumar, Chi Hieu Le, Florian Magnani, Juan Manuel Maqueira, Josefa Mula, Michael Packianather, Paulo Peças, Maria Teresa Ribeiro Pereira, Daryl Powell, Anupama Prashar, Masood Ur Rehman, José Carlos Vieira De Sá, Henrik Saabye, Selim Erol, Leonor Teixeira & Helen Zak

To cite this article: Peter Hines, Guilherme Luz Tortorella, Jiju Antony, David Romero, Aidan Walsh, Darrin Taylor, Anabela Carvalho Alves, Massimo Bertolini, Rodrigo Caiado, Krisztina Demeterj, José Dinis-Carvalho, Luís Pinto Ferreira, Diego Fettermann, Moacir Godinho Filho, Paolo Gaiardelli, Graham Howe, Guven Gurkan Inan, Maneesh Kumar, Chi Hieu Le, Florian Magnani, Juan Manuel Maqueira, Josefa Mula, Michael Packianather, Paulo Peças, Maria Teresa Ribeiro Pereira, Daryl Powell, Anupama Prashar, Masood Ur Rehman, José Carlos Vieira De Sá, Henrik Saabye, Selim Erol, Leonor Teixeira & Helen Zak (10 Jun 2025): A global industrial perspective on lean industry 4.0: a qualitative wide-angle lens approach, Production Planning & Control, DOI: 10.1080/09537287.2025.2509143

To link to this article: https://doi.org/10.1080/09537287.2025.2509143

© 2025 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.

Published online: 10 Jun 2025.

Submit your article to this journal

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=tppc20

PRODUCTION PLANNING & CONTROL
https://doi.org/10.1080/09537287.2025.2509143

Taylor & Francis
Taylor & Francis Group

OPEN ACCESS Check for updates

A global industrial perspective on lean industry 4.0: a qualitative wide-angle lens approach

Peter Hines[a,b], Guilherme Luz Tortorella[c,d,e], Jiju Antony[f], David Romero[g], Aidan Walsh[a,b], Darrin Taylor[a,b], Anabela Carvalho Alves[h], Massimo Bertolini[i], Rodrigo Caiado[j], Krisztina Demeterj[k], José Dinis-Carvalho[l], Luís Pinto Ferreira[m], Diego Fettermann[n], Moacir Godinho Filho[o], Paolo Gaiardelli[p], Graham Howe[q], Guven Gurkan Inan[r], Maneesh Kumar[s], Chi Hieu Le[t], Florian Magnani[u,v#], Juan Manuel Maqueira[w], Josefa Mula[x], Michael Packianather[y], Paulo Peças[z], Maria Teresa Ribeiro Pereira[m], Daryl Powell[aa], Anupama Prashar[ab], Masood Ur Rehman[ac], José Carlos Vieira De Sá[m], Henrik Saabye[ad], Selim Erol[ae], Leonor Teixeira[af], and Helen Zak[b]

[a]Department of Management and Organisation, South East Technological University, Waterford, Ireland; [b]Shingo Institute, Jon M. Huntsman School of Business, Utah State University, Logan, UT, USA; [c]Department of Mechanical Engineering, The University of Melbourne, Melbourne, Australia; [d]IAE Business School, Universidad Austral, Buenos Aires, Argentina; [e]Campus Belo Horontale, Fundacao Dom Cabral, Belo Horizonte, Brazil; [f]Department of Industrial and Systems Engineering, Khalifa University, Abu Dhabi, UAE; [g]Departments of Industrial Engineering and Mechatronics, Tecnológico de Monterrey, Mexico City, Mexico; [h]ALGORITMI/LASI R&D Center, Escola de Engenharia da Universidade do Minho, Minho, Portugal; [i]'Enzo Ferrari' Engineering Department, University of Modena and Reggio Emilia, Modena, Italy; [j]Tecgraf Institute, Pontifical Catholic University of Rio de Janeiro, Rio de Janeiro, Brazil; [k]Corvinus University of Budapest, Hungary & Bábes-Bolyai University, Cluj Napoca, Hungary; [l]Escola de Engenharia da Universidade do Minho, Minho, Portugal; [m]LAETA/INEGI, ISEP, Polytechnic of Porto, Porto, Portugal; [n]Department of Production and Systems Engineering, Universidade Federal de Santa Catarina, Florianopolis, Brazil; [o]Ecole de Management de Normandie, Metis Lab, Le Havre, France; [p]Department of Management, Information and Production Engineering, Università degli Studi di Bergamo, Bergamo, Italy; [q]MADE Cymru, University of Wales Trinity Saint David, Saint David, UK; [r]School of Social Sciences, Heriot-Watt University, Edinburgh, UK; [s]Cardiff Business School, Cardiff University, Cardiff, UK; [t]Faculty of Engineering and Science, University of Greenwich, Greenwich, UK; [u]Aix-Marseille Université, CERGAM, Aix en Provence, France; [v]CERGAM, Ecole Centrale Méditerranée, Marseille, France; [w]Department of Business Administration, University of Jaen, Jaen, Spain; [x]Research Centre on Production and Management, Catedrática de Universidad en Universitat Politècnica de València, Valencia, Spain; [y]School of Engineering, Cardiff University, Cardiff, UK; [z]XIDMEC, Instituto Superior Técnico, Universidade de Lisboa, Portugal; [aa]SINTEC Manufacturing, University of South-Eastern Norway (USN), Kongsberg, Norway; [bb]Management Development Institute Gurgaon, Gurgaon, India; [ac]School of Engineering, Glasgow University, Glasgow, UK; [ad]Department of Materials and Production, Aarhus University, Aarhus, Denmark; [ae]Institute of Industrial Engineering and Management, University of Applied Sciences Wiener Neustadt, Wiener Neustadt, Austria; [af]Department of Economics, Management, Industrial Engineering and Tourism (DEGEIT), Universidade de Aveiro, Aveiro, Portugal

ABSTRACT

This paper provides an insight into the global state of Lean Industry 4.0 (LI4) with over 1,000 industry responses. The approach employs a rigorous qualitative open-response survey. Our findings indicate that there was no unified industry perspective of LI4 terminology. The evolution of I4 is taking a similar path to Lean and making the same mistakes by not focusing on leadership, engagement, competencies, and behaviours. Past academic research has perhaps over-emphasised the environment and supply chain. The benefits of LI4 application are largely in terms of efficiency, cost reduction, learning and engagement. This work contributes by highlighting research avenues: why a piecemeal approach has been taken by industry to LI4, why LI4 has not been more widespread, and more detailed studies around contingent factors). It also provides industry with lessons on how to implement LI4 and the mistakes to avoid such as seeing implementation as a purely technical exercise.

ARTICLE HISTORY
Received 5 February 2024
Accepted 13 May 2025

KEYWORDS
Lean; industry 4.0; qualitative survey; global

1. Introduction

The linkage between Lean and Industry 4.0 (LI4) has become well-established (Ejsmont et al. 2020; Moraes, Carvalho, and Sampaio 2023). It is widely cited that this improves organisational and financial performance (Tortorella and Fettermann 2018; Guerrero, Mula, and Tormo 2023). Most of the literature suggests a synergistic effect (Buer et al. 2021) with the tools and process focus of Lean combined with the technology focus of Industry 4.0 (I4). Ciano et al. (2021, 1387) suggest that Lean's 'high streamlined process orientation with defined tasks and times, its standardisation of work and places, and its emphasis on visual control and transparency facilitate the implementation of the Industry 4.0 information sharing and

CONTACT Peter Hines peter.hines@setu.ie
[#]Present address: Florian Magnani, Université Jean Moulin Lyon 3, iaelyon School of Management, UR Magellan, France; Daryl Powell, Department of Business, Strategy and Political Science, University of South-Eastern Norway, Kongsberg, Norway

© 2025 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.
This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (http://creativecommons.org/licenses/by-nc-nd/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

automation'. It has been argued that a focus on Lean alone is not sufficient (Salvadorinho and Teixeira 2020) and neither is a sole focus on the technologies of Industry 4.0 (Breque, De Nul, and Petridis 2021; Tortorella et al. 2023a).

Various challenges have been identified for industry, including: whether Industry 4.0 is beneficial to an existing Lean organisation (Bittencourt, Alves, and Leão 2021); what the enablers (Machado et al. 2021) and barriers to integration are (Stentoft and Rajkumar 2020); how too measure maturity (Kolla, Minufekr, and Plapper 2019) and develop roadmaps (Solheim and Powell 2020); and whether the approach is more applicable in certain industries (Danese, Mocellin, and Romano 2021), developed/developing countries (Pagliosa, Tortorella, and Ferreira 2019), or size of companies (Agostini and Nosella 2019).

Much of the past research has focused on the technological aspects of LI4 (Moraes, Carvalho, and Sampaio 2023) and has shown the linkage of Lean tools and I4 technologies (Pagliosa, Tortorella, and Ferreira 2019; Rajab, Afy-Shararah, and Salonitis 2022). The practical evidence of the integration of Lean and Industry 4.0 (e.g. the merging between kanban systems and Enterprise Resource Planning, or the combination between preventive maintenance techniques with wireless sensors and Internet-of-Things) are quite often private-owned solutions that need to be tailored to specific company needs (Kolberg, Knobloch, and Zühlke 2017), lacking generalisation to broader industry contexts. Commonly adopted research methods have encompassed localised quantitative surveys (Ghaithan et al. 2021; Pagliosa, Tortorella, and Ferreira 2019) and literature reviews (Nedjwa, Bertrand, and Boudemagh 2022; Moraes, Carvalho, and Sampaio 2023). The research community is also highly concentrated in a few countries (Ejsmont et al. 2020), with Hines et al. (2023) reporting that half of the top 300 researchers come from 6 countries (Italy, India, UK, USA, Portugal, Germany). There are, however, significant gaps in the literature, especially in terms of empirical research taking a more socio-technical perspective (Ejsmont et al. 2020; Hines et al. 2023; Lima et al. 2023).

This paper seeks to address these gaps and provide a global industry perspective on the current state and future directions of LI4 based on an in-depth, open-question, qualitative survey administered by a worldwide team of 33 academic researchers and 6 partner organisations. This unparalleled access yielded 1,030 usable responses from 6 continents and 66 countries.

After this introduction, a literature review focuses on the major gaps in the field, followed by a methodology section explaining and justifying our approach, a description of the research stages, their standards and validation steps, as well as how various research concerns were addressed. Subsequently, we provide our findings, discuss them, and offer a set of observations. Finally, we provide a set of conclusions and future research opportunities.

2. Literature review

This literature review seeks less to establish what literature exists and more to examine what does not exist to an appropriate breadth or depth. The literature is both recent and plentiful, with over 200 publications in the last five years (Alsadi et al. 2023) and several summaries (Moraes, Carvalho, and Sampaio 2023). It is overwhelmingly positive about the relationship between Lean and I4, with a primary focus on the technological tie-up between Lean tools and I4 technologies (Núñez-Merino et al. 2020; Lucantoni et al. 2022; Moraes, Carvalho, and Sampaio 2023). This is mainly due to the dominance of researchers from an engineering background (Ejsmont et al. 2020; Pagliosa, Tortorella, and Ferreira 2019). Lean is frequently presented as the foundation for I4, or that I4 enhances Lean's effectiveness (Rosin et al. 2020).

There have been frequent calls for future research. One of the most comprehensive frameworks for this is provided by Hines et al. (2023), devised from a survey with the top 300 academics in the field and which we use here to explore the research gaps. We will therefore summarise those gaps in the literature as our purpose is to provide a global industry perspective on the current state and future directions of LI4 based on those gaps.

The term 'Lean Industry 4.0 (LI4)', or, to a lesser degree, 'Lean 4.0', is favoured by academics. Hines et al. (2023) identify the need to follow the views of people in industry as current knowledge is limited in geographical coverage (Tortorella, Giglio, and van Dun 2019; Buer et al. 2021; Tortorella et al. 2023b) making generalisation hazardous. This call for more evidence from industry is widely echoed in the literature (Horváth and Szabó 2019; Pagliosa, Tortorella, and Ferreira 2019; Alsadi et al. 2023).

The specific gaps identified by Hines et al. (2023) are summarised in Table 1. The first area is conceptual/empirical research covering areas such as the causal relationship between LI4 and an understanding of the real issues within industry and case studies. Several studies have looked at causality with Lean, invariably seen as a precursor of LI4. These have either been based on literature reviews (Buer, Strandhagen, and Chan 2018; Pagliosa, Tortorella, and Ferreira 2019) or close geography-focused quantitative surveys (Tortorella and Fettermann 2018). The real issues in industry have been studied by a few authors: Stentoft and Rajkumar (2020) in a Danish survey; Chiarini and Kumar (2020b) in the Italian cases; Machado et al. (2021) in an expert panel approach; Al Balkhy, Sweis, and Lafhaj (2021) in a Jordanian survey; Singh and Jha (2021) conceptually; and Oliveira-Dias et al. (2023) in the Spanish supply chain. What is lacking is the type of widespread qualitative geographical study provided by this work.

The second area concerns people within LI4. Currently, research is quite limited, with people often portrayed as static recipients of new technologies (Nahavandi 2019; Bittencourt, Alves, and Leão 2021), with only a few studies focusing on areas such as the role of the employee (Romero, Stahre, and Taisch 2020), leadership (Tortorella et al. 2018), and human resources (Kumar 2018). There have also been some wider studies such as the van Dun and Kumar (2023) review of social enablers, and Tortorella et al. (2023b) study of organisational culture and I4. What is lacking is a more thorough review of the role of people at different levels of

Table 1. Research gaps identified in LI4 (adapted from Hines et al. 2023).

L14: Past, Present, Future Gap Area	Specific Gap	Support for Gap
Conceptual/Empirical	Causal Relationship between Lean and Industry 4.0 and whether there is a best way.	(Buer, Strandhagen, and Chan 2018; Tortorella and Fettermann 2018; Ejsmont et al. 2020; Pagliosa, Tortorella, and Ferreira 2019)
	Practical research on the real issues of working with Lean Industry 4.0.	(Tortorella and Fettermann 2018; Pagliosa, Tortorella, and Ferreira 2019)
	Case study research, including which combination of tools and technologies should be applied in which order, insights into the 'chicken and egg' paradox, and comparative cases.	(Tortorella, Giglio, and van Dun 2019; Ciano et al., 2021)
Human	Human impact and involvement.	(Nahavandi 2019; Romero et al. 2020, Bittencourt, Alves, and Leão 2021; Breque, De Nul, and Petridis 2021)
	Understanding the role of the employee and leader.	(Kumar 2018; Romero et al. 2020; Tortorella et al. 2018; da Silva et al. 2022; van Dun & Kumar 2023)
Enablers, Barriers, Roadmap, Maturity	Enablers of Lean Industry 4.0.	(Stentoft and Rajkumar 2020; Macias-Aguayo et al. 2022)
	Barriers to Lean Industry 4.0.	(Ghobakhloo and Fathi 2019; Haddud and Khare 2020; Salvadorinho and Teixeira 2020; Macias-Aguayo et al. 2022)
	Implementation roadmap.	(Kolla, Minufekr, and Plapper 2019; Sassanelli et al. 2020; Nedjwa, Bertrand, and Boudemagh 2022)
	Maturity assessment.	(Kolla, Minufekr, and Plapper 2019; Sassanelli et al. 2020; Nedjwa, Bertrand, and Boudemagh 2022)
Supply Chain, Sustainability, Resilience	Understanding customer perspectives and collaboration.	(Danese, Mocellin, and Romano 2021; Reyes, Mula, and Díaz-Madroñero 2023; Choudary et al. 2022; Filho et al. 2022)
	Industry 4.0 and sustainability and circular economy.	(Kamble, Gunasekaran, and Dhone 2020; John, Sampayo, and Peças 2021)
	Industry 4.0 and resilience.	(Belhadi et al. 2021; Velarde, Kefalikis, and Hines 2024)
Contingency	Contingency around firm size, industry, development of economy, organisational culture, single vs. multiple sites, and outside of manufacturing.	(Agostini and Nosella 2019; Ciano et al., 2019; Kolla, Minufekr, and Plapper 2019; Ejsmont et al., 2020; Kipper et al., 2020; Reinhardt, Oliveira, and Ring 2020; Pagliosa, Tortorella, and Ferreira 2019; Yang et al. 2023)
Competencies, Training, Education	How to identify new competencies; what they are; and how they might be developed.	(Ansari, Erol, and Sihn 2018; Buer et al., 2018; Ciano et al, 2021; Maisiri et al., 2021; Hines and Netland 2023)
Readiness, Inputs, Results	How ready are organisations to undertake Lean Industry 4.0?	(McDermott et al. 2023; Qureshi et al., 2023)
	What inputs are required?	(Stentoft and Rajkumar 2020; Macias-Aguayo et al., 2022)
	Triple bottom line results of implementation.	(Cattaneo et al. 2017; Pamornmast et al., 2019; Ganjavi & Fazlollahtabar, 2023; Filho et al. 2022)
Implications for Policy Makers	Implications for policy makers such as security, ethical, and support services in promoting Lean Industry 4.0.	(Breque, De Nul, and Petridis 2021; Larrea & Garcia, 2021)

the organisation, which departments are driving LI4, what the people-related enablers are, as well as the people-related inhibitors and benefits area, and how these compare in importance to other factors.

The third area encompasses the wider enablers and barriers, and whether companies have existing maturity assessments and roadmaps. There have been several studies on enablers and inhibitors, as recently summarised by Guerrero, Mula, and Tormo (2023). Many of these earlier papers point to single enablers or barriers (Horváth and Szabó 2019). The most cited enablers in the literature (Guerero et al. 2023) were: coordination and collaboration among supply chain members; big data and analytics; cloud computing; cobots and automated guided vehicles (AGV); and waste recovery, reduction, and pollution monitoring. The most cited barriers were a lack of understanding of the importance of I4 at top management levels, poor team and cross-functional management, ineffective employee training, and a lack of government policy framework/support.

Whilst there are many published examples of maturity assessments (Chiera et al. 2021) and roadmaps (Tiamaz et al. 2019) in Lean, there are fewer examples of maturity assessments (Hajoary, Balachandra, and Garza-Reyes 2024) and roadmaps (Gajo 2023) in I4. Even more scarce are maturity assessments (Pagliosa, Tortorella, and Ferreira 2020) and roadmaps (Solheim and Powell 2020) in LI4.

The fourth area is supply chain, sustainability, and resilience. There are some existing works in the supply chain area: Danese, Mocellin, and Romano (2021), in the wine industry; a conceptual work by Reyes, Mula, and Díaz-Madroñero (2023) in sustainability with the John, Sampayo, and Peças (2021) study of drivers and design principles; and Kamble, Gunasekaran, and Dhone (2020) work into Indian manufacturing, as well as links between these two areas (Khanzode, Sarma, and Goswami 2023; Filho et al. 2022). There are also rare works linking resilience to LI4 (Belhadi et al. 2021). There seems to be a gap in LI4 in understanding the customer perspective on supply chain, sustainability, and resilience.

The fifth area pertains to contingency, as many texts imply a standard approach (Szász et al. 2020). However, some suggest a more contingent approach (Netland 2016; Szász et al. 2020), including the impact of company size (Agostini and Nosella 2019; Kolla, Minufekr, and Plapper 2019), the economic development level of the host country (Ciano et al. 2019; Pagliosa, Tortorella, and Ferreira 2019), region of the world (Kipper et al. 2020; Ejsmont et al. 2020), size of firm (Kolla, Minufekr, and Plapper 2019; McDermott et al. 2023) and industry type (Reinhardt, Oliveira, and Ring 2020; Yang et al. 2023). All these areas lack a wide-ranging, detailed, systematic review.

The sixth area suggested by Hines et al. (2023) is in the knowledge on the competencies required for LI4 at each level of the organisation. Adoption requires expertise in a range of new or combined competencies (Ansari, Erol, and Sihn 2018), including hard and soft skills (Buer, Strandhagen, and Chan 2018). However, there is a lack of understanding of what they are, at which levels they should be applied, who should lead this competency development, and what outside support is required (Maisiri, Van Dyk, and Coetzee 2021).

The seventh area is around readiness, inputs, and results. There is a lack of understanding about how ready firms are to undertake this journey, although a few recent texts have started addressing this area in micro-small organisations (McDermott et al. 2023) and supply chains (Farwa Quereshi et al. 2023; Duarte and Mc Dermott 2024). There is also some ambiguity about what inputs are required (Stentoft and Rajkumar 2020; Guerrero, Mula, and Tormo 2023) and what implementation results might be expected, although there seems to be considerable academic interest in the achievement of a triple bottom line (Cattaneo et al. 2017; Filho et al. 2022).

The last of the Hines et al. (2023) gaps is related to the implications for policymakers. This area has received little attention, partly because this type of research is done by the regional planning/studies community, which, except for Larrea and Garcia (2021), has been slow to address this gap. Even recent work in the area still typically addresses Lean (Maslyuk and Medvedeva 2023), I4 (Saharan and Pathak 2023; Senna, Roca, and Barros 2023), and Industry 5.0 (Breque, De Nul, and Petridis 2021) separately.

Overall, most empirical studies have so far failed to provide global qualitative perspectives and how their studies provide unique insights. In addition, these studies approach LI4 either from a narrow or superficial perspective, lacking depth or breadth in their analyses. There is a clear need for a more joined-up perspective on LI4 to support industry and the organisations/enterprises of the future. This research gap has motivated the conduction of our work.

3. Methodology

We wished for an unprecedented level of depth and breadth in our research. Hence, we rejected traditional approaches of qualitative interviews like case studies, which provide depth but not breadth (Maxwell 2013), as well as quantitative surveys which afford breadth but limited depth (Tortorella, Giglio, and van Dun 2019). We used a qualitative approach that saw the world in terms of people, situations, events, and processes, rather than as a set of variables as in quantitative research (Maxwell 2013). We also sought to identify any unanticipated phenomenon and generate grounded theories about them (Glaser and Strauss 1967). We additionally aimed to explore causal explanations for what we found.

We chose a qualitative survey, an approach 'which prioritise(s) qualitative research values and harness(es) the rich potential of qualitative data … (and has) … much to offer' (Braun et al. 2021, 641). It allows for clear, comprehensive responses, including unforeseen answers (Creswell 2014), a diversity of responses from a large geographical population, and deep insights into the research topic (Braun et al. 2021, 641). Due to the labour-intensive nature of coding and analysis, the approach typically involves few questions (4-10) and sample sizes are small (20-99), with very few over 100 (Braun et al. 2021). In our case, we set the ambition of a very detailed survey with 26 mostly open-ended questions (42 including sub-questions), and a very wide coverage with purposive, non-probability sampling that targeted individuals/organisations that we perceived would be able to contribute based on their knowledge/experience of LI4 (Appendix A). The questionnaire followed the approach of Hines et al. (2023) in terms of collecting information about the background of participants, their past orientation (such as whether they applied Lean before, after or with Industry 4.0), their present (such as the terminology they use for LI4) and the future (such as who do you think should provide support to you). The detailed questions were designed to address the detailed gaps we showed in Table 1. We believe that is provided an holistic approach to the topic.

We consider this to be a wide-angle lens approach (Toerein and Wilkinson 2004; Aznar-Mas, Huerta, and Marin-Garcia 2023) that provides the potential to capture a diversity of perspectives, experiences, and sense-making (Braun et al. 2021). A summary of the qualitative interview, quantitative survey, and our qualitative survey approach is provided (Table 2). This table was developed by one of the authors and revised and validated following a review by the other authors.

The questionnaire was sent to individuals known to the authors with a purposeful sampling as discussed below. It was circulated electronically using Google Forms which allowed for download and aggregation of the results using an excel spreadsheet.

The approach taken is not without limitations. The main one is that it provides only a relatively high-level view of industry views which might be complemented with more detailed research such as interviews or case studies (Cresswell 2014). It was done at a single point in time and hence could be repeated at a later stage to give a dynamic perspective (Tripathi and Shanker 2024). Additionally, bias in qualitative research is common, and may occur due to researchers or participants. Researcher bias may happen if researchers unknowingly interpret data to meet their hypotheses or include only data that they think are relevant.

Table 2. Comparison of qualitative interviews, quantitative surveys, qualitative surveys.

Criteria	Qualitative Interviews	Quantitative Surveys	Qualitative Surveys (our approach)
Depth of questioning (number of questions)	Medium/High depending on design	Low	Medium/High
Breadth of questioning (geography, industry, size of firm)	Low	Medium/High depending on survey size	High
Time	High (for participant and researcher)	Low (for participant and researcher)	Low for participant but more time intensive to code/analyse than quantitative surveys
Cost	High	Low	Low
Anonymity	Not possible	Possible	Anonymous unless the participant wished to disclose email.
Flexibility of questioning	Low to High depending on whether questions are structured, semi-structured or unstructured.	Low as questions are structured	Low as questions are structured
Flexibility of response	Low as at fixed time	High as completed in participant's own time and *may* allow for several sittings giving refection time	High as completed in participant's own time and allowed several sittings giving refection time
Social Desirability	Problematic	Low concern	Low concern
Leading Questions	Can be problematic depending on skill of researcher	Low concern	Low concern

Participant bias derives from responses to questions based on what participants think are the right answers or what are socially acceptable rather than what they really feel (Galdas 2017). To mitigate these forms of bias, we undertook several measures. First, we framed open-ended questions to prevent participants from simply agreeing or disagreeing. We also assured that different questions were worded differently and that they were engaging throughout the interview. Second, we considered all the obtained data, and analysed it with a clear and unbiased mindset (Petticrew et al. 2008).

3.1. Authorship

Due to the ambition of the research, it was necessary to build a strong interdisciplinary core team of 6 researchers and supplement this with a wider team of 27 researchers and 6 partner organisations across 5 continents. The role of the core team was to frame the research, recruit the wider team and partners, develop the questionnaire, pilot it, send it out en masse, analyse the data, synthesise the information, and draft the paper. The role of the wider team was to provide local language translation of the questionnaire, send the questionnaire out, and, most critically, review and revise drafts for important intellectual content. The questionnaire was sent out to a purposive sample, a common approach in qualitative research (Cresswell 2014) being people known to the research team. This approach was chosen as it allowed us to make the most out of limited resources and ensure a large sample. As the team all had an interest in Lean and Industry 4.0 it is likely that the respondents are from more advanced firms in one or both of these areas. They also agreed on the choice of journal. Together with the core team, they approved the final version and agreed to be accountable for the paper's accuracy and integrity. In line with authorship principles outlined by Taylor & Francis (2023), this has allowed us to include members of both the core and wider teams as named authors. Six additional partners were used to widen our research access but were not credited with co-authorship.

3.2. Research stages

To demonstrate the research stages and the rigour involved, we have developed a protocol, extracted data, and synthesised the resulting information (Tranfield et al. 2003; Macpherson and Holt 2007). This is illustrated by a four-fields map (Koura 1988) as this provides a holistic, beginning-to-end perspective explaining the process in a clear, simple, graphic style (Dimancescu 1992). With the addition of a fifth field for a validation check, it allows for replicability (Lundmark, Protzko, and Weissenbilder 2023). Table 3 summarises the nine-stage research approach, including the standard and validation checks adopted for each stage, with dark shading for the leading role and light shading for the support role (a copy of the coding book is available from the corresponding author).

Our novel approach was not without its limitations nor concerns, which are summarised in Table 4 using a 3C approach (Francis 2002) together with the causes of the concerns and the countermeasures we adopted. It is also worth mentioning that our analyses were mainly one-dimensional. No linkages between topics were investigated. Although this categorisation allows a better understanding of the investigated phenomenon, it may restrict the depth of the analysis.

4. Findings and discussion

4.1. Respondent sample

We received 1,030 usable responses from 66 countries across 6 continents, with the geographical split illustrated in Figure 1. An initial open-coding approach was adopted for the data whereby two members of the research team independently pilot-coded the survey responses. As is common with open-ended qualitative survey questions, a widely dispersed range of responses was interpreted resulting in a large number of codes attributed to responses to some questions. The coders then discussed the codes generated and created a further refined coding scheme that grouped codes into a 5-point

Table 3. Research stages, roles, standards, validation checks.

Stage #	Stage Description	Core Team (6)	Ethics Committee	Wider Team (27)	Partners (6)	Standards	Validation Check
1	Understand key gaps in Lean Industry 4.0 literature	■				Summary of views of 87 key researches	Hines et al. 2023 paper published in Quality Management Journal
						Extensive literature search one core author	Literature search checked for gaps by core team
2	Recruit Wider Research Team and Partners	■		■		A group capable of accessing a global sample of 1000+ usable responses	Research/Partner from 18 countries (5 continents) with 1030 usable responses received
						Saturation coverage possible in survey responses by geography (6 continents and at least 50 countries), industry (30 sectors), company size (5%+ in each of four bands) and type (20%+ in each of 3 types)	Responses from 6 continents and 66 countries, 42 sectors (+ other), 5%+ in 4 defined size bands and 8% in each company type group
3	Develop Questionnaire and Survey Letter and Ethics Protocol	■				One core team member developed comprehensive user friendly questionnaire in plain English with survey letter and ethics protocol developed by 3 core authors	Checked, amended and validated by other core team
			■			Questionnaire and survey approach is ethical	Checked by other core team and through 2 iterative rounds in ethics committee in lead author's University
4	Translate Questionnaire and Survey Letter	■		■		Translate into user friendly key languages where English was less widely spoken to be able to reach target survey size	Google translation in French, German, Italian, Portuguese, Spanish and Turkish checked for usability by native speakers in Core/Wider Team
5	Pilot Questionnaire	■				Survey piloted using Google Forms in November/December 2022 with 41 responses	Checked whether respondents could understand survey (and language) and respond in usable way in 10 countries across 3 continents (all usable)
6	Send Questionnaire & Responses Received	■		■		Survey requests sent seeking anonymous response in Google Forms (unless recipient wanted to receive a copy of the results or be involved in future research)	Checked whether respondents completed in a usable form (1030 out of 1042 usable)
7	Data Analysis	■				Coding book developed by one of the core team with typically 10-15 codes (min. 3 max. 36)	Checked, amended and validated by other members of the core team
						Coding undertaken by another member of core team in order to ensure internal coding consistency with codes slightly modified (with typically 10-30 codes, min. 3 max. 116)	Revised coding approached checked for logic, consistency and rigour by coding book author
8	Synthesise Information	■				Information synthesised into excel spreadsheet, tables and figures	Information reviewed by core team for logic, consistency and rigour as well as usability
9	Write up and Review	■		■		Write up at top journal standard	Checked accuracy/integrity, revised and approved by core and wider team

Table 4. Limitations of research: Concern, cause, countermeasure (3 C).

Concern	Cause	Countermeasure
Complexity of managing very large team size	To gain a very wide survey coverage	Strict project management protocol was established using excel spreadsheet and frequent email communications.
Low flexibility of questioning	Questions fixed in advance	Pilot with 19 responses to adjust wording (for interpretation), format (for ease of use) and questions (for probing depth and clarity of responses).
Too rigid	Inability to ask supplementary questions	Pilot to identify and include any further potential questions, resulting in a long survey.
Length of questionnaire (26 questions including sub-questions requiring 42 responses)	Seeking depth of understanding	A wide research team is accessing a large sample population. Highly topical subject and offering respondents a copy of the findings to encourage participation and completion.
Very large data set	Depth and breadth of research	Extensive labour-intensive coding and analysis.
Safeguarding	Large number of participants and large data set developed and stored	Safe guarding mechanisms developed by researchers, cleared in two iterations through lead researcher's university research ethics review board and shared with participants.
Access to under-represented groups	Hard to reach potential respondents in some industries/countries	A large group of researchers (33) across 16 countries collaborated in this work together with 7 partner organisations. Responses were received from 66 countries, although no responses were received from low-income countries.

coding scale that enabled the data to be analysed and presented in a more meaningful manner.

The income level distribution of the country of the respondents (Hamadeh et al. 2022) was: 81% from high-income countries; 12% from upper-middle-income; 7% from lower-middle-income countries; and none from low-income countries. There was a wide range of industries represented, with 3% from primary industries; 75% from secondary industries; and 22% from tertiary industries. The site-size split of respondents was 54% from large enterprises (250+ employees); 23% from medium (50-249); 14% from small (10-49); and 8% from micro (1-9). Most of the respondents were from multinational organisations (51%), with 21% having multiple sites in one country and 28% having a single site.

We believe that this spread makes it the most comprehensive and representative survey in terms of geography (Tortorella and Fettermann 2018), development level (Rosin et al. 2020), company type (Buer, Strandhagen, and Chan 2018), organisational size (Kolla, Minufekr, and Plapper 2019), and number of locations (McKie et al. 2021).

4.2. Current position

There has been some debate among academics about what LI4 should be called, with the majority view being 'Lean Industry 4.0 (LI4)' or 'Lean 4.0' (Hines et al. 2023). However, our survey suggests there is far less consensus in industry, with LI4 and Lean 4.0 favoured by less than a quarter of respondents (Table 5). Around the same percentage refers to the topic either as Lean or Industry 4.0 (4.0 & I4.0) and there is a far longer list of terms with many not giving it a name (8%), or using internal terminology or specific tools from LI4. This would suggest a greater separation in industry between Lean and Industry 4.0, contradicting the popular conjoint viewpoint (Buer et al. 2021; Ejsmont et al. 2020; Tortorella et al. 2023a).

This leads us to consider whether I4 follows Lean or not. We asked which started first or whether they started simultaneously, finding that 72% of firms started Lean before I4, with 11% starting I4 first, and 17% at around the same time. This demonstrates a chronology of application but not, in our opinion, anything about causality as widely suggested in the literature (Rosin et al. 2020; Powell, Morgan, and Howe 2021). The reason for this finding is that Lean started earlier starting around 1990 whereas Industry 4.0 was not widely implemented until the last few years. Hence, the majority of firms had some type of lean before Industry 4.0 (Tortorella, Giglio, and van Dun 2019). However, as 11% of our sample are implementing Industry 4.0 first causality cannot be conferred.

Our findings around chronology are supported by our questioning about the application of Lean and I4, with Lean consistently applied 5-15% more widely in specific parts of the organisation than I4 (Figure 2). The ordering of the roll-out across different departments appears to follow a similar path, with manufacturing/operations areas first, then warehouse/internal logistics, followed by office/support functions, supply chain/suppliers, and product development. This supports the literature regarding the starting point typically being in manufacturing/operations with a subsequent spreading to other functions (Kumar 2018; Tortorella et al. 2021). It does not, however, lend support to industry having a high level of focus on the wider supply chain as widely implied in the literature (Danese, Mocellin, and Romano 2021; Choudhary et al. 2022; Filho et al. 2022; Reyes, Mula, and Díaz-Madroñero 2023) and questions whether there is a practical gap to be filled.

Hines et al. (2023) found that the academic study of LI4 was dominated by researchers from an engineering background. Our research sought to gauge the focus of Lean and I4 in industry (Table 6). Over half of the respondents (51%) indicated that Lean was run by a Lean (or similar) function; 30% that it was part of one department (most often

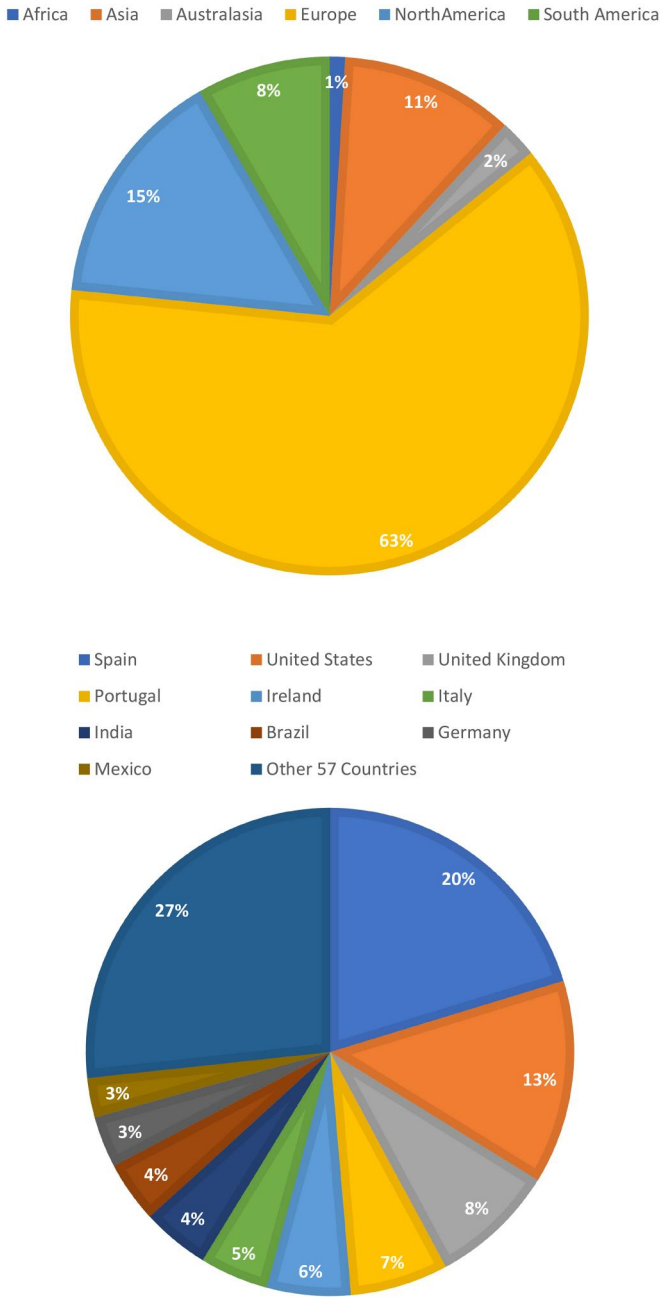

Figure 1. Geographical spread of responses ($n = 1{,}030$).

production or quality); 8% that it was run by management; and 7% that it had no official name.

In contrast, I4 activity was most often (37%) managed by a specific department (typically production); included within the Lean (or Lean synonym) function (24%); within an I4 (or synonym) function (13%); has no official name (13%); or is run by management (10%). Only in 1% of cases was there a specifically named LI4 (or synonym) function. This would suggest that Lean is well established as the de facto improvement approach in most organisations and that it is moving towards incorporating I4 technologies. The reverse of this does happen, but it is relatively rare and even more rare is the fully integrated LI4 widely discussed in academia.

In our survey, we sought to gauge the organisation's maturity in both Lean (Figure 3) and I4 (Figure 4). For that,

Table 5. Terminology used for lean industry 4.0 (academia data from Hines et al. 2023).

Terminology for Lean Industry 4.0	Industry %	Academia %
Lean Industry 4.0	17%	34%
Industry 4.0	11%	8%
Lean	9%	2%
No preference/no suggestion/don't know	8%	0%
Lean 4.0	7%	20%
Combination of terms 'Lean' and 'Digital'	6%	10%
Combination of terms 'Lean' and 'Manufacturing'	4%	6%
4.0/I4.0	3%	2%
Continuous Improvement	3%	0%
Company Own Name/Toyota Production System	2%	0%
Specific Industry 4.0 Technology	2%	0%
Factory of the Future/Smart Manufacturing	2%	2%
Operational Excellence	2%	1%
Keep Lean and Industry 4.0 separate	1%	1%
Specific Lean Tool (e.g. 5S, JIT, VSM, A3)	1%	0%
Lean Industry	1%	1%
Common Sense	0%	0%
Other Terms	19%	11%
Total	100%	100%

we adopted existing frameworks that represented the socio-technical nature of Lean (Chiera et al. 2021) and the technological perspective of I4 (Tortorella et al. 2023a). In the Chiera et al. (2021) Lean case, the technology dimension was removed leaving nine dimensions for Lean together with the nine I4 clusters suggested by Tortorella et al. (2023a). In both cases, a coding score was assigned to each of these with dimensions ranging from '1' to '5', where 1 was none, 2 early stage (just started or focusing on one or two areas), 3 partial (adopted in some areas, e.g. manufacturing, but not been fully adopted), 4 high (adopted across all areas at a good level), and 5 advanced (adopted across all areas at a very high level). It should be noted that, as these two maturity frameworks are independent, it would be hazardous to compare the absolute scores between the Lean scores and the I4 scores. However, the comparison within each set, and the relative scores between the two sets, are valid.

The average ratings for Lean (Figure 3) ranged from 2.96 for 'the company employs continuous flow processing' to 4.20 for 'the company is flexible in dealing with customers', with a total average score of 3.46. The mode score for each of the Lean factors was 4, affirming that all aspects of Lean were typically well-established and coherent, as suggested by Chiera et al. (2021).

In the case of I4 (Figure 4), the lowest average was 1.78 for the use of collaborative robots, and the highest was 2.66 for the application of cloud computing, with a total average score of 2.16. The mode ranges considerably for the different technologies, with no usage (1) highest for 3D printing, augmented reality/simulation, collaborative robots, and machine/deep learning; early stages (2) for the internet of things, big data, and wireless sensors; partial (3) for remote control/monitoring; and high (4) for cloud computing. This suggests that the use of the various technologies is piecemeal. It therefore raises the question as to whether I4 is as coherent an approach in industry as commonly supposed in the academic literature (Tortorella et al. 2023a; Moraes, Carvalho, and Sampaio 2023), and, indeed, whether the I4 revolution has widely taken hold yet, let alone integrated with Lean.

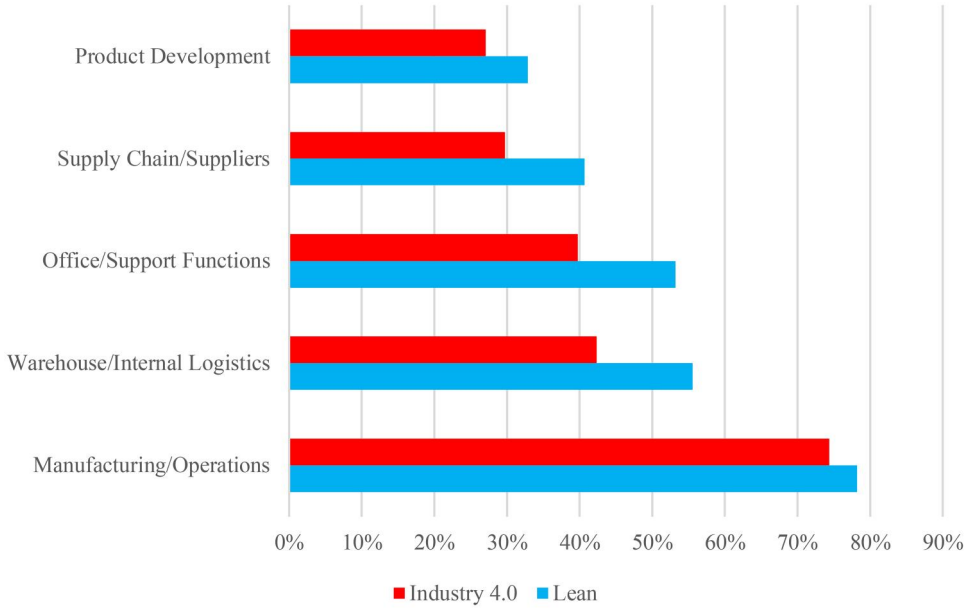

Figure 2. Application of lean and industry 4.0.

Table 6. Responsibility for lean and industry 4.0.

Responsibility for:	Lean		Industry 4.0	
Totals and Percentages:	Total	%	Total	%
Lean Terminology (Operational Excellence, Continuous Improvement, Lean, Process Improvement, Business Excellence, or Company Specific Lean Terminology)	527	51%	249	24%
Industry 4.0 Terminology (Digital/Smart/Automation/Industrialisation/4.0/Advanced Manufacturing)	16	2%	137	13%
Lean Industry 4.0 Terminology (Variant of Lean and Industry 4.0)	5	0%	14	1%
Specific Department	310	30%	385	37%
• Production/Operations/S&OP/Manufacturing/Construction/Industrial	154	15%	150	15%
• Quality	52	5%	39	4%
• Engineering/Advanced Engineering/Manufacturing Engineering	22	2%	40	4%
• Supply Chain	20	2%	14	1%
• R&D/Technical/Innovation/Product Development/Design & Development	11	1%	27	3%
• Technical/Technology	11	1%	20	2%
• IT/Computing/Computer/Computer Science/Informatics	4	0%	42	4%
• Other	36	3%	53	5%
Other				
• Management	81	8%	102	10%
• Everybody	21	2%	10	1%
• No Programme/No Name/Confidential	70	7%	133	13%
Total	1030	100%	1030	100%

We can surmise from Figures 3 and 4 that the majority of the firms are implementing lean and certain technologies of Industry 4.0. The interpretation of the following tables should therefore be taken within this context, although for the sake of consistency we will continue to use the terminology Lean Industry 4.0.

The industry views on the use of LI4 maturity assessments and roadmaps are informative, with 43% of respondents claiming to have a maturity assessment and 50% an implementation roadmap. These figures are surprisingly high bearing in mind the discussion above. We would suggest that these maturity assessments and roadmaps are more likely to be internal approaches or tools from consultancy firms that probably do not cover the holistic view of LI4 we present. Clearly, more detailed research is required, a point made by Kolla, Minufekr, and Plapper (2019), Sassanelli, Rossi, and Terzi (2020), and Nedjwa, Bertrand, and Boudemagh (2022).

We investigated the main reasons why the respondents' organisations wished to pursue LI4 (Table 7a), and what they had found the benefits to be (Table 7b). In these, and the following tables, the respondents' answers have been clustered according to logical groups following a discussion within the core team in line with our coding book. These were deemed to be the most sensible choices for clustering by the team based on their experience.

The academic literature in this area is often confined to single cases or literature reviews with unquantified results. The reasons given in the literature for starting are varied, often with a strong focus on growing competition and customer requirements (Horváth and Szabó 2019; Stentoft and Rajkumar 2020), although cost reduction and a lack of qualified workers is mentioned, more often by consultancies or development agencies (OECD 2017). The most frequently reported benefits are flexibility of production, productivity, reduced inventory, quality, reliability, and cost reduction (Alsadi et al. 2023).

In our survey, the main reason reported for starting (13%) was to improve efficiency/productivity/optimisation, and this was also the main reported benefit (17%). In addition, the other main reasons for starting were also internal business reasons such as competitiveness, cost reduction, continuous improvement, and process improvement. We found that customer and market reasons were much less frequently mentioned, as were issues concerning employees with wider social and environmental reasons receiving few mentions. We can conclude that organisations are largely implementing LI4 for internal reasons, with only indirect benefits to customers. This follows the earlier pattern of Lean in the 1990s where internal efficiency concerns predominated over

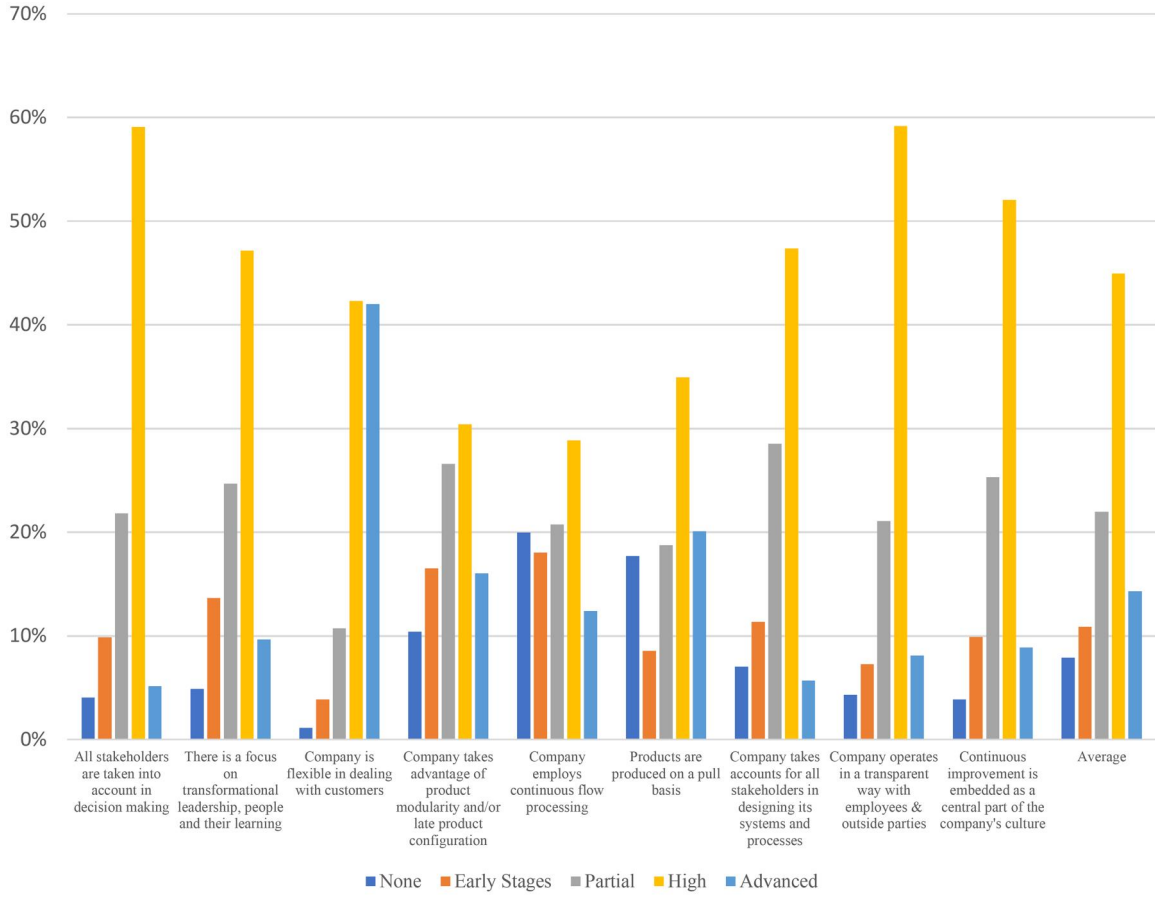

Figure 3. Lean maturity.

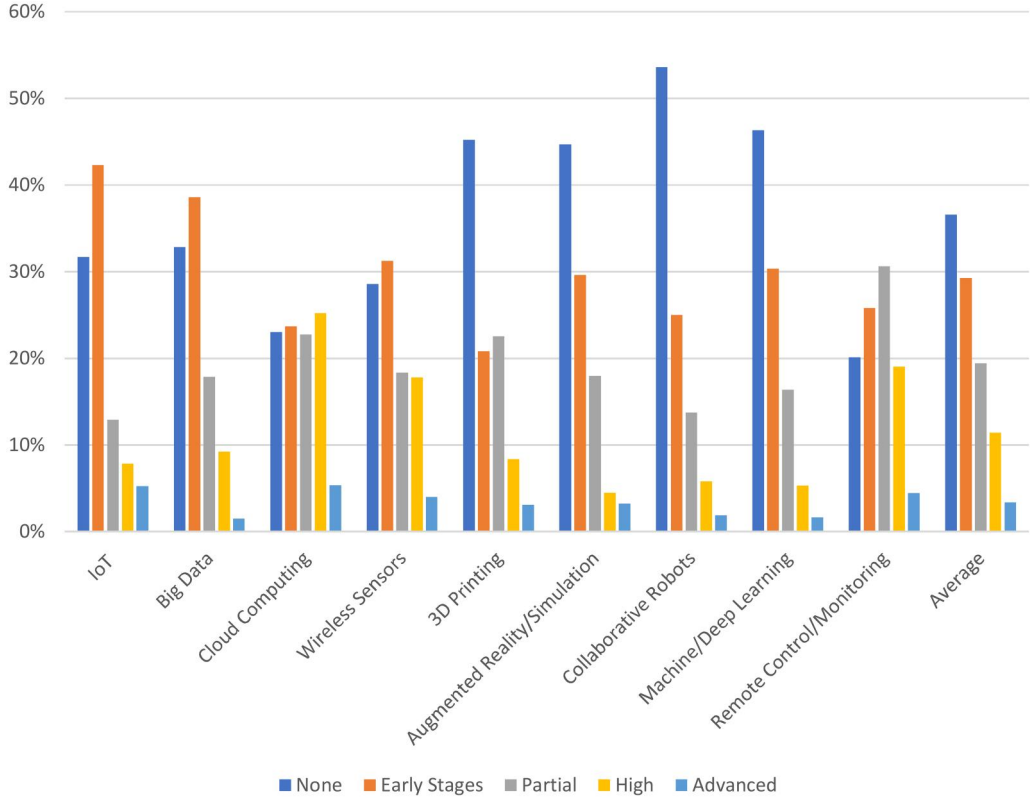

Figure 4. Industry 4.0 maturity.

Table 7a. Reasons for starting the LI4 journey.

Reasons for Starting	#	Internal Business Reasons	Customer/ Market Reasons	Employee Related Reasons	Society Related Reasons	Not Started	Unsure	None	%
Efficiency/Productivity/Optimisation	116								13%
To Be Up To Date/The Future	85								9%
Competitive/Competitive Advantage	80								9%
Cost/Waste Reduction	55								6%
Continuous Improvement	50								6%
Process/System Improvement/Flow	43								5%
Market Demand	39								4%
Survival	34								4%
Strategy	29								3%
Customer Requirement/Value	29								3%
Other Reasons	258								29%
Not Started	77								9%
None	0								0%
Total	895	679	68	47	11	77	13	0	100%
Percentage	100%	76%	8%	5%	1%	9%	1%	0%	100%

Table 7b. Resulting benefits of the LI4 journey.

Resulting Benefits	#	Internal Business Reasons	Customer/ Market Reasons	Employee Related Reasons	Society Related Reasons	Not Started	Unsure	None	%
Efficiency/Productivity/Optimisation	150								17%
Cost/Waste Reduction	104								12%
Real Time Data Availability/Reliability	97								11%
Faster/Time	56								6%
Learning/Development/Coaching/Unlocking Potential	38								4%
Process/System Improvement/Flow	37								4%
Control/Stability/Lower Variation	30								3%
Continuous Improvement	29								3%
Engagement/Involvement/Empowerment/Autonomy	28								3%
Quality	25								3%
Other Benefits	313								35%
Not Started	38								4%
None	11								1%
Total	956	745	29	118	2	38	13	11	100%
Percentage	100%	78%	3%	12%	0%	4%	1%	1%	100%

commercial effectiveness. In many cases, it took firms a long time to learn that, in fact, both are needed simultaneously (Hines et al. 2008).

The benefits received largely follow a similar pattern, with internal benefits predominating such as efficiency, caused by factors including reduced waste, faster changeovers, and fewer breakdowns. However, almost twice as many people report cost reduction as the largest benefit than those seeing it as the largest reason for starting. It is noticeable that data availability is seen as a major benefit, although it was not a major reason for starting. Employee-related areas such as learning, development, involvement, and engagement come out much more strongly as a benefit.

These findings indicate that, in variance with the literature, the industrial perspective about direct customer needs driving LI4 may have been overstated (Cimini et al. 2017), and internal reasons (Stentoft and Rajkumar 2020) and the desire to stay up-to-date (PWC 2016) understated. Employee-related issues also seem to have been underplayed in the literature, especially in terms of the benefits for employees, an area that has only recently been addressed (Molino, Cortese, and Ghislieri 2020; Salvadorinho and Teixeira 2023). It also questions the prominence given in the literature to environmental concerns and the wider supply chain (Filho et al. 2022).

The biggest challenges are concerned with gaining knowledge and building a strategy cluster (26%), as might be expected with a new approach for organisations such as I4 or LI4 (Table 8a). The most frequently cited challenge (9%) is cost and budget creation. This links to the second-, fourth-, and sixth-ranked challenges of gaining leadership buy-in (5%), knowledge (3%), and developing a strategy (3%). The second cluster of challenges concerns implementation (24%), which might be more apparent to those a little way into their journey. The other barriers include change management (4%) and leadership involvement (3%). The third major cluster is around cultural enablers (24%), with specific areas of culture (3%), mindset (3%), and competency (2%) all making the top 10. These areas might be apparent at any time in the journey, whereas data collection/analysis (2%) – the only other challenge in the top ten – is more likely to be a concern once LI4 has started. It is noticeable that there was no major focus on sustaining the change, although this is often cited in the Lean literature as very important (Hines et al. 2008).

The relatively early stage of I4 might explain this for most companies. We should note that, although it was possible to identify the top 10 challenges, the responses were very widely dispersed, with 61% falling outside of the top 10 with a wide range of other factors such as quality, flexibility, and customer satisfaction. The full data set is available from the corresponding author for this and other answers for any reader who wishes to review the full set of individual answers.

Table 8a. Biggest challenges in implementing LI4.

Biggest Challenges	#	Gaining Knowledge & Building Strategy	Implementation	Cultural Enablers	Ongoing Use	Internal/ External Drivers	Sustaining the Change	Planning	Not Started	Unsure	%
Budget/Cost	79										9%
Buy In Leadership/Sites	47										5%
Change Management	37										4%
Knowledge	30										3%
Culture	28										3%
Strategy for Lean/Digital/ Technology/Data	28										3%
Leadership Involvement	27										3%
Mindset	24										3%
Competency	23										2%
Data Collection/Redundancy/ Analysis/Management/ Usage	23										2%
Other Reasons	568										61%
Not Started	12										1%
Total	926	241	226	226	27	78	45	41	12	27	100%
Percentage	100%	26%	24%	24%	3%	8%	5%	4%	1%	3%	100%

Table 8b. Most important enablers in implementing LI4.

Most Important Enabler	#	People	Technology	Change Management	Lean	Internal Influence	Outside Influence	Supplier	Not Started	Unsure	%
Training/Digital Skills/Learning Education/Skills/Experience	59										6%
Attitude/Mindset	58										6%
Senior Management	40										4%
Employees	37										4%
People Involvement/Commitment	37										4%
Technology (Access/Adoption/Optimisation)	35										4%
Change Management	32										3%
Data (Meaningful/Collection/Accuracy/ Fast Analysis)	32										3%
Lean Foundation	25										3%
Management Commitment	25										3%
Other Reasons	533										56%
Not Started	36										4%
Total	949	440	160	129	71	58	22	5	36	27	100%
Percentage	100%	46%	17%	14%	7%	6%	2%	1%	4%	3%	100%

These findings concur with the literature that the major barriers concern cost (Ghobakhloo and Fathi 2019; Macias-Aguayo et al. 2022), buy-in (Macias-Aguayo et al. 2022; van Dun and Kumar 2023), knowledge (Haddud and Khare 2020; Guerrero, Mula, and Tormo 2023), culture and mindset (Salvadorinho and Teixeira 2020; van Dun and Kumar 2023), and change management (Salvadorinho and Teixeira 2020; Macias-Aguayo et al. 2022 Guerrero, Mula, and Tormo 2023). However, low support was demonstrated for other factors in the literature, such as state support (McDermott et al. 2023), wrong equipment/solution (McDermott et al. 2023; Guerrero, Mula, and Tormo 2023), technological incompatibility (Macias-Aguayo et al. 2022), training (Guerrero, Mula, and Tormo 2023), and problem-solving (Saabye, Kristensen, and Wæhrens 2022). We would however suggest that the major challenges change at different implementation stages, something that has not been discussed in the literature.

Our respondents identified primary enablers that fall into three major clusters: people (46%), technology (17%), and change management (14%) (Table 8b). The top five enablers were all in the people area, namely: training (6%), attitude/mindset (6%), senior management (4%), employees (4%), and people involvement/commitment (4%). These human factors have received little attention in the literature, except for Hong, Zhang, and Ding (2018), Ivanov et al. (2021), and Pessot et al. (2020), who all stress the importance of knowledge acquisition/training. Again, there was a wide range of individual factors with 56% falling outside of the top ten, including areas such as the availability of budgets, having a coherent strategy, management support, and appropriate culture.

The second cluster was technology, with access to technology, its adoption and optimisation (4%), and data collection/analysis (3%) identified as the most important areas. This finding is widely supported in the literature (Horváth and Szabó 2019; Rajut and Singh 2019; Ivanov et al. 2021; McDermott et al. 2023).

The third cluster was change management, an area that, except for Komkowski et al. (2023), seems almost unmentioned in the literature. The fourth enabler area is about Lean (7%), with 3% suggesting a Lean foundation. Bearing in mind the importance that 'Lean first then digitise' is given in the literature (Rosin et al. 2020; Powell, Morgan, and Howe 2021), this is a surprisingly low percentage.

The literature does provide a wide range of other factors that are not supported by our findings, including coordination and collaboration among supply chain members (Hong, Zhang, and Ding 2018; Pessot et al. 2020); cloud computing (Chiarini, Belvedere, and Grando 2020a); cobots and

Table 9a. Most important senior management roles in LI4.

Most Important Role of Senior Management	#	Leadership	Strategy	Management	Implementation	None	Not Started	Unsure	%
Leadership Support	81								11%
Strategy (Direction/Objectives/Priorities)	45								6%
Budget Approval	35								5%
Communications (Constant/Consistent)	32								4%
Understanding/Benchmarking LI4 & Role	27								4%
Promotion/Advocacy/Believing/Ownership	27								4%
Sponsorship/Championing	25								3%
Leading by Example	24								3%
Training/Learning	22								3%
Buy-In/Commitment (and Other Senior Staff)	21								3%
Other Reasons	416								54%
Not Started	10								1%
None	6								1%
Total	771	448	101	121	65	6	10	20	100%
Percentage	100%	58%	13%	16%	8%	1%	1%	3%	100%

Table 9b. Most important front-line management roles in LI4.

Most Important Role of Front-Line Management	#	Leadership	Implementation	Management	Strategy	Not Started	Unsure	%
Training/Learning	56							7%
Implementing	54							7%
Data Collection/Robustness/Analysis/Management	37							5%
Engaging/Motivate/Empowering Others	34							4%
Process/Value Stream Management/Improvement	29							4%
Adoption of Technology	28							4%
Understanding/Benchmarking LI4 & Role	27							3%
Leadership Support	25							3%
Promotion/Advocacy/Believing/Ownership	24							3%
Problem Solving	21							3%
Other Reasons	432							55%
Not Started	16							2%
Total	783	383	201	126	45	16	12	100%
Percentage	100%	49%	26%	16%	6%	2%	2%	100%

Table 9c. Most important front-line worker roles in LI4.

Most Important Role of Front-Line Workers	#	Leadership	Implementation	Management	Strategy	Not Started	Unsure	%
Implementing	92							12%
Training/Learning	83							11%
Data Collection/Robustness/Analysis/Management	54							7%
Open to Learn/Think/Change/Take Responsibility	41							5%
Create/Maintaining/Apply Standards	36							5%
Understanding/Benchmarking LI4 & Role	35							5%
Day Job	34							4%
Continuous Improvement	32							4%
Generate Ideas	28							4%
Problem Solving	27							3%
Other Reasons	292							38%
Not Started	23							3%
Total	777	332	253	124	33	23	12	100%
Percentage	100%	43%	33%	16%	4%	3%	2%	100%

AGV (Chiarini, Belvedere, and Grando 2020a; Ivanov et al. 2021); and waste recovery, reduction, and pollution monitoring (Hong, Zhang, and Ding 2018; Rajput and Singh 2019). These are either specific technologies or the environmental and supply chain aspects mentioned above that researchers might be interested in, but they are not seen as major enablers by industry.

The most important roles of different people in LI4 management have received little attention in the literature (Moraes, Carvalho, and Sampaio 2023; van Dun and Kumar 2023), especially at lower organisational levels. We have sought to address this gap by inquiring about the main role of senior management, front-line leaders, and front-line workers (Table 9a–c). In different ways, the leadership cluster was the most important at each of these levels, with scores of 58%, 49%, and 43% respectively.

At the senior level, this area covered 8 of the top 10 factors, including: leadership support (11%); constant and consistent communication (4%); understanding what LI4 is and their role, for instance through benchmarking (4%), believing in LI4 and promoting it (4%), being a champion (3%), leading by example (3%), learning and/or training others (3%), and being committed (3%).

At the front-line leader level, the leadership role (5/10 top factors) is more in terms of learning and/or training others (7%), engaging others (4%), understanding what LI4 is and their role (3%), leadership support (3%), and believing in LI4 and promoting it (3%).

Table 10. Most important competency.

Most Important Competency	#	People	Technology	Behaviours & Mindset	Lean	Change Management	Strategy	Management	Lean & Technology	Not Started	Unsure	%
Learning/Training/Education	49											5%
Data/Data Collection/Data Literacy/Data Analysis	43											5%
Flexibility/Agility	42											4%
Open Mindedness	39											4%
Lean	35											4%
Change Management	32											3%
Process Knowledge and Improvement	25											3%
Communications (Constant/Consistent)	21											2%
People Development	21											2%
Strategy (Planning/Roadmap)	20											2%
Other Reasons	624											65%
Not Started	3											0%
Total	954	126	131	311	131	118	55	21	10	3	46	100%
Percentage	100%	13%	13.7%	33%	13.9%	12%	6%	2%	1%	0%	5%	100%

At the front-line worker level (3/10 factors), the leadership role is about: learning and/or training others (11%), being open to change and taking responsibility (5%) and understanding what LI4 is and their role, for instance, through benchmarking (5%).

Hence, the leadership role varies by level, with a role more around understanding, advocacy, and championing at senior levels; training and engaging at the front-line manager level; and learning and taking responsibility at the front-line worker level. Similarly, Alieva and Powell (2023) stressed the importance of top management leadership, middle management involvement, and employee education. These types of senior leadership roles and front-line worker roles have been proposed by Komkowski et al. (2023). Similarly, Sony and Naik (2019) stressed the importance of top management involvement and commitment, and van Dun and Kumar (2023) suggested transformation leadership with socio-emotional capabilities and sensitivity to individual differences as being very important to achieve employee acceptance. Romero, Stahre, and Taisch (2020) noted the need for smart workers, and the role of enhancing workers' skills and being able to undertake several tasks was stressed by Cimini, Lagorio, and Gaiardelli (2023).

We identified senior management strategy (13%), primarily around direction, objectives and priorities (6%), as a second cluster, as well as management (16%), primarily around budget approval (5%), as a third cluster. Strategy played a smaller part at the lower two levels. Implementation was far more important, with 26% and 33% of the total score. At the front-line manager level, this involved hands-on implementation (7%), data collection and management (5%), managing processes (4%), and the adoption of new technologies (4%); whereas at the front-line worker level, it involved hands-on implementation (12%), data collection and management (7%), the day job (4%), continuous improvement (4%), generating ideas (4%), and problem-solving (3%).

A third management cluster was identified at the front-line manager (16%) and front-line worker (16%) levels. This was more focused on managing the problem-solving for the managers (3%), and creating, managing, or applying standards for workers (5%).

We found a wide distribution of other factors at each level. At the senior level, we found Gemba follow-up, involvement and coaching. At the front-line manager level, these included coaching, sponsorship, and openness to learn; with commitment, engagement and culture also important at the front-line worker level.

Linked to the roles are people's new competencies (Table 10). There was a surprisingly low percentage within the Lean (14%) and I4 (14%) areas, as well as LI4 (1%). Data management was the only purely technical competency identified in the top ten (5%). This contrasts with the I4 literature which stresses the need for hard industrial engineering skills (Maisiri, Van Dyk, and Coetzee 2021). We found that behaviours and mindset (33%), people (13%), and change management (12%) were more strongly advocated, thus supporting the thinking that soft skills and people should be at

the centre of an LI4 transformation (Agostinho and Baldo 2021). The highest-ranking competencies in these areas were learning (5%), flexibility (4%), and open-mindedness (4%). This supports the emerging literature that focuses on the need for employee adaptability (Sony and Naik 2019), making them open to change (Salvadorinho and Teixeira 2023), and self-leadership or distributed leadership (Schultz 2021). We conclude that industry has a greater need for changes in social rather than technical skills, a finding increasingly seen with Lean competencies (Walsh, Harrington, and Hines 2020).

Our last area of enquiry concerned industry requirements for outside support (Table 11). Two of the clusters, namely awareness raising and knowledge (10%), and explaining benefits, business case, and Return on Investment (3%), are required at the start of the journey. Six of the clusters might be needed at any point of the journey (training and education (17%), case studies and other research (7%), grants for pilots and implementation (6%), other general support (5%), benchmarking exemplar sites (4%), and advice on trends and providers (4%)). Two clusters are more likely to be needed during implementation (experience sharing between companies (10%) and implementation support (8%)). These findings regarding government support, education, and sharing best practices, largely concur with the local study in the West of Ireland by McDermott et al. (2023), although not their high-identified need for grants explained by their sample being only small/micro enterprises.

The main providers identified for each area of support are shown in Table 11. The most important providers are government bodies at all levels (22%), consultants (18%), universities/academies (17%), technology providers (12%), and industry/professional bodies (11%). This finding contradicts the SME case research by Larrea and Estensoro (2021) which stressed the importance of local development agencies and vocational training centres. It does however support the Ansari, Erol, and Sihn (2018), Cannas et al. (2020), and Erol et al. (2022) propositions of the role of universities/academies/technology centres. Our results show that many previous studies tended to focus on one element of the support required rather than taking a more independent study of the holistic needs of industry.

In summary, looking at how the factors interact, we can see that organisations most frequently started a Lean journey and have found some of the techniques within Industry 4.0 as useful and have employed them for specific needs rather than adopting Industry 4.0 *in toto*. They have sought to be competitive and efficient whilst staying up to date. In general they have achieved efficiency gains as well as saving time largely through better data availability. There have also been gains in terms of learning and engagement. In terms of the future, the change management and human factors are most important particularly for those who have taken a technology first approach.

5. Summary observations

Our research enabled us to take both a wide-angle and deep look at the views of industry about LI4, leading us to develop 10 key observations.

Observation 1: Whilst the academic community has widely gravitated towards the use of Lean Industry 4.0 (LI4) or Lean 4.0, industry uses a far more wide-ranging terminology.

Observation 2: We have found clear evidence that, in most cases, I4 follows Lean, and that its evolution follows a similar functional evolution. We have not found evidence that industry widely views the former as dependent on the latter.

Observation 3: There are several areas where the academic community has widely called for further research but without widespread interest within industry, including the application of LI4 into the customer perspective, supply chain, sustainability, and resilience.

Observation 4: Despite the widespread academic interest in linking Lean and I4, this link appears to have only been taken up in a few organisations, with the digital tools either just being added to the Lean toolkit or the two areas being largely managed by different teams. It appears that the age of a truly integrated LI4 has not arrived for most organisations.

Observation 5: Most of the surveyed organisations had a high application of the different Lean aspects, and thus we can conclude that Lean is mature. The I4 application was more piecemeal, and indeed many organisations with technologies were perhaps not even aware they were applying I4. It appears that I4, and LI4, are not yet seen as a unified approach.

Observation 6: The people aspect in LI4 has been more pronounced than expected in terms of the reasons for doing it, its benefits, and its challenges. Indeed, more than half of the enabler responses were related to people or change management. This trend follows the earlier evolution of Lean.

Observations 7: The most important role of people at all levels is around leadership, with this role varying by level: being more around understanding, advocacy, and championing at senior levels; more around training and engaging at front-line manager level; and more around learning and taking responsibility at front-line worker level.

Observation 8: The industrial perspective is that change management is very important in terms of challenges and enablers.

Observation 9: The most important competencies were related to behaviours and mindset (37%), ability to learn (13%), and ability to manage change (8%). This reinforced our observations about the importance of people and change management. Overall, industry has a greater need for changes in social rather than technical skills.

Observation 10: The need of industry for outside support changed depending on the starting point and stage of evolution, with governmental agencies, consultancies, and universities/academies seen as the most useful providers.

6. Conclusions

The wide-angled lens plus depth of this research provides us with the most detailed global study yet of industry views of LI4. However, the work complements and contrasts with the earlier study by Hines et al. (2023) and previous studies

Table 11. Most important external requirements & identified support providers for LI4 implementation.

Most Important External Requirements	Number of Help Needs	Outside Help Needs (%)	Providers										
			Government Body	Consultants	University/ Academia	Technology Providers	Industry/ Professional Bodies	Other Companies	Company Networks	Technology Centres	Training Companies	Corporate/ Group	Customers	Schools
Training and Education from Short Course to Degrees	140	17%	3%	3%	5%	1%	1%	0%	0%	1%	1%	0%	0%	1%
Awareness Raising and Knowledge	87	10%	2%	1%	2%	1%	1%	0%	0%	0%	0%	0%	0%	0%
Experience Sharing between Companies	80	10%	1%	1%	1%	1%	2%	2%	1%	0%	0%	0%	0%	0%
Implementation Support	68	8%	2%	3%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%
Case Studies, Use Cases and Other Research with Success/Failure Stories	59	7%	1%	2%	2%	1%	1%	0%	1%	0%	0%	0%	0%	0%
Grants for Pilots and Implementation	46	6%	4%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Other General Support	45	5%	3%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
Benchmarking Exemplar Sites	34	4%	0%	1%	0%	0%	0%	1%	1%	0%	0%	0%	0%	0%
Advice on Trends, Providers	30	4%	2%	1%	1%	0%	1%	0%	0%	0%	0%	0%	0%	0%
Explain Benefits, Business Case & Return on Investment	28	3%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Other	213	26%	3%	5%	4%	5%	3%	1%	1%	1%	0%	0%	1%	0%
Total	830	100%	22%	18%	17%	12%	11%	7%	4%	3%	2%	2%	1%	1%

which often focus on one element to explain phenomena rather than the complexity shown here. Contrasts also include the widespread technical viewpoint of the subject and the I4 reliance on Lean. It also confirms that LI4, and indeed I4, are still in their infancy in industry, although Lean is much more holistically applied. We conclude that a truly integrated LI4 has not arrived for most organisations.

There is, however, substantial academic interest in this linkage (Alsadi et al. 2023), raising questions as to whether: a) we are repeating our own marketing message; b) we are predicting the future; and/or c) why there is not more industry integration between Lean and I4.

Our work has major implications for academia and industry. For academia, we have highlighted areas where there is little call for further research (such as the application of LI4 into the customer perspective, supply chain, sustainability, and resilience) and areas which are fertile for further investigation. Some of this might involve a more detailed analysis of our dataset and specific areas such as enablers and challenges as well as the role of management. In addition, more contingent analysis can be carried out such as variations by industry, geography, and firm size, as well as correlations within and between Lean and I4 application and maturity stages, thus helping establish viable evolutionary roadmaps and maturity assessments. Additionally, new methodologies or research designs, such as field experiments or design science research, could be utilised in future studies to help address the gaps identified.

Other research that we would recommend include: 1) why I4 has been adopted in a piecemeal way and is not being viewed by industry as a unified approach; 2) why the application of LI4 in industry has not been more widespread; 3) the fact that industry is making the same mistakes it did with Lean by not sufficiently focusing on the role of people, competencies, and change management within LI4; and 4) the support structures required for firms in implementing LI4; and 5) further more in-depth study of the whole subject area through case studies or longitudinal research to complement the qualitative survey findings.

The implications for industry include the fact the key learning from Lean implementation around leadership, people, learning, and change management apply equally or more to LI4. Hence, those in industry would be well advised to review their past learnings from their own and others' Lean applications. There is much more potential within LI4 than is currently being exploited, and there is a clear need to avoid I4 being seen merely as a technological trend applied by engineers or computer scientists. The most important areas to focus on are leadership, mindset and behaviour with people, ability to learn, and change management competencies. Further, future studies could outline a simple, actionable framework for how organisations can better integrate LI4.

We have also identified that the key needs of industry vary according to organisations' starting point and stage of implementation and that they might seek to address such needs through self-help networks or by working with outside providers such as government agencies, consultancies, or universities/academies. Our results will also help external providers focus their support for industry. If all these entities can

successfully work together, perhaps the age of LI4 can be arrived at in a more widespread way, and in the very near future.

Acknowledgement

We would like to thank Enterprise Ireland, HKPO, ICBE, Lean Forum, Shingo Institute and UnoPro who contributed with research access and UPV Generalitat Valenciana 'Production and Logistics Optimization in Industry 4.0 (i4OPT)' PROMETEO/2021/065 for partial funding.

Disclosure statement

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

Funding

This work was partially funded by the UPV Generalitat Valenciana "Production and Logistics Optimization in Industry 4.0 (i4OPT)" PROMETEO/2021/065.

Notes on contributors

Peter Hines is a Visiting Professor at South East Technological University, Waterford, Ireland, and a Faculty Fellow of the Shingo Institute, Jon M. Huntsman School of Business, Utah State University, USA. He is the former Director of the Lean Enterprise Research Centre, Cardiff University, Wales, UK. His current research focuses on the intersection of Lean with Industry 4.0 and people.

Guilherme Tortorella has more 12 years experience as a Manufacturing and Continuous Improvement Manager in the automotive industry, having worked in sites in Brazil, Mexico, Uruguay, the UK and USA. Additionally, he has worked as an Industry Consultant for 7 years. With more than 240 journal articles published, 2 books and 15 book chapters, his research is mainly focused in Operations Management, more specifically on Lean Management, Industry 4.0, and Supply Chain Management. He is the Editor-in-Chief of the Journal of Lean Systems, and Associate Editor of the International Journal of Quality & Reliability, International Journal of Lean Six Sigma, Production Journal, and Operations Management Research Journal.

Jiju Antony is recognised worldwide as a leader in Lean Six Sigma methodology for achieving and sustaining process excellence. He is currently serving as a Professor of Quality and Operational Excellence in Newcastle Business School, UK. He has published over 600 journal and conference papers and 14 books. He is a Fellow of the Royal Statistical Society (UK), Fellow of the Chartered Quality Institute (CQI), Fellow of the Institute of Operations Management (FIOM), Fellow of the American Society for Quality (ASQ), Fellow of the Higher Education Academy, Fellow of the International Lean Six Sigma, Fellow of the Institute of the Six Sigma Professionals (ISSP) and Vice President of Research for the International Academy of Quality (IAQ).

David Romero is a Professor of Advanced Manufacturing at the Departments of Industrial Engineering and Mechatronics of the Tecnológico de Monterrey University in Mexico and the Scientific Vice-chairman for the World Manufacturing Foundation. His research interests focus on Human Cyber-Physical Systems and Digital Lean Manufacturing. Furthermore, he is an Agenda Contributor at the World Economic Forum (WEF) Council on 'Shaping the Future of Advanced Manufacturing and Value Chains'.

Aidan Walsh is a Lecturer in Management Studies at the School of Business, South East Technological University, Waterford, Ireland; Joint Programme Director of the Lean Enterprise Excellence executive/practitioner programme portfolio; and Co-Lead of the Academy of Lean Enterprise Excellence in the RIKON Research Centre. Aidan's current research focuses on Lean implementation in Healthcare, and the people dimension of Lean and Industry 4.0 integration.

Darrin Taylor is a Lecturer in Management at the School of Business, South East Technological University, Waterford, Ireland; Joint Programme Director of the Lean Enterprise Excellence executive/practitioner programme portfolio; and Co-Lead of the Academy of Lean Enterprise Excellence in the RIKON Research Centre. Darrin's research interests are primarily focused on the Individual and Socio elements of Lean as a Socio-Technical System.

ORCID

Peter Hines http://orcid.org/0000-0003-1169-5912
Anabela Carvalho Alves http://orcid.org/0000-0002-2926-4187
Massimo Bertolini http://orcid.org/0000-0002-7871-966X
José Dinis-Carvalho http://orcid.org/0000-0002-9724-0312
Moacir Godinho Filho http://orcid.org/0000-0001-6150-1333

References

Agostinho, Vagner., Jr., and Christian R. Baldo. 2021. "Assessment of the Impact of Industry 4.0 on the Skills of Lean Professionals." *Procedia CIRP* 96: 225–229. https://doi.org/10.1016/j.procir.2021.01.079.

Agostini, Lara, and Anna Nosella. 2019. "The Adoption of Industry 4.0 Technologies in SMEs: results of an International Study." *Management Decision* 58 (4): 625–643. https://doi.org/10.1108/MD-09-2018-0973.

Al Balkhy, Wassim, Rateb Sweis, and Zoubeir Lafhaj. 2021. "Barriers to Adopting Lean Construction in the Construction Industry–The Case of Jordan." *Buildings* 11 (6): 222. https://doi.org/10.3390/buildings11060222.

Alieva, Jamila, and Daryl J. Powell. 2023. "The Significance of Employee Behaviours and Soft Management Practices to Avoid Digital Waste during a Digital Transformation." *International Journal of Lean Six Sigma* 14 (1): 1–32. https://doi.org/10.1108/IJLSS-07-2021-0127.

Alsadi, Juman, Jiju Antony, Toufic Mezher, Raja Jayaraman, and Maher Maalouf. 2023. "Lean and Industry 4.0: A Bibliometric Analysis, Opportunities for Future Research Directions." *Quality Management Journal* 30 (1): 41–63. https://doi.org/10.1080/10686967.2022.2144785.

Ansari, Fazel, Selim Erol, and Wilfried Sihn. 2018. "Rethinking Human-Machine Learning in Industry 4.0: How Does the Paradigm Shift Treat the Role of Human Learning?" *Procedia Manufacturing* 23: 117–122. https://doi.org/10.1016/j.promfg.2018.04.003.

Aznar-Mas, Lourdes E., Lorena A. Huerta, and Juan A. Marin-Garcia. 2023. "Effectiveness of the Use of Open-Ended Questions in Student Evaluation of Teaching in an Engineering Degree." *Journal of Industrial Engineering and Management* 16 (3): 521–534. https://doi.org/10.3926/jiem.5620.

Belhadi, Amine, Venkatesh Mani, Sachin S. Kamble, Syed A. R. Khan, and Surabhi Verma. 2021. "Artificial Intelligence-Driven Innovation for Enhanced Supply Chain Resilience and Performance under the Effect of Supply Chain Dynamism: An Empirical Investigation." *Annals of Operations Research* 333 (2): 627–652. https://doi.org/10.1007/s10479-021-03956-x.

Bittencourt, Victor L., Anabela C. Alves, and Celina P. Leão. 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.

Braun, Virginia, Victoria Clarke, Elicia Boulton, Louise Davey, and Charlotte McEvoy. 2021. "The Online Survey as a *Qualitative* Research Tool." *International Journal of Social Research Methodology* 24 (6): 641–654. https://doi.org/10.1080/13645579.2020.1805550.

Breque, Maija, Lars De Nul, and Athanasios Petridis. 2021. "Industry 5.0: Towards a Sustainable, Human-Centric and Resilient European Industry." Brussels, BE: European Commission. https://op.europa.eu/en/publication-detail/-/publication/468a892a-5097-11eb-b59f-01aa75ed71a1/language-en

Buer, Sven-Vegard, Jan O. Strandhagen, and Felix T. S. Chan. 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.

Buer, Sven-Vegard, Marco Semini, Jan O. Strandhagen, and Fabio Sgarbossa. 2021. "The Complementary Effect of Lean Manufacturing and Digitalisation on Operational Performance." *International Journal of Production Research* 59 (7): 1976–1992. https://doi.org/10.1080/00207543.2020.1790684.

Cannas, Violetta G., Maria P. Ciano, Giovanni Pirovano, Rossella Pozzi, and Tommaso Rossi. 2020. "i-FAB: Teaching How Industry 4.0 Supports Lean Manufacturing." In *Proceedings of the 6th European Lean Educator Conference. ELEC 2019 Lecture Notes in Networks and Systems*, edited by M. Rossi, M. Rossini, S. Terzi, 122: 47–55. Cham: Springer. https://doi.org/10.1007/978-3-030-41429-0_6.

Cattaneo, Laura, Monica Rossi, Elisa Negri, Daryl Powell, and Sergio Terzi. 2017. "Lean Thinking in the Digital Era." In *Product Lifecycle Management and the Industry of the Future. PLM 2017. IFIP Advances in Information and Communication Technology*, edited by J. Ríos, A. Bernard, A. Bouras, S. Foufou, 517: 371–381. Cham: Springer. https://doi.org/10.1007/978-3-319-72905-3_33.

Chiarini, Andrea, and Maneesh Kumar. 2020b. "Lean Six Sigma and Industry 4.0 Integration from Operational Excellence: evidence from Italian Manufacturing Companies." *Production Planning & Control* 32 (13): 1084–1101. https://doi.org/10.1080/09537287.2020.1784485.

Chiarini, Andrea, Valeria Belvedere, and Alberto Grando. 2020a. "Industry 4.0 Strategies and Technological Developments. An Exploratory Research from Italian Manufacturing Companies." *Production Planning & Control* 31 (16): 1385–1398. https://doi.org/10.1080/09537287.2019.1710304.

Chiera, Mariastella, Francesco Lupi, Andrea Rossi, and Michele Lanzetta. 2021. "Lean Maturity Assessment in ETO Scenario." *Applied Sciences* 11 (9): 3833. https://doi.org/10.3390/app11093833.

Choudhary, K., N. Sangwa, K. Sangwan, and R. Singh. 2022. "Impact of Lean and Quality Management Practices on Green Supply Chain Performance: An Empirical Study on Ceramic Enterprises." *Quality Management Journal* 29 (3): 193–211. https://doi.org/10.1080/10686967.2022.2083036.

Ciano, M. P., R. Pozzi, T. Rossi, and F. Strozzi. 2019. "How IJPR Has Addressed 'Lean': A Literature Review Using Bibliometric Tools." *International Journal of Production Research* 57 (15-16): 5284–5317. https://doi.org/10.1080/00207543.2019.1566667.

Ciano, Maria Pia., Patrick Dallasega, Guido Orzes, and Tommaso Rossi. 2021. "One-to-One Relationships between Industry 4.0 Technologies and Lean Production Techniques: A Multiple Case Study." *International Journal of Production Research* 59 (5): 1386–1410. https://doi.org/10.1080/00207543.2020.1821119.

Cimini, Chiara, Alexandra Lagorio, and Paolo Gaiardelli. 2023. "The Evolution of Operators' Role in Production: how Lean Manufacturing and Industry 4.0 Affect Job Enlargement and Job Enrichment." *International Journal of Production Research* 61 (24): 8493–8511. https://doi.org/10.1080/00207543.2022.2152894.

Cimini, Chiara, Roberto Pinto, Giuditta Pezzotta, and Paolo Gaiardelli. 2017. "The Transition Towards Industry 4.0: Business Opportunities and Expected Impacts for Suppliers and Manufacturers." In *Advances in Production Management Systems. The Path to Intelligent, Collaborative and Sustainable Manufacturing. APMS 2017. IFIP Advances in Information and Communication Technology*, edited by H. Lödding, R. Riedel, K-D. Thoben, G. von Cieminski, D. Kiritsis, 513: 119–126. Cham: Springer. https://doi.org/10.1007/978-3-319-66923-6_14.

Cresswell, J. 2014. *Education Research: Conducing and Evaluating Quantitative and Qualitative Research*. Chandler: Pearson.

da Silva, Leonardo B. P., Ramon Soltovski, Joseane Pontes, Fernana T. Treinta, Paulo Leitão, Elaine Mosconi, Luis M. M. de Resende, and Rui T. Yoshino. 2022. "Human Resources Management 4.0: Literature Review and Trends." *Computers & Industrial Engineering* 168: 108111. https://doi.org/10.1016/j.cie.2022.108111.

Danese, Pamela, Riccardo Mocellin, and Pietro Romano. 2021. "Designing Blockchain Systems to Prevent Counterfeiting in Wine Supply Chains: A Multiple-Case Study." *International Journal of Operations & Production Management* 41 (13): 1–33. https://doi.org/10.1108/IJOPM-12-2019-0781.

Dimancescu, Dan. 1992. *The Seamless Enterprise: Making Cross Functional Management Work*. New York, NY: HarperCollins.

Duarte, Susana, and Olivia Mc Dermott. 2024. "The Dimensions of Lean-Green 4.0 Readiness a Systematic Literature Review." *Production Planning & Control:* 1–13. https://doi.org/10.1080/09537287.2024.2348522.

Ejsmont, Krzysztof, Bartlomiej Gladysz, Donatella Corti, Fernando Castaño, Wael M. Mohammed, and Jose L. M. Lastra. 2020. "Towards 'Lean Industry 4.0' – Current Trends and Future Perspectives." *Cogent Business & Management* 7 (1): 1781995. https://doi.org/10.1080/23311975.2020.1781995.

Erol, Selim, Johanna Schwaighofer, F. Hofer, and Gabor Princz. 2022. "Fabrication Labs as Essential Buildings Blocks of Regional Innovation Systems." Poster Presented at Conference 15. Forschungsforum Der Österreichischen Fachhochschulen, Villach, Austria, April 2022. https://doi.org/10.13140/RG.2.2.35790.33600.

Filho, Moacir G., Luiza Monteiro, Renata d O. Mota, Jessica d S. L. Gonella, and Lucila M. d S. Campos. 2022. "The Relationship between Circular Economy, Industry 4.0 and Supply Chain Performance: A Combined ISM/Fuzzy MICMAC Approach." *Sustainability* 14 (5): 2772. https://doi.org/10.3390/su14052772.

Francis, Mark. 2002. "Understanding Lower Innovation Product Development Processes in the UK Fast Moving Consumer Goods Sector." PhD diss., Cardiff University.

Gajo, Atheer H. A. 2023. "A Managerial Roadmap Development For Industry 4.0-Based Smart Manufacturing Enterprise Cross-Sector Study In Turkey." PhD diss., University of Turkish Aeronautical Association. https://doi.org/10.5281/zenodo.7634152.

Galdas, P. 2017. "Revisiting Bias in Qualitative Research: Reflections on Its Relationship with Funding and Impact." *International Journal of Qualitative Methods* 16 (1): 1609406917748992. https://doi.org/10.1177/1609406917748992.

Ganjavi, Nasim, and Hamed Fazlollahtabar. 2023. "Integrated Sustainable Production Value Measurement Model Based on Lean and Six Sigma in Industry 4.0 Context." *IEEE Transactions on Engineering Management* 70 (6): 2320–2333. https://doi.org/10.1109/TEM.2021.3078169.

Ghaithan, Ahmed, Mohammed Khan, Awsan Mohammed, and Laith Hadidi. 2021. "Impact of Industry 4.0 and Lean Manufacturing on the Sustainability Performance of Plastic and Petrochemical Organizations in Saudia Arabia." *Sustainability* 13 (20): 11252. https://doi.org/10.3390/su132011252.

Ghobakhloo, Morteza, and Masood Fathi. 2019. "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.

Glaser, Barney G., and Anselm L. Strauss. 1967. *The Discovery of Grounded Theory: Strategies for Qualitative Research Observations*. Chicago, IL: Aldine Publishing Company.

Guerrero, Blanca, Josefa Mula, and Guillermina Tormo. 2023. "Enablers and Barriers to Industry 4.0 Implementation." In *Industry 4.0: The Power of Data. Lecture Notes in Management and Industrial Engineering*, edited by L. R. Izquierdo, J. I. Santos, J. J. Lavios, V. Ahedo. Cham: Springer. https://doi.org/10.1007/978-3-031-29382-5_30.

Haddud, Abubaker, and Anshuman Khare. 2020. "Digitizing Supply Chains Potential Benefits and Impact on Lean Operations." *International Journal of Lean Six Sigma* 11 (4): 731–765. https://doi.org/10.1108/IJLSS-03-2019-0026.

Hajoary, Pinosh K., P. Balachandra, and Jose A. Garza-Reyes. 2024. "Industry 4.0 Maturity and Readiness Assessment: An Empirical Validation Using Confirmatory Composite Analysis." *Production Planning & Control* 35 (14): 1779–1796. https://doi.org/10.1080/09537287.2023.2210545.

Hamadeh, Nada, Catherine van Rompaey, Eric Metreau, and Shwetha G. Eapen. 2022. "New World Bank Country Classifications by Income Level: 2022-2023." https://blogs.worldbank.org/opendata/new-world-bank-country-classifications-income-level-2022-2023

Hines, Peter, and Torbjørn H. Netland. 2023. "Teaching a Lean Masterclass in the Metaverse." *International Journal of Lean Six Sigma* 14 (6): 1121–1143. https://doi.org/10.1108/IJLSS-02-2022-0035.

Hines, Peter, Guilherme L. Tortorella, Jiju Antony, and David Romero. 2023. "Lean Industry 4.0: Past, Present and Future." *Quality Management Journal* 30 (1): 64–88. https://doi.org/10.1080/10686967.2022.2144786.

Hines, Peter, Pauline Found, Gary Griffiths, and Richard Harrison. 2008. *Staying Lean: Thriving, Not Just Surviving*. Cardiff: LERC.

Hong, Jiangtao, Yibin Zhang, and Minqui Ding. 2018. "Sustainable Supply Chain Management Practices, Supply Chain Dynamic Capabilities, and Enterprise Performance." *Journal of Cleaner Production* 172: 3508–3519. https://doi.org/10.1016/j.jclepro.2017.06.093.

Horváth, Dóra, and Roland Zs Szabó. 2019. "Driving Forces and Barriers of Industry 4.0: Do Multinational and Small and Medium-Sized Companies Have Equal Opportunities?" *Technological Forecasting and Social Change* 146: 119–132. https://doi.org/10.1016/j.techfore.2019.05.021.

Ivanov, Dmitry, Christopher S. Tang, Alexandre Dolgui, Daria Battini, and Ajay Das. 2021. "Researchers' Perspective on Industry 4.0: multi-Disciplinary Analysis and Opportunities for Operations Management." *International Journal of Production Research* 59 (7): 2055–2078. https://doi.org/10.1080/00207543.2020.1798035.

John, Lenin, Manuel Sampayo, and Paulo Peças. 2021. "Lean & Green on Industry 4.0 Context – Contributions to Understand L&G Drivers and Design Principles." *International Journal of Mathematical, Engineering and Management Sciences* 6 (5): 1214–1229. https://doi.org/10.33889/IJMEMS.2021.6.5.073.

Kamble, Sachin, Angappa Gunasekaran, and Neelkanth C. Dhone. 2020. "Industry 4.0 and Lean Manufacturing Practices for Sustainable Organisational Performance in Indian Manufacturing Companies." *International Journal of Production Research* 58 (5): 1319–1337. https://doi.org/10.1080/00207543.2019.1630772.

Khanzode, Akshay, G., P. R. S. Sarma, and Mohit Goswami. 2023. "Modelling Interactions of Select Enablers of Lean Six-Sigma considering Sustainability Implications: An Integrated Circular Economy and Industry 4.0 Perspective." *Production Planning & Control* 34 (10): 1020–1036. https://doi.org/10.1080/09537287.2021.1980908.

Kipper, Liane M., Leonardo B. Furstenau, Daniel Hoppe, Rejane Frozza, and Sandra Iepsen. 2020. "Scopus Scientific Mapping Production in Industry 4.0 (2011-2018): a Bibliographic Analysis." *International Journal of Production Research* 58 (6): 1605–1627. https://doi.org/10.1080/00207543.2019.1671625.

Kolberg, D., J. Knobloch, and D. Zühlke. 2017. "Towards a Lean Automation Interface for Workstations." *International Journal of Production Research* 55 (10): 2845–2856. https://doi.org/10.1080/00207543.2016.1223384.

Kolla, Sri, Meysam Minufekr, and Peter Plapper. 2019. "Deriving Essential Components of Lean and Industry 4.0 Assessment Model for Manufacturing SMEs." *Procedia CIRP* 81: 753–758. https://doi.org/10.1016/j.procir.2019.03.189.

Komkowski, Tim, Jiju Antony, Jose A. Garza-Reyes, Guilherme L. Tortorella, and Tanawadee Pongboonchai-Empl. 2023. "The Integration of Industry 4.0 and Lean Management: A Systematic Review and Constituting Elements Perspective." *Total Quality Management & Business Excellence* 34 (7-8): 1052–1069. https://doi.org/10.1080/14783363.2022.2141107.

Koura, Kozo. 1988. "Administrative Aspects and Key Points of Cross-Functional Management." In *Cross-Functional Management: Principles and Practical Applications*, edited by Kurogane, Kenji. (1993). Tokyo, Japan: Asian Productivity Organization.

Kumar, Atul. 2018. "HRM 4.0: High on Expectations." *International Journal of Enhanced Research in Educational Development* 6 (1): 24–26. https://doi.org/10.5281/zenodo.6677191.

Larrea, Miren, and Miren Estensoro. 2021. "Governance of Industry 4.0 Policies: Making Knowledge Services Accessible for SMEs." *Regional Studies* 55 (10-11): 1839–1850. https://doi.org/10.1080/00343404.2021.1954612.

Lima, Bianca F., Julio V. Neto, Renan S. Santos, and Rodrigo G. G. Caiado. 2023. "A Socio-Technical Framework for Lean Project Management Implementation towards Sustainable Value in the Digital Transformation Context." *Sustainability* 15 (3): 1756. https://doi.org/10.3390/su15031756.

Lucantoni, Laura, Sara Antomarioni, Filippo Emanuele Ciarapica, and Maurizio Bevilacqua. 2022. "Implementation of Industry 4.0 Techniques in Lean Production Technology: A Literature Review." *Management and Production Engineering Review* 13 (3): 83–93. https://doi.org/10.24425/mper.2022.142385.

Lundmark, Sebastien, John Protzko, and Marcus Weissenbilder. 2023. "The Need for Public Opinion and Survey Methodology Research to Embrace Preregistration and Replication, Exemplified by a Team's Failure to Replicate Their Own Findings on Visual Cues in Grid-Type Questions." *International Journal of Public Opinion Research* 35 (1): 1–15. https://doi.org/10.1093/ijpor/edac040.

Machado, Eduardo, Luiz F. Scavarda, Rodrigo G. G. Caiado, and Antonio M. T. Thomé. 2021. "Barriers and Enablers for the Integration of Industry 4.0 and Sustainability in Supply Chains of MSMEs." *Sustainability* 13 (21): 11664. https://doi.org/10.3390/su132111664.

Macias-Aguayo, Jamie, Lizzi Garcia-Castro, Kleber F. Barcia, Duncan McFarlane, and Jorge Abad-Moran. 2022. "Industry 4.0 and Lean Six Sigma Integration: A Systematic Review of Barriers and Enablers." *Applied Sciences* 12 (22): 11321. https://doi.org/10.3390/app122211321.

Macpherson, A., and R. Holt. 2007. "Knowledge, Learning and Small Firm Growth: A Systematic Review of the Evidence." *Research Policy* 36 (2): 172–192. https://doi.org/10.1016/j.respol.2006.10.001.

Maisiri, Whisper, Liezl Van Dyk, and Rojanette Coetzee. 2021. "Development of an Industry 4.0 Competency Maturity Model." *SAIEE Africa Research Journal* 112 (4): 189–197. https://ieeexplore.ieee.org/document/9580772.

Maslyuk, Nataliya A., and Nadezhda V. Medvedeva. 2023. "Lean Manufacturing Technologies as a Basis for Rationalizing the Regional Investment Standard." *Power and Administration in the East of Russia* 1 (102): 59–69. https://doi.org/10.22394/1818-4049-2023-102-1-59-69.

Maxwell, Joseph A. 2013. *Qualitative Research Design: An Interactive Approach*. 3rd ed. Thousand Islands, CA: Sage Publications Inc.

McDermott, Olivia, Stuart Nelson, Jiju Antony, and Michael Sony. 2023. "Industry 4.0 Readiness in West of Ireland Small and Medium and Micro Enterprises – an Exploratory Study." *Quality Management Journal* 30 (2): 105–120. https://doi.org/10.1080/10686967.2023.2171325.

McKie, Martin G., Richard A. Jones, J. Miles, and Ian R. Jones. 2021. "Improving Lean Manufacturing Systems and Tools Engagement Through the Utilisation of Industry 4.0, Improved Communication and a People Recognition Methodology in a UK Engine Manufacturing Centre." *Procedia Manufacturing* 55: 371–382. https://doi.org/10.1016/j.promfg.2021.10.052.

Molino, Monica, Claudio C. Cortese, and Chiara Ghislieri. 2020. "The Promotion of Technology Acceptance and Work Engagement in Industry 4.0: From Personal Resources to Information and Training." *International Journal of Environmental Research and Public Health* 17 (7): 2438. https://doi.org/10.3390/ijerph17072438.

Moraes, André, André M. Carvalho, and Paulo Sampaio. 2023. "Lean and Industry 4.0: A Review of the Relationship, Its Limitations, and the Path Ahead with Industry 5.0." *Machines* 11 (4): 443. https://doi.org/10.3390/machines11040443.

Nahavandi, Saeid. 2019. "Industry 5.0–A Human-Centric Solution." *Sustainability* 11 (16): 4371. https://doi.org/10.3390/su11164371.

Nedjwa, Elafri, Rose Bertrand, and Souad S. Boudemagh. 2022. "Impacts of Industry 4.0 Technologies on Lean Management Tools: A Bibliometric Analysis." *International Journal on Interactive Design and Manufacturing (IJIDeM)* 16 (1): 135–150. https://doi.org/10.1007/s12008-021-00795-9.

Netland, Torbjørn H. 2016. "Critical Success Factors for Implementing Lean Production: The Effect of Contingencies." *International Journal of Production Research* 54 (8): 2433–2448. https://doi.org/10.1080/00207543.2015.1096976.

Núñez-Merino, Miguel, Juan M. Maqueira-Marín, José Moyano-Fuentes, and Pedro J. Martínez-Jurado. 2020. "Information and Digital Technologies of Industry 4.0 and Lean Supply Chain Management: A Systematic Literature Review." *International Journal of Production Research* 58 (16): 5034–5061. https://doi.org/10.1080/00207543.2020.1743896.

OECD. 2017. "Key Issues for Digital Transformation in the G20." https://www.oecd.org/g20/key-issues-for-digital-transformation-in-the-g20.pdf

Oliveira-Dias, Diéssica d., Juan M. Maqueira-Marin, José Moyano-Fuentes, and Helena Carvalho. 2023. "Implications of Using Industry 4.0 Base Technologies for Lean and Agile Supply Chains and Performance." *International Journal of Production Economics* 262: 108916. https://doi.org/10.1016/j.ijpe.2023.108916.

Pagliosa, Marcos M., Guilherme L. Tortorella, and João C. E. Ferreira. 2020. "Maturity Level Assessment for Industry 4.0 Integration into Lean Manufacturing." In *Industry 4.0*, edited by Carolina Machado and J. Paulo Davim, 191–240. Boca Raton, FL: CRC Press.

Pagliosa, Marcos, Guilherme L. Tortorella, and João C. E. Ferreira. 2019. "Industry 4.0 and Lean Manufacturing: A Systematic Literature Review and Future Research Directions." *Journal of Manufacturing Technology Management* 32 (3): 543–569. https://doi.org/10.1108/JMTM-12-2018-0446.

Pamornmast, Chayongkan, Thanaporn Sriyakul, and Kittisak Jermsittiparsert. 2019. "Can Lean Manufacturing and 4.0 Industry Enhance the Financial Performance of Pharmaceutical Industries of Thailand? Mediating Role of Waste Reduction Behavior." *Systematic Reviews in Pharmacy* 10 (2): 318–327. https://doi.org/10.5530/srp.2019.2.04.

Pessot, Elena, Andrea Zangiacomi, Cinzia Battistella, Valerie Rocchi, Alessandro Sala, and Marco Sacco. 2020. "What Matters in Implementing Factory of the Future: Insights from a Survey in European Manufacturing Regions." *Journal of Manufacturing Technology Management* 32 (3): 795–819. https://doi.org/10.1108/JMTM-05-2019-0169.

Petticrew, M., M. Egan, H. Thomson, V. Hamilton, R. Kunkler, and H. Roberts. 2008. "Publication Bias in Qualitative Research: what Becomes of Qualitative Research Presented at Conferences?" *Journal of Epidemiology and Community Health* 62 (6): 552–554. https://doi.org/10.1136/jech.2006.059394.

Powell, Daryl, Richard Morgan, and Graham Howe. 2021. "Lean First … Then Digitalize: A Standard Approach for Industry 4.0 Implementation in SMEs." In *Advances in Production Management Systems. Artificial Intelligence for Sustainable and Resilient Production Systems. APMS 2021. IFIP Advances in Information and Communication Technology*, edited by A. Dolgui, A. Bernard, D. Lemoine, G. von Cieminski, and D. Romero, 631, 31–39. Cham: Springer. https://doi.org/10.1007/978-3-030-85902-2_4.

PWC. 2016. "Industry 4.0: Building the Digital Enterprise: Aerospace, Defence and Security Key Findings." https://www.pwc.co.uk/who-we-are/regions/west/industry-4-0-aerospace-key-findings.pdf

Qureshi, Farwa, Abida Ellahi, Yasir Javed, Mobashar Rehman, and Hafiz Mudassir Rehman. 2023. "Empirical Investigation into Impact of IT Adoption on Supply Chain Agility in Fast Food Sector in Pakistan." *Cogent Business & Management* 10 (1): 2170516. https://doi.org/10.1080/23311975.2023.2170516.

Qureshi, Karishma, Bhavesh G. Mewada, Sumeet Kaur, and Mohamed R. N. M. Qureshi. 2023. "Assessing Lean 4.0 for Industry 4.0 Readiness Using PLS-SEM towards Sustainable Manufacturing Supply Chain." *Sustainability* 15 (5): 3950. https://doi.org/10.3390/su15053950.

Rajab, Sulaiman, Mohamed Afy-Shararah, and Konstantinos Salonitis. 2022. "Using Industry 4.0 Capabilities for Identifying and Eliminating Lean Wastes." *Procedia CIRP* 107: 21–27. https://doi.org/10.1016/j.procir.2022.04.004.

Rajput, Shubhangini, and Surya Prakash Singh. 2019. "Connecting Circular Economy and Industry 4.0." *International Journal of Information Management* 49: 98–113. https://doi.org/10.1016/j.ijinfomgt.2019.03.002.

Rajut, S., and S. Singh. 2019. "Connecting Circular Economy and Industry 4.0." *International Journal of Infrastructure Management C* 49: 98–113.

Reinhardt, Ingrid Carla, Dr Jorge C. Oliveira, and Dr Denis T. Ring. 2020. "Current Perspectives on the Development of Industry 4.0 in the Pharmaceutical Sector." *Journal of Industrial Information Integration* 18: 100131. https://doi.org/10.1016/j.jii.2020.100131.

Reyes, John, Josefa Mula, and Manuel Díaz-Madroñero. 2023. "Development of a Conceptual Model for Lean Supply Chain Planning in Industry 4.0: multidimensional Analysis for Operations Management." *Production Planning & Control* 34 (12): 1209–1224. https://doi.org/10.1080/09537287.2021.1993373.

Romero, David, Johan Stahre, and Marco Taisch. 2020. "The Operator 4.0: Towards Socially Sustainable Factories of the Future." *Computers & Industrial Engineering* 139 (1): 106128. https://doi.org/10.1016/j.cie.2019.106128.

Rosin, Frédéric, Pascal Forget, Samir Lamouri, and Robert Pellerin. 2020. "Impact of Industry 4.0 Technologies on Lean Principles." *International Journal of Production Research* 58 (6): 1644–1661. https://doi.org/10.1080/00207543.2019.1672902.

Saabye, Henrik, Thomas B. Kristensen, and Brian V. Wæhrens. 2022. "Developing a Learning-to-Learn Capability: insights on Conditions for Industry 4.0 Adoption." *International Journal of Operations & Production Management* 42 (13): 25–53. https://doi.org/10.1108/IJOPM-07-2021-0428.

Saharan, Teena, and Anchal Pathak. 2023. "Government Implications of Infrastructural Development and CSR in Industry 4.0." In *Industry 4.0 and the Digital Transformation of International Business*, edited by Singh, G., Goel, R. V., 251–271. Singapore: Springer.

Salvadorinho, Juliana P., and Leonor Teixeira. 2020. "The Bilateral Effects Between Industry 4.0 and Lean: Proposal of a Framework Based on Literature Review." Proceedings of 5th NA International Conference on Industrial Engineering and Operations Management Conference. 10-14 August 2020. Detroit, MI. 643–654.

Salvadorinho, Juliana P., and Leonor Teixeira. 2023. "Happy and Engaged Workforce in Industry 4.0: A New Concept of Digital Tool for HR Based on Theoretical and Practical Trends." *Sustainability* 15 (3): 2781. https://doi.org/10.3390/su15032781.

Sassanelli, Claudio, Monica Rossi, and Sergio Terzi. 2020. "Evaluating the Smart Maturity of Manufacturing Companies along the Product Development Process to Set a PLM Project Roadmap." *International Journal of Product Lifecycle Management* 12 (3): 185–209. https://doi.org/10.1504/IJPLM.2020.109789.

Schultz, Cecilia M. 2021. "The Relationship between Self-Leadership, the Future of Human Resource Management, and Work Engagement." *SA Journal of Human Resource Management* 19 (a1701): 1–12. https://doi.org/10.4102/sajhrm.v19i0.1701.

Senna, Pedro P., Jaime B. Roca, and Ana C. Barros. 2023. "Overcoming Barriers to Manufacturing Digitalization: Policies across EU Countries." *Technological Forecasting and Social Change* 196 (8): 122822. https://doi.org/10.1016/j.techfore.2023.122822.

Singh, Kulvinder, and Sudan Jha. 2021. "Lean Manufacturing – An Analytical Approach towards Industry 4.0." Proceedings of the 2nd International Conference on Smart Electronics and Communication (ICOSEC). 07-09 October 2021. Trichy, India. 1690–1695. https://doi.org/10.1109/ICOSEC51865.2021.9591684.

Solheim, Anja B., and Daryl J. Powell. 2020. "A Learning Roadmap for Digital Lean Manufacturing." In *Advances in Production Management Systems. Towards Smart and Digital Manufacturing. APMS 2020. IFIP Advances in Information and Communication Technology*, edited by D. Romero, 592: 417–424. Springer, Cham. https://doi.org/10.1007/978-3-030-57997-5_48.

Sony, Michael, and Subhash Naik. 2019. "Key Ingredients for Evaluating Industry 4.0 Readiness for Organizations: A Literature Review." *Benchmarking: An International Journal* 27 (7): 2213–2232. https://doi.org/10.1108/BIJ-09-2018-0284.

Stentoft, Jan, and Christopher Rajkumar. 2020. "The Relevance of Industry 4.0 and Its Relationship with Moving Manufacturing out, Back and Staying at Home." *International Journal of Production Research* 58 (10): 2953–2973. https://doi.org/10.1080/00207543.2019.1660823.

Szász, Levante, Krisztina Demeter, Béla-Gergely Rácz, and Dávid Losonci. 2020. "Industry 4.0: A Review and Analysis of Contingency and Performance Effects." *Journal of Manufacturing Technology Management* 32 (3): 667–694. https://doi.org/10.1108/JMTM-10-2019-0371.

Taylor & Francis. 2023. "Defining Authorship in Your Research Paper: Co-Authors, Corresponding Authors, and Affiliations." https://authorservices.taylorandfrancis.com/editorial-policies/defining-authorship-research-paper/

Tiamaz, Younes, and Nissine Souissi, SIWEB Team, Mohammadia School of Engineering, Mohammed V University, Rabat, Morocco. 2019. "Lean Roadmap: A Step by Step Guide for a Process Manager." *International Journal of Innovative Technology and Exploring Engineering* 8 (9): 3171–3177. https://doi.org/10.35940/ijitee.I7480.078919.

Toerein, Merran, and Sue Wilkinson. 2004. "Exploring the Depilation Norm: A Qualitative Questionnaire Study of Women's Body Hair Removal." *Qualitative Research in Psychology* 1 (1): 69–92. https://doi.org/10.1191/1478088704qp006oa.

Tortorella, Guilherme L., Anupama Prashar, Guido C. Junior, Sherif Mostafa, Alistair Barros, Rui M. Lima, and Peter Hines. 2023b. "Organizational Culture and Industry 4.0 Design Principles: An Empirical Study on Their Relationship." *Production Planning & Control* 35 (11): 1263–1277. https://doi.org/10.1080/09537287.2023.2170294.

Tortorella, Guilherme L., Diego de Castro Fettermann, Alejandro Frank, and Giuliano Marodin. 2018. "Lean Manufacturing Implementation: leadership Styles and Contextual Variables." *International Journal of Operations & Production Management* 38 (5): 1205–1227. https://doi.org/10.1108/IJOPM-08-2016-0453.

Tortorella, Guilherme L., Flavio S. Fogliatto, Paulo A. Cauchick-Miguel, Sherah Kurnia, and Daniel Jurburg. 2021. "Integration of Industry 4.0 Technologies into Total Productive Maintenance Practices." *International Journal of Production Economics* 240: 108224. https://doi.org/10.1016/j.ijpe.2021.108224.

Tortorella, Guilherme L., Ricardo Giglio, and Desirée H. van Dun. 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, Guilherme L., Tarcisio A. Saurin, Peter Hines, Jiju Antony, and Daniel Samson. 2023a. "Myths and Facts of Industry 4.0." *International Journal of Production Economics* 255: 108660. https://doi.org/10.1016/j.ijpe.2022.108660.

Tortorella, Guilherme Luz, and Diego Fettermann. 2018. "Implementation of Industry 4.0 and Lean Production in Brazilian Manufacturing Companies." *International Journal of Production Research* 56 (8): 2975–2987. https://doi.org/10.1080/00207543.2017.1391420.

Tranfield, D., D. Denyer, and P. Smart. 2003. "Towards a Methodology for developing evidence-Informed Management Knowledge by Means of Systematic Review." *British Journal of Management* 14 (3): 207–222. https://doi.org/10.1111/1467-8551.00375.

Tripathi, Anadya, and Rama Shanker. 2024. "Longitudinal Analysis and Sample Size Calculation in Contraceptive Studies." *International Journal of Statistics and Applied Mathematics* 9 (1): 1–5. https://www.mathsjournal.com.

van Dun, Desirée H., and Maneesh Kumar. 2023. "Social Enablers of Industry 4.0 Technology Adoption: transformational Leadership and Emotional Intelligence." *International Journal of Operations & Production Management* 43 (13): 152–182. https://doi.org/10.1108/IJOPM-06-2022-0370.

Velarde, Sergio, Kostas Kefalikis, and Peter Hines. 2024. "Remote Kaizen Events: A Response to COVID-19 and the New Normal." *Total Quality Management & Business Excellence* 35 (11–12): 1378–1417. https://doi.org/10.1080/14783363.2024.2369938.

Walsh, Aidan P., Denis Harrington, and Peter Hines. 2020. "Are Hospital Managers Ready for Value-Based Healthcare? A Review of the Management Competence Literature." *International Journal of Organizational Analysis* 28 (1): 49–65. https://doi.org/10.1108/IJOA-01-2019-1639.

Yang, Chen, Shulin Lan, Zhiheng Zhao, Mengdi Zhang, Wei Wu, and George Q. Huang. 2023. "Edge-Cloud Blockchain and IoE-Enabled Quality Management Platform for Perishable Supply Chain Logistics." *IEEE Internet of Things Journal* 10 (4): 3264–3275. https://doi.org/10.1109/JIOT.2022.3142095.

Appendix A. Survey instrument

Background

1. In which country do you primarily work?
2. What industry are you in?
3. How many people are employed at your organisation?
   a. 0-9
   b. 10-49
   c. 50-249
   d. 250+
4. Does your organisation have:
   a. A single site?
   b. More than one site in your country?
   c. Sites in more than one country?

Past

1. What department do you work in within your organisation?
   Operations/Manufacturing
   Engineering/Maintenance
   Supply Chain/Purchasing/Logistics
   IT/ICT/Digitisation
   Lean or equivalent
   Other (please specify)
2. Did you:
   Start to apply Lean BEFORE Industry 4.0?
   Start to apply Lean AFTER Industry 4.0?
   Apply Lean and Industry 4.0 AROUND THE SAME TIME?

Present

1. The most frequently used term for this topic is Lean Industry 4.0, although several other terms have been proposed. What term do you prefer to use?
2. How do you define Lean Industry 4.0 (or your preferred terminology)?
3. Where has Lean been applied in your organisation?
   Manufacturing
   Warehouse/Internal Logistics
   Supply Chain/Suppliers
   Product Development
   Office/Support Functions
4. What is the name of the team, organisation or department PRIMARILY responsible for promoting Lean in your company?

5a. What word or a short phrase would you use to describe your company in terms of your adoption of all stakeholders (customer, employees, company owners) are taken into account in decision making?

5b. What word or a short phrase would you use to describe your company in terms of whether there is a focus on transformational leadership, a focus on people and their learning?
5c. What word or a short phrase would you use to describe your company in terms of whether the company is flexible in dealing with customers?
5d. What word or a short phrase would you use to describe your company in terms of whether the company takes advantage of product modularity and/or late product configuration?
5e. What word or a short phrase would you use to describe your company in terms of whether the company employs continuous flow processing?
5f. What word or a short phrase would you use to describe your company in terms of whether products are produced on a pull basis?
5g. What word or a short phrase would you use to describe your company in terms of whether the company takes into account the needs of all stakeholders (customer, employees, company owners) when designing its systems and processes?
5h. What word or a short phrase would you use to describe your company in terms of whether the company operates in a transparent way with employees and outside interested parties?
5i. What word or a short phrase would you use to describe your company in terms of whether continuous improvement is embedded as a central part of the company's culture?
6. Where has Industry 4.0 been applied in your organisation?
Manufacturing
Warehouse/Internal Logistics
Supply Chain/Suppliers
Product Development
Office
7. What is the name of the team, organisation or department PRIMARILY responsible for promoting Industry 4.0 in your company?
8a. What word or a short phrase would you use to describe your company in terms of your adoption of Internet of Things?
8b. What word or a short phrase would you use to describe your company in terms of your adoption of Big Data?
8c. What word or a short phrase would you use to describe your company in terms of your adoption of Cloud Computing?
8d. What word or a short phrase would you use to describe your company in terms of your adoption of Wireless Sensors?
8e. What word or a short phrase would you use to describe your company in terms of your adoption of 3D Printing?
8f. What word or a short phrase would you use to describe your company in terms of your adoption of Augmented Reality/ Simulation?
8g. What word or a short phrase would you use to describe your company in terms of your adoption of Collaborative Robots?
8h. What word or a short phrase would you use to describe your company in terms of your adoption of Machine/Deep Learning?
8i. What word or a short phrase would you use to describe your company in terms of your adoption of Remote Control/Monitoring?
9. Why did you start your Lean Industry 4.0 journey?
10. What have you found are the three most important benefits of applying Lean industry 4.0?
11. What have you found to be the most important enablers to make Lean Industry 4.0 work well?
12. What is the most important activity of senior staff in your company in applying Lean Industry 4.0?
13. What is the most important activity of front-line managers (first level) in applying Lean Industry 4.0?
14. What is the most important activity of front line (direct) workers in applying Lean Industry 4.0?
15. Do you have a roadmap for your implementation of Lean Industry 4.0?
16. Do you use a maturity assessment for your Lean Industry 4.0 journey?
17. What is the most important skill or competency in successfully applying Lean Industry 4.0?

Future

1. What is the most important challenge you are facing with Lean Industry 4.0?
2. What is the most important thing that could be done by outside organisations to help you as a business with the implementation of Lean Industry 4.0?
3. Who do you think should provide this support for you?

Next steps

- If you would like to receive a copy of the final paper, please tick this box (please provide company email below)
- If you are happy to take part in future research, please tick this box (please provide company email below)

Please provide your company email if you have ticked one or more of the above:

[INSERT COMPANY EMAIL ADDRESS]

Thank you for completing our survey. Your time is much appreciated.