

34th CIRP Design Conference

Assessment Model for Facilitating Digital Retrofitting in Manufacturing: Key Factors and Practical Insights

Abdulrahman Alqoud^a, Jelena Milisavljevic-Syed^{a*}, Konstantinos Salonitis^a^a School of Aerospace Transport and Manufacturing (SATM), Cranfield University, Cranfield MK43 0AL, UK* Corresponding author. Tel.: +44(0) 1234 758533. E-mail address: jelenams@cranfield.ac.uk

Abstract

In an era where factories are required to evolve or face obsolescence, digital retrofitting offers a lifeline to manufacturing companies striving to stay competitive. Digital retrofitting, the process of integrating cutting-edge technologies such as IoT components into legacy manufacturing systems, is emerging as a crucial strategy. However, due to the diversity of these legacy systems, a one-size-fits-all solution is ineffective. Despite the transformative potential of digital retrofitting, there is a noticeable gap in the tools that enable decision-makers to accurately assess their readiness for this process. To bridge this gap, it is essential to identify and evaluate critical factors that determine a system's preparedness for integration with advanced technologies. This study proposes 21 key factors that must be considered to ensure readiness for digitalisation. These factors are grouped under four critical dimensions: strategy and organisation, workforce enhancement, smart factory, and smart process. Engagement with 18 industry practitioners was undertaken to validate these factors, ensuring their practical relevance. The findings provide valuable insights into the critical factors that need to be evaluated before embarking on the journey of digitalisation, ensuring that companies are fully prepared to integrate new technologies and optimise their manufacturing processes.

© 2024 The Authors. Published by Elsevier B.V.

This is an open access article under the CC BY-NC-ND license (<https://creativecommons.org/licenses/by-nc-nd/4.0>)

Peer-review under responsibility of the scientific committee of the 34th CIRP Design Conference

Keywords: *Assessment Model; Maturity Model; Digital Retrofitting; Industry 4.0, Manufacturing.*

1. Introduction

In the context of the digital transformation in the manufacturing industry, small-and-medium-sized manufacturing enterprises (SMMEs) are integral to economic growth and are now adapting to the digital wave through digital retrofitting [1,2]. This process involves adding new digital technologies like Internet of Things components (IoT), including sensors, gateways, and actuators to existing systems to enable connectivity and real-time data analytics [3]. It can lead to enhanced productivity, efficiency, cost savings, and competitive advantages, allowing businesses to remain competitive [4]. Despite these benefits, digital retrofitting presents distinct challenges, notably in terms of knowledge and resource availability, especially for SMMEs [5]. There is a critical need for a practical guide to navigating these complexities and optimizing the adoption process [6]. In this context, the

maturity and assessment models become particularly valuable. It offers a structured approach to assessing readiness and guiding businesses through the strategic implementation of these technologies, ensuring they are aligned with their specific needs and capabilities [7]. These models are instrumental in identifying the levels of operational and technological development and providing a strategic plan for future growth [8]. Academic contributions have illuminated the readiness and maturity models for Industry 4.0, with studies categorising maturity models based on various factors related to technology, people, and strategy, with an emphasis on the technological aspect [9–11]. Although these studies offer theoretical frameworks, their practical application is often limited, especially in assessing infrastructure and addressing the managerial aspects of organisational change [12]. Industry models, such as the one developed by Lichtblau et al [13], PricewaterhouseCoopers' (PwC) assessment model [14], and

Rockwell Automation's maturity model [15] offer frameworks and valuable tools for organisational readiness assessment. However, these models often overlook the specific needs of digital retrofitting in SMMEs.

Current literature reveals a gap in assessment models that are specifically designed for the digital retrofitting requirements of SMMEs, which face unique challenges due to their limited resources, technical expertise, and organisational culture [16][17]. There is a discernible need for holistic studies, which consider both technological and managerial elements, aligning academic insights with industry practices to meet the requirements of digital retrofitting.

To bridge this gap, the focus of this study is on identifying and validating essential factors as an initial step in constructing a comprehensive assessment model. This entails evaluating the readiness of SMMEs for adopting Industry 4.0 technologies and involves a critical assessment of these factors from both academic and industry perspectives. The specific realities and needs of manufacturing enterprises poised for digital transformation are also considered. The following research questions are addressed:

- I. *What are the critical factors related to digital retrofitting that should be considered in assessing manufacturers for a successful transition to Industry 4.0 era?*
- II. *How can these factors be validated from academic and industry perspectives?*

To address the research questions, the approach includes a literature review and survey. The paper is organized as follows: The methodology, encompassing the data collection process and data analysis techniques, is detailed in Section 2. Findings and discussions aligned with the research questions are presented in Section 3. Finally, in Section 4, the conclusions and limitations are highlighted.

2. Methodology

To answer research questions, a two-pronged method is employed. The first step involves a review of the academic literature to identify the key factors relevant to assessing manufacturing readiness. This is followed by administering a survey designed to validate the outcomes of the literature review with insights from industry practitioners. This dual approach is selected to synergise insights from academic research with practical industry experience.

2.1. Literature review

The methodology is executed in sequential phases. Initially, a research protocol is developed, setting precise inclusion and exclusion criteria. A thorough literature search followed, spanning three databases, including Scopus, ScienceDirect, and Google Scholar. The search entailed rigorous screening of abstracts, titles, and full texts. The subsequent phase involved meticulous data extraction and findings integration. Search parameters aligned with the defined criteria guide publication retrieval using specific keywords. These terms-assessment model, maturity model, readiness model,

Industry 4.0, manufacturing, SMEs- are combined and queried within titles, abstracts, and keywords. Despite a high volume of initial results, a manual selection process is used to refine the list of studies most relevant to the research question. From 31 chosen publications, relevant data are systematically extracted and catalogued using a structured template. A summary of the search strings and keywords used in the literature search process is presented in Figure 1. The findings from this literature review are intended to address Research Question One.

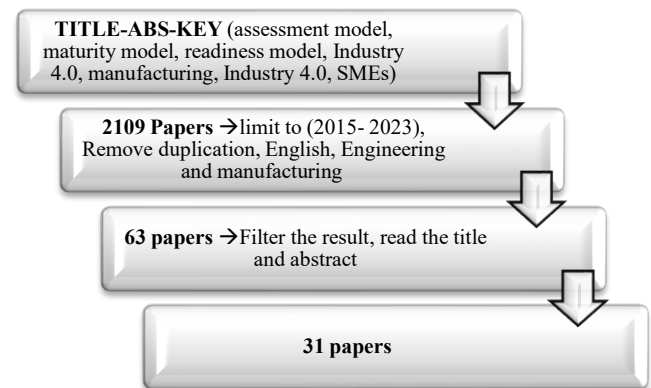


Fig. 1. Literature review search process

2.2. Online survey

In this research, an online survey is conducted to validate the factors extracted from the literature review related to the research topic. The survey comprised a mix of open-ended questions designed to elicit comprehensive responses. The aim of this survey is to establish content validity, serving as the method used to answer Research Question Two by confirming the clarity, relevance, and suitability of the factors identified. In this research, participants consist of individuals working in manufacturing and those serving as assessors within the sector. The criteria for selecting and excluding these participants are outlined in Table 1.

Table 1. Participants' inclusion and exclusion criteria

Inclusion	Exclusion
People who work in the manufacturing sector	People who do not work in the manufacturing sector or who have no experience in digitalisation or assessing manufacturers
People who work as assessors for manufacturers	
People who have experience in digital transformation to Industry 4.0	
A minimum of 5 years' experience	People under 18 years old and Experience less than 5 years

2.3. Close-ended questions

The Content Validity Ratio (CVR), a method originally developed by Lawshe [18] and later refined by Lynn [19] is used to assess how well test items represent the concept of interest. A practitioner panel of 18 evaluated the relevance of each factor related to digital retrofitting on a 4-point scale, ranging from 1 (not relevant) to 4 (highly relevant). The CVR is calculated for each item, with higher values indicating greater relevance.

$$CVR = \frac{n_e - \frac{N}{2}}{N/2} \quad (1)$$

“ n_e : The number of raters who deemed the item essential (rating 3 or 4).”

“ N : The total number of raters.”

Items with a CVR value below the threshold of 0.62, indicative of essential relevance as per ten raters, are removed to ensure the model's accuracy in reflecting digital retrofitting.

2.4. Open-ended questions

Open-ended questions allow participants to express opinions freely, offering more information or correcting provided options. This format allows researchers to delve deeper and gain further understanding. An example of the content validation with open-ended and closed-ended questions is shown in Figure 2.

Fig. 2. Example of content validity questions

3. Result and Discussion

This section presents the findings according to the outlined methodology, with the study's results arranged sequentially: first, the outcomes of the literature review, followed by the results of the online survey.

3.1. Result of literature review

The findings from the literature review are summarised in Table 2, which outlines the identified Industry 4.0 assessment dimensions for manufacturing firms. A total of 127 dimensions are found across various readiness models, which typically range from 2 to 9 dimensions in each study. After consolidating similar dimensions, the top three- 'Strategy and Organisation,' 'Technology', and 'Smart Operations and Process' - are highlighted due to their

frequency and pivotal importance roles. For a detailed breakdown of all dimensions and their frequencies, refer to Table 2.

Table 2. Summary of dimensions frequency

Dimension	Frequency	Authors
Strategy and Organisation	25	[13,20–22]
Smart Operations and Process	19	[13,20,21,23,24]
Technology	19	[25–29]
Data and IT	14	[22,26,30–32]
Smart Products	9	[22,30,33]
Human and Employees	9	[25,30,34]
Environmental	7	[35,36]
Leadership	5	[34,37]
Business Model	4	[14,38]
Supply Chain	4	[31]
Social	3	[28]
Others (Operability, Virtual World, Physical, World Dynamic Capability)	4	[30,35]

After examining the dimensions, the key critical dimensions essential for a successful transition to Industry 4.0 era are identified and include:

- I. **Strategy and organisation:** Assessing whether an organisation's culture, leadership, and management practices are in alignment with digital retrofitting goals.
- II. **Workforce development:** Evaluating the workforce's readiness and the extent of skills training necessary for employees to effectively engage with and apply digital retrofitting technologies.
- III. **Smart factory:** Measuring the degree to which advanced technologies and infrastructure are integrated into the manufacturing setting to enable efficient and intelligent digital retrofitting workflows.
- IV. **Smart processes:** Gauging the use of technology and data analytics to enhance and streamline retrofitting processes, ensuring a seamless transition into digital methodologies.

Additionally, sub-dimensions are identified as the most relevant factors critical to the assessment of manufacturing readiness for the successful adoption of Industry 4.0 technologies.

3.2. Survey results

The results of the online survey are presented in this section to validate the identified factors, with an analysis grounded in both academic and industry standpoints. The Content Validity Ratio (CVR) is used for this purpose, with most factors exhibiting high relevance, reflected in CVR percentages ranging from 78% to 100%. Significantly, two factors achieved the highest CVR of 100%, underscoring their critical importance, as confirmed by practitioners in both domains. Furthermore, responses to open-ended questions are instrumental in refining and elucidating the factors for enhanced clarity. The principal dimensions and sub-dimensions (factors) identified in this research are illustrated in Table 3 and Figure 3.

Table 3. Assessment factors for digital retrofitting

Dimensions	Factors
A. Strategy and Organisation Dimension	1. I4.0 Strategy Implementation 2. Collaboration with Partners 3. Budget Allocation 4. Leadership Support 5. Digitalization Objectives 6. Change Management Plan 7. Risk Management Plan
B. Workforce Development Dimension	1. Employee Acceptance Changes 2. Employee Competency 3. Employee Development Budget 4. Employee Skill Acquisition
C. Smart Factory Dimension	1. ICT Function 2. Machine Connectivity 3. Machine-to-Machine Communication 4. Human-Machine Interface Systems 5. Control System in Machines
D. Smart Processes Dimension	1. Data Privacy and IT Security 2. Cloud Adoption 3. Integration in Manufacturing Processes 4. Data-Driven Decision-Making 5. Sharing of Enterprise Data

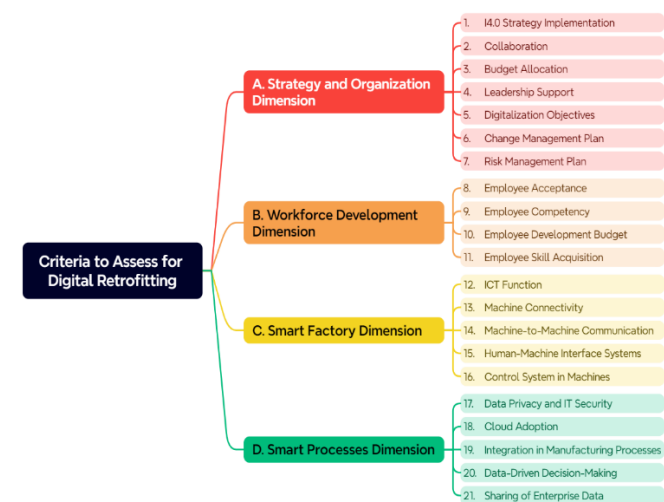


Fig. 3. Assessment factors for digital retrofitting

4. Conclusion

In transitioning to Industry 4.0, it is essential for manufacturing companies to critically evaluate key factors. This includes understanding the implications of new technologies, investing in the required resources, and ensuring employee readiness. Furthermore, the development of a comprehensive data processing strategy is imperative to safeguard data and utilize it effectively during this digital transformation. In this research key factors that are critical to assess before transitioning into Industry 4.0 are identified. By integrating academic insights with industry feedback, the study outlined pivotal dimensions: Strategy and Organization, Workforce Development, Smart Factory, and Smart Processes. These dimensions were validated through a Content Validity Ratio (CVR), with most factors showing high relevance. This research highlights the multifaceted nature of Industry 4.0 readiness and the imperative of a holistic assessment strategy that facilitates digital retrofitting. It illuminates the pathway for SMMEs to evaluate and enhance their capabilities, aligning their organisational objectives with the innovations of the digital age. The results of this study provide a foundation for future research to build upon these foundations and for industry practitioners to implement these insights into actionable strategies for digital excellence. The next step is to develop a questionnaire based on the identified factors, which can be critical for assessing and guiding SMMEs through the Industry 4.0 transition. This tool crucial for firms to pinpoint readiness and prioritise improvements. A key limitation of this study is that it focuses solely on factors related to digital retrofitting of legacy systems without taking into account factors such as supply chain and customer satisfaction.

References

- [1] D. Jaspert, M. Ebel, A. Eckhardt, J. Poepplbuss, Smart retrofitting in manufacturing: A systematic review, *J Clean Prod* 312 (2021) 127555. <https://doi.org/10.1016/j.jclepro.2021.127555>.
- [2] C.L. Niemeyer, I. Gehrke, K. Müller, D. Küsters, T. Gries, Getting Small Medium Enterprises started on Industry 4.0 using retrofitting solutions, *Procedia Manuf* 45 (2020) 208–214. <https://doi.org/10.1016/j.promfg.2020.04.096>.
- [3] A. Alqoud, D. Schaefer, J. Milisavljevic Syed, Industry 4.0: A Systematic Review of Legacy Manufacturing System Digital Retrofitting, *Manufacturing Review*- under Review (2022).
- [4] J.I. García, R.E. Cano, J.D. Contreras, Digital retrofit: A first step toward the adoption of Industry 4.0 to the manufacturing systems of small and medium-sized enterprises, *Proc Inst Mech Eng B J Eng Manuf* 234 (2020) 1156–1169.
- [5] S. Mittal, M.A. Khan, J.K. Purohit, K. Menon, D. Romero, T. Wuest, A smart manufacturing adoption framework for SMEs, *Int J Prod Res* 58 (2020) 1555–1573. <https://doi.org/10.1080/00207543.2019.1661540>.
- [6] S. Wiesner, P. Gaiardelli, N. Gritti, G. Oberti, Maturity models for digitalization in manufacturing-applicability for SMEs, in: *Advances in Production Management Systems*.

- Smart Manufacturing for Industry 4.0: IFIP WG 5.7 International Conference, APMS 2018, Seoul, Korea, August 26–30, 2018, Proceedings, Part II, Springer, 2018: pp. 81–88.
- [7] F. Hein Pensel, H. Winkler, A. Brückner, M. Wölke, I. Jabs, I.J. Mayan, A. Kirschenbaum, J. Friedrich, C. Zinke-Wehlmann, Maturity assessment for Industry 5.0: A review of existing maturity models, *J Manuf Syst* 66 (2023) 200–210. <https://doi.org/https://doi.org/10.1016/j.jmsy.2022.12.009>.
- [8] F. Simetinger, J. Basl, A pilot study: An assessment of manufacturing SMEs using a new Industry 4.0 Maturity Model for Manufacturing Small- and Middle-sized Enterprises (I4MMSME), *Procedia Comput Sci* 200 (2022) 1068–1077. <https://doi.org/https://doi.org/10.1016/j.procs.2022.01.306>.
- [9] V. Felch, B. Asdecker, E. Sucky, Maturity models in the age of Industry 4.0—Do the available models correspond to the needs of business practice?, (2019).
- [10] M. Hizam-Hanafiah, M.A. Soomro, N.L. Abdullah, Industry 4.0 Readiness Models: A Systematic Literature Review of Model Dimensions, *Information* 11 (2020) 364.
- [11] S. Mittal, D. Romero, T. Wuest, Towards a Smart Manufacturing Maturity Model for SMEs (SM3E), in: I. Moon, G.M. Lee, J. Park, D. Kiritsis, G. von Cieminski (Eds.), *Advances in Production Management Systems. Smart Manufacturing for Industry 4.0*, Springer International Publishing, Cham, 2018: pp. 155–163.
- [12] A. Amaral, P. Peças, A Framework for Assessing Manufacturing SMEs Industry 4.0 Maturity, *Applied Sciences* 11 (2021) 6127. <https://www.mdpi.com/2076-3417/11/13/6127>.
- [13] K. Lichtblau, V. Stich, R. Bertenrath, M. Blum, M. Bleider, A. Millack, K. Schmitt, E. Schmitz, M. Schröter, *Industrie 4.0 Readiness* [eng.], (2015).
- [14] Reinhard Geissbauer, Jesper Vedso, Stefan Schrauf, *Industry 4.0: Building the digital enterprise*, 2016.
- [15] Rockwell Automation, Rockwell Automation. The Connected Enterprise Maturity Model: How ready is your company to connect people, processes, and technologies for bigger profits?, Rockwell Automation (2015).
- [16] A. Alqoud, D. Schaefer, J. Milisavljevic Syed, Industry 4.0 : Challenges and Opportunities of Digitalisation Manufacturing Systems, in: *ICMR Accepted Paper*, UK, University of Derby, 2022: p. 6.
- [17] T. Masood, P. Sonntag, *Industry 4.0: Adoption challenges and benefits for SMEs*, Elsevier 121 (2020) 103261.
- [18] C.H. Lawshe, A quantitative approach to content validity, *Pers Psychol* 28 (1975) 563–575.
- [19] M.R. Lynn, Determination and quantification of content validity, *Nurs Res* 35 (1986) 382–386. <https://doi.org/10.1097/00006199-198611000-00017>.
- [20] D. Dikhanbayeva, S. Shaikholla, Z. Suleiman, A. Turkyilmaz, Assessment of Industry 4.0 Maturity Models by Design Principles, Sustainability 12 (2020) 9927. <https://doi.org/10.3390/su12239927>.
- [21] J. Schroderus, L.A. Lasrado, K. Menon, H. Kärkkäinen, Towards a Pay-Per-X Maturity Model for Equipment Manufacturing Companies, *Procedia Comput Sci* 196 (2022) 226–234. <https://doi.org/https://doi.org/10.1016/j.procs.2021.12.009>.
- [22] L.D. Rafael, G.E. Jaione, L. Cristina, S.L. Ibon, An Industry 4.0 maturity model for machine tool companies, *Technol Forecast Soc Change* 159 (2020) 120203. <https://doi.org/10.1016/j.techfore.2020.120203>.
- [23] A. Schumacher, S. Erol, W. Sihn, A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises, *Procedia CIRP* 52 (2016) 161–166. <https://doi.org/10.1016/j.procir.2016.07.040>.
- [24] M. Spaltini, F. Acerbi, M. Pinzone, S. Gusmeroli, M. Taisch, Defining the Roadmap towards Industry 4.0: The 6Ps Maturity Model for Manufacturing SMEs, *Procedia CIRP* 105 (2022) 631–636.
- [25] F. Simetinger, J. Basl, A pilot study: An assessment of manufacturing SMEs using a new Industry 4.0 Maturity Model for Manufacturing Small-and Middle-sized Enterprises (I4MMSME), *Procedia Comput Sci* 200 (2022) 1068–1077.
- [26] E. Colangelo, C. Fries, T.-F. Hinrichsen, Á. Szaller, G. Nick, Maturity model for ai in smart production planning and control system, *Procedia CIRP* 107 (2022) 493–498.
- [27] S.E.D. Board, The Smart Industry Readiness Index (SIRI), 2023 (2018). <https://doi.org/https://siri.incit.org/>.
- [28] Y. Kayikci, Y. Kazancoglu, N. Gozacan-Chase, C. Lafci, L. Batista, Assessing smart circular supply chain readiness and maturity level of small and medium-sized enterprises, *J Bus Res* 149 (2022) 375–392.
- [29] L. Stefan, W. Thom, L. Dominik, K. Dieter, K. Bernd, Concept for an evolutionary maturity based Industrie 4.0 migration model, *Procedia CIRP* 72 (2018) 404–409. <https://doi.org/https://doi.org/10.1016/j.procir.2018.03.155>.
- [30] G. Nick, T. Kovács, A. Kő, B. Kádár, Industry 4.0 readiness in manufacturing: Company Compass 2.0, a renewed framework and solution for Industry 4.0 maturity assessment, *Procedia Manuf* 54 (2021) 39–44.
- [31] S. Jayashree, M.N.H. Reza, C.A.N. Malarvizhi, M. Mohiuddin, Industry 4.0 implementation and Triple Bottom Line sustainability: An empirical study on small and medium manufacturing firms, *Heliyon* 7 (2021).
- [32] G. Reinhard, V. Jesper, S. Stefan, *Industry 4.0: Building the digital enterprise*, 2016.
- [33] Y. Lukhmanov, D. Dikhanbayeva, B. Yertayev, E. Shehab, A. Turkyilmaz, An advisory system to support Industry 4.0 readiness improvement, *Procedia CIRP* 107 (2022) 1361–1366.

- [34] J. Basl, P. Doucek, A metamodel for evaluating enterprise readiness in the context of Industry 4.0, *Information* 10 (2019) 89.
- [35] L. Bretz, F. Klinkner, M. Kandler, Y. Shun, G. Lanza, The ECO maturity model—a human-centered industry 4.0 maturity model, *Procedia CIRP* 106 (2022) 90–95.
- [36] L. Gerlitz, Design management as a domain of smart and sustainable enterprise: business modelling for innovation and smart growth in Industry 4.0, *Entrepreneurship and Sustainability Issues* 3 (2016) 244.
- [37] S. Kolla, M. Minufekr, P. Plapper, Deriving essential components of lean and industry 4.0 assessment model for manufacturing SMEs, *Procedia CIRP* 81 (2019) 753–758.
- [38] W.M.G. (Warwick Manufacturing Group), An Industry 4 readiness assessment tool, 2023 (2017).



DSPACE

<https://dspace.org/>

Assessment Model for facilitating digital retrofitting in manufacturing: key factors and practical insights

Alqoud, Abdulrahman; Milisavljevic-Syed, Jelena; Salonitis, Konstantinos

2024-10-15

Elsevier

<https://doi.org/10.1016/j.procir.2024.07.053>

Alqoud A, Milisavljevic-Syed J, Salonitis K. (2024) Assessment Model for facilitating digital retrofitting in manufacturing: key factors and practical insights. *Procedia CIRP*, Volume 128, October 2024, pp. 508-513. 34th CIRP Design Conference, 3-5 June 2024, Cranfield University, UK