Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine CONFERENCE PAPER ARCHIVE

IFAC PapersOnLine 58-19 (2024) 899–904

Assessing Zero-Defect Manufacturing Maturity: a review of the state of the art

Danusuya Pachimuthu*, Marta Pinzone*, Marco Taisch*

**Politecnico di Milano, Department of Management Engineering, Lambruschini 4b, 20156 Milan (Italy) (e-mail: danusuya.pachimuthu@polimi.it; marta.pinzone@polimi.it; marco.taisch@polimi.it).*

Abstract: This paper presents a review of the current research literature about Quality 4.0 and Zero-Defect Manufacturing maturity assessment. Thirty-five articles were identified, and their content analyzed to map the main dimensions and factors, the definition of maturity levels, assessment methods, applicability to SMEs and other characteristics of existing studies. Limitations of existing research and areas where further investigation is needed were also pinpointed to inform future research directions.

Copyright © 2024 The Authors. This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/)

Keywords: Zero-Defect, Zero Defect, Quality 4.0, Readiness, Maturity, Assessment

1. INTRODUCTION

Quality 4.0 refers to the digitalization of quality management-related systems and processes using advanced digital technologies. Quality 4.0 is more than technology; according to Antony et al., (2022), it is based on the goal-oriented, symbiotic relationship between people, processes, and technology. Within the broad Quality 4.0 research field, one of the most promising emerging approaches today is Zero-Defect Manufacturing (ZDM). ZDM is a paradigm "for ensuring both process and product quality by reducing defects through corrective, preventive, and predictive techniques, using mainly data-driven technologies and guaranteeing that no defective products leave the production sustainability" Psarommatis et al., 2022. ZDM is expected to allow manufacturers to reap benefits in terms of financial performance, customer value proposition, environmental and social performance (Fragapane et al., 2023; Caiazzo et al., 2022; Psarommatis et al., 2020).

As highlighted by Psarommatis et al. (2022b), Psarommatis and May (2023), and implementing quality 4.0 and ZDM is not straightforward, especially for SMEs, necessitating guidelines for a successful transition. In this respect, assessing company's maturity for ZDM is a strategic step that allows for targeted and effective improvements, minimizes risks, and sets the stage for a successful transformation roadmap towards achieving and sustaining high levels of quality.

In this context, the aim of the present study is to perform a scoping review of existing research literature on quality 4.0 and ZDM readiness and maturity assessment, in order to map the extent and nature of research on the topic, identify key concepts and pinpoint areas where further investigation is needed.

According to its objective the remainder of the paper is structured as follows: in Section 2 the literature review methodology is outlined; then, Section 3 presents the results of the literature analysis which focused both on bibliometric data and content of the selected articles; finally, Section 4 discusses the findings and outlines their implications for researchers and practitioners interested in ZDM.

2. MATERIALS AND METHODS

2.1 Literature review

To address the above-mentioned objective, a scoping review was conducted. The review was carried out following the recommendations of the PRISMA 2020 statement (Tricco et al., 2018).

To compile the review, articles were searched in the Scopus database using a specific keyword combination. The search criteria involved looking for articles with keywords related to three main fields: 1, zero defect and quality; 2. readiness, maturity, success factors, etc; 3. Industry 4.0, Industry 5.0, smart manufacturing, etc. The terms were searched in the abstract, title, and keywords. Only articles, reviews, and conference proceedings written in English and published between 2013 and 2024 were included. Initially, 304 items were identified through this search. Subsequently, the results underwent three refinement steps:

- Step 1 – Application of Scopus database filters on subject areas to exclude not relevant items. For instance, papers related to nursing, medicine and hospitality were excluded.
- Step 2 - Screening of titles to exclude items that did not specifically address ZDM or quality 4.0.
- Step 3 - Reading of abstract and full text and exclusion of not relevant items. In this step, the same criteria used in step 2 were applied.

After completing these steps, a total of 35 papers remained in the sample (Figure 1).

2405-8963 Copyright © 2024 The Authors. This is an open access article under the CC BY-NC-ND license.
Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2024.09.167

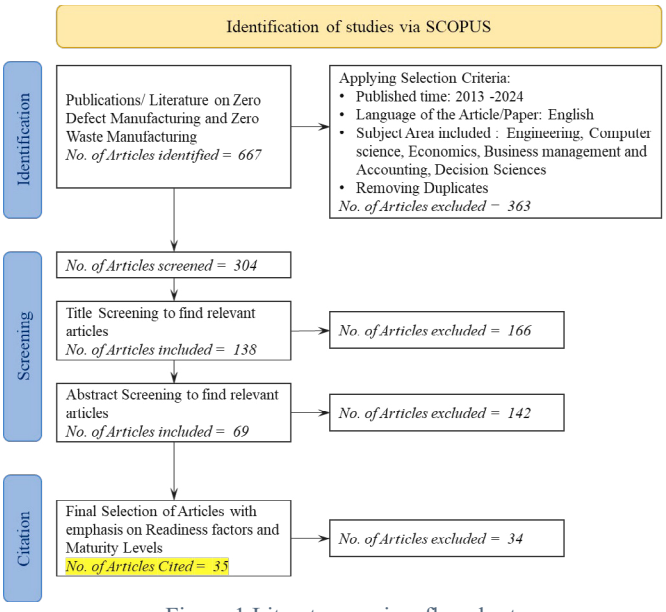

Figure 1 Literature review flowchart

Bibliometric data of the selected articles were retrieved from Scopus and analysed following the recommendations of Donthu et al., (2021) to map the contributions of research constituents (e.g., authors, institutions, countries, and journals). Subsequently, papers' content was analysed using the 6Ps framework (i.e., Product, Process, Platform, Performance, People, Partners) proposed by Spaltini et al., (2022) to dissect and categorize the main readiness/maturity dimensions and factors presented in each paper. As suggested by Caggiano et al., (2023) and Hein-Pensel et al., (2023), information on readiness/maturity levels, the assessment method, focus on SMEs' specificities and validation in industry were also collected and analysed.

3. RESULTS

3.1 Descriptive Analysis

3.1.1 Distribution across the time period

The industry-wide drive to achieve improved quality standards and operational efficiency has resulted in a significant increase in research attention towards the goal of Zero-Defect Manufacturing (ZDM) and the importance of readiness evaluations in recent years. Figure 2 presents the timeline of the literature, which further advocates to strategic shift towards proactive quality management.

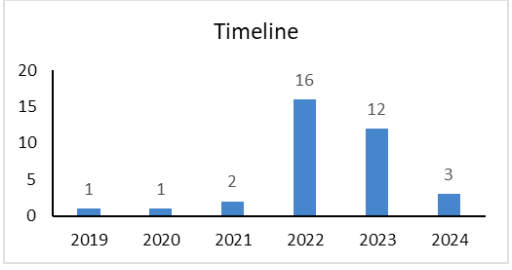

Figure 2 Publication years of selected articles

3.1.2 Author and Affiliation analysis

Table 1 represents the leading authors and the universities invested in this field of research. Another interesting observation is that of the global distribution of these articles, presented in Figure 3. Among the identified authors, Jiju Antony, Michael Sony and Olivia Mc Dermott have a Lean Six Sigma background while Foivos Psarommatis and Gokan May are among the most profilic authors in the emerging ZDM research stream.

Table 1 Most prolific authors

Authors	No. Articles	University
Jiju Antony	4	Khalifa University
Michael Sony	4	Namibia University of Science and Technology
Olivia Mc Dermott	4	National University of Ireland
Kashif Ali	3	Universiti Teknologi Petronas
Satirenjit Kaur Johl	3	Universiti Teknologi Petronas
Deusdedith Pastory Maganga	3	University of Dar es Salaam
Ismail W.R. Taifa	3	University of Dar es Salaam
Foivos Psarommatis	3	University of Oslo
Anupama Prashar	2	Management Development Institute
Gokan May	2	University of North Florida
Victor Azamfirei	2	Malardalen University
Hadi Balouei Jamkhaneh	2	Persian Gulf University
Reza Shahin	2	Universite Gustave Eiffel
David Vykydal	2	VŠB-Technical University of Ostrava
Jaroslav Nenadál	2	VŠB-Technical University of Ostrava
Raja Jayaraman	2	Khalifa University

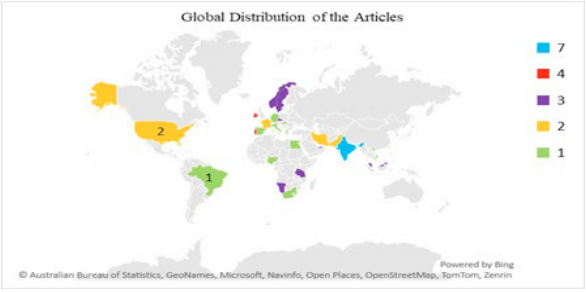

Figure 3 Geographical distribution of articles

3.1.3 Article types and sources

As shown in Figure 4, most of the selected documents are original research papers published in academic journals.

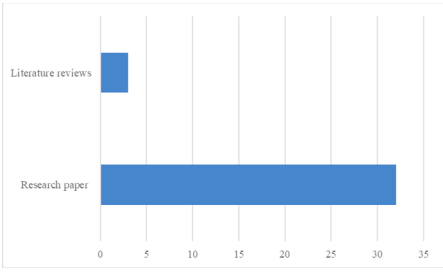

Figure 4 Document type

As reported in Table 2, one third of the selected articles are published by two journals: the TQM Journal and the International Journal of Quality and Reliability Management. On the other hand, the International Conference on Flexible Automation and Intelligent Manufacturing stands out among international conferences. Consistently with the interdisciplinary nature of the topic, the other articles are mostly published in journals related to quality and operations management, manufacturing, and computer engineering.

Table 2 Sources

Source	Type	No. Articles
TQM Journal	J	7
International Journal of Quality and Reliability Management	J	6
Lecture Notes in Mechanical Engineering	C	3
Total Quality Management and Business Excellence	J	3
International Conference on Quality Engineering and Management	C	2
Quality Innovation Prosperity	J	2
Sustainability (Switzerland)	J	2
IFIP Advances in Information and Communication Technology	C	1
International Journal of Computer Integrated Manufacturing	J	1
International Journal of Production Research	J	1
Lecture Notes in Networks and Systems	C	1
Operations and Supply Chain Management	J	1
Periodica Polytechnica Social and Management Sciences	J	1
Quality and Reliability Engineering International	J	1
Quality Engineering	J	1
Sensors	J	1
Sensors International	J	1
Total Articles		*35*

3.2 Content Analysis

3.2.1. Distribution of Studies: SME Emphasis, Industrial Cases, and Empirical Research

Figure 5 portrays the categorization of the collected articles based on the specific focus and aspects observed from the articles:

(i) **SME focus:** in three articles there was a focus on SMEs' characteristics and requirements, such as resource constraints (Ali & Johl, 2023; Antony et al., 2023).

(ii) **Empirical studies:** ten of the identified papers were based on industrial case studies or validated the proposed artifact in an industrial environment (Antony et al., 2023).

(iii) **Specific Industry focus:** three articles focused on a specific industry and investigated the most relevant factors for ZDM implementation in that industry, e.g., the food sector adopts process-centric strategies (Dror, 2022), while the automotive sector mostly adopts product-centric strategies (Prashar, 2023).

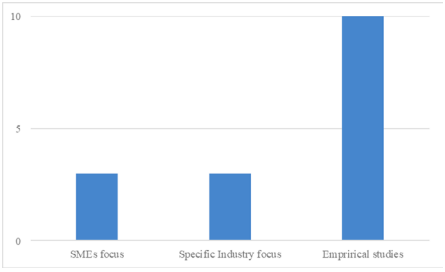

Figure 5 Articles' characteristics

3.2.2. Readiness / Maturity Factors

The Readiness/Maturity Factors mapped from the review could be showcased in anyone of the 6P framework's dimensions as shown in Table 3.

Product Dimension: Product *design for quality* was the most recurrent factor emphasizing on embedding quality concerns into the design phase, which in-turn enables manufacturers to proactively ensure a higher level of product quality throughout the lifecycle. Furthermore, the product design integrates new age quality characteristics – smart traceability, and product intelligence to enable monitoring, and repairing/lifecycle extending activities which resonates with the ZDM goal.

Process Dimension: Factors such as *quality management system, Data assisted decision-making system, and Quality strategy* are the most found factors in this dimension. Collectively, these factors address the structural systems, and strategies and strategies that connect the digital tools (digital quality testing, and self-learning machines/systems), and methods (preventive/repairing/predictive) to embed quality into every aspect of the organization's operations. Aligning quality strategies within the system is crucial in shaping the chances of establishing a successful ZDM.

Platform Dimension: Technology oriented factors such as *Advanced Data analytics, Simulation techniques, Data management capabilities, and IT infrastructure* are among the most noted factors. Digitalization has given way to the flow of massive data which in turn has made advanced analytics possible. This technological progression facilitates real-time monitoring of quality parameters. Furthermore, these factors promote information access, process openness, stakeholder

interaction, and data sharing, central to achieve quality objectives and for the successful ZDM adoption.

People Dimension: *Top management, Quality Culture, and workforce upskilling* form the foundational factors, found from this review. Establishing advanced systems/processes, building digital infrastructure, and training employees on quality skills start from the management commitment towards quality objectives. Furthermore, these factors are central to developing the holistic quality narrative necessary for the creation of a robust foundation for ZDM.

Partnership Dimension: *Supplier centeredness, Customer centeredness, and External collaboration* were the most observed factors in this dimension, which presents quality improvement as a shared objective in the ZDM context.

3.2.3. Readiness / Maturity Levels

It is observed that there were totally eight articles that presented a maturity/readiness scale with the definition of multiple maturity/readiness levels. Out of them, 5 papers had a similar portrayal ranging from No Readiness/Low readiness to Very high level of readiness. Moreover, the Table 4 represents a different approach taken by some articles to present the maturity/readiness levels.

Regarding the assessment method, the main used one was either self-assessment form the internal personnel or third-party assessment consisting of experts classifying the maturity levels based on information provided by the company.

4. DISCUSSION AND CONCLUSIONS

To achieve ZDM, evaluating a company's maturity and identifying necessary improvements are essential. This paper presents a review of the current state of Quality 4.0 and ZDM readiness and maturity assessment. Based on the literature review, it is evident that research on ZDM readiness and maturity assessment is still in its early stages but has seen rapid growth in recent years.

Given the multifaceted nature of ZDM, encompassing business, technical, and social dimensions, a holistic perspective is crucial. Among the analyzed dimensions (Product, Process, Platform, People, Partners, Performance), the literature highlights People, Process, and Platform as pivotal for successful ZDM implementation.

While technology and human capital are frequently discussed in relation to ZDM progress, a first research gap is the lack of attention to environmental sustainability aspects. Resource consumption, waste generated, and environmental impacts are often overlooked in existing studies. Therefore, future research could bridge this gap by exploring the ecological footprint of ZDM and strategies to integrate sustainability considerations into the ZDM assessment process, towards Zero Waste Manufacturing.

Table 4 Maturity Levels

	Description of readiness / maturity levels
Zonnenshain & Kenett, 2020	FOCUS: Presents Data usage as maturity level to facilitate data-driven decision making in Q4.0 context. MATURITY LEVELS: Level 1: Firefighting: random reports to be delivered yesterday. Level 2: Inspection: a focus on descriptive statistics. Level 3: Process view: modelling variability with statistical distributions. Level 4: Quality by design: planning interventions and experiments for data gathering. Level 5: Learning and discovery: a holistic view of data science. ASSESSMENT: Formal and Informal assessment (Thirds party or Self-Assessment)
Konstantinidis et al., 2023	FOCUS: Technology maturity assessment MATURITY LEVELS: Level 1: indicates the abilities to collect and visualize data Level 2: indicates the abilities to collect, process and publish data Level 3: indicates the abilities to collect, transform and publish meta-data to industrial manufacturing system Level 4: indicates the abilities to collect, restore, process and publish meta-data on an advanced level using AI and IoT Level 5: indicates the abilities to autonomously transform, process, and publish context-aware metadata using self-adaptable processing techniques and I5.0 visualization and integration technologies. ASSESSMENT: Not mentioned in the paper
(Nenadál et al., 2022)	FOCUS: Maturity assessment for Quality 4.0 MATURITY LEVELS: Level 1 – Not applied Level 2 - Beginner Level 3 - Partially applied Level 4 - Partially established Level 5 - Mostly established Level 6 - Advanced Level 7 – Leader ASSESSMENT: Direct assessment with structured E-Questionnaire

Table 3 Readiness/maturity factors mapping

TITLE OF THE PAPER	PRODUCT	PROCESS	PLATFORM	PEOPLE	PARTNERSHIPS	PERFORMANCES
(Psarommatis et al., 2024)			✓	✓		
(Azamfirei et al., 2024)	✓		✓	✓	✓	
(Almeida & Abreu, 2024)				✓		
(Zulfiqar et al., 2023)				✓		
(Konstantinidis et al., 2023)			✓	✓		
(Antony, Sony, et al., 2023)	✓		✓	✓		
(Antony, McDermott, et al., 2023)	✓		✓	✓		
(Khourshed & Gouhar, 2023)		✓	✓	✓	✓	
(Ali & Johl, 2023)		✓	✓	✓		✓
(Maganga & Taifa, 2023a)			✓	✓		
(Maganga & Taifa, 2023b)		✓	✓	✓	✓	✓
(Prashar, 2023a)		✓	✓	✓	✓	✓
(Maganga & Taifa, 2023c)		✓	✓	✓	✓	
(Psarommatis et al., 2023)		✓	✓	✓		✓
(Van Nguyen et al., 2023)	✓	✓	✓	✓	✓	
(Jamkhaneh et al., 2022)		✓	✓	✓	✓	
(Vykydal & Nenadál, 2022)	✓	✓	✓		✓	
(Zulqarnain et al., 2022)		✓	✓	✓	✓	
(Thekkoote, 2022)			✓	✓	✓	
(Mittal et al., 2022)		✓	✓	✓	✓	
(Ali & Johl, 2022a)		✓	✓	✓	✓	
(Tambare et al., 2022)		✓	✓	✓	✓	
(Dror, 2022)	✓	✓	✓			✓
(Sureshchandar, 2022)	✓	✓	✓	✓	✓	
(Fonseca et al., 2021)		✓	✓	✓		
(Dias et al., 2022)		✓	✓	✓		
(Ali & Johl, 2022b)	✓	✓	✓	✓	✓	✓
(Balouei Jamkhaneh et al., 2022)	✓	✓	✓	✓	✓	✓
(Souza et al., 2022)		✓	✓	✓		✓
(Prashar, 2023b)		✓	✓	✓	✓	
(Javaid et al., 2021)		✓				✓
(Zonnenshain & Kenett, 2020)		✓		✓	✓	
(Sader et al., 2019)	✓	✓		✓	✓	

Additionally, the Product and Partnership dimension as well as horizontal and vertical integration with stakeholders (e.g., suppliers, customers, etc.) have received little attention so far. This represents a second main gap identified in current research. Future research can delve into stakeholder relationships and product traceability to realize ZDM along the value chain and the product lifecycle. Future research can investigate trusted data sharing flows and how they can be enabled by the adoption of appropriate architectures (Nazarenko et al., 2021), ontologies and standards (e.g., Psarommatis et al., 2023), manufacturing data spaces (IDSA, 2019) and Digital Product Passports (King et al., 2023).

Enhancing the definition of readiness/maturity levels and refining assessment methods is also crucial for ensuring measurement reliability and validity in future studies. Finally, the third main gap emerging from the state-of-the-art analysis is the limited number of ZDM and quality 4.0 maturity models, frameworks and readiness assessments that reflect the specific requirements and challenges of SMEs. Thus, future research should focus on tailoring models and assessments to suit SME characteristics and requirements, thereby reducing barriers to entry and transition risks.

In conclusion, researchers and practitioners aiming for zero defects should heed the findings and recommendations of this study. Developing robust ZDM maturity models and assessment tools through rigorous methodologies, such as design science (Kırmızı and Kocaoglu, 2022), and validating them in real industrial settings is crucial for advancing ZDM implementation. Integrating environmental sustainability toward zero waste, including stakeholders along the value chain and product lifecycle, and customizing models and assessments for SMEs represent valuable directions for future research.

ACKNOWLEDGMENTS

This study has been partially funded by the Horizon Europe project FLASH-COMP – GA number: 101058458

SELECTED REFERENCES

Ali, K., & Johl, S. K. (2023). Impact of total quality management on industry 4.0 readiness and practices: does firm size matter? *International Journal of Computer Integrated Manufacturing*, *36*(4), 567–589. https://doi.org/10.1080/0951192X.2022.2128213

Antony, J., Sony, M., Furterer, S., McDermott, O., & Pepper, M. (2022). Quality 4.0 and its impact on organizational performance: an integrative viewpoint. *The TQM Journal*, *34*(6), 2069–2084. https://doi.org/10.1108/TQM-08-2021-0242

Antony, J., Sony, M., McDermott, O., Jayaraman, R., & Flynn, D. (2023). An exploration of organizational readiness factors for Quality 4.0: an intercontinental study and future research directions. *International Journal of Quality and Reliability Management*, *40*(2), 582–606. https://doi.org/10.1108/IJQRM-10-2021-0357

Caggiano, M., Semeraro, C., & Dassisti, M. (2023). A Metamodel for Designing Assessment Models to support transition of production systems towards Industry 5.0. *Computers in Industry*, *152*, 104008. https://doi.org/https://doi.org/10.1016/j.compind.2023.104008

Caiazzo, B., Di Nardo, M., Murino, T., Petrillo, A., Piccirillo, G., & Santini, S. (2022). Towards Zero Defect Manufacturing paradigm: A review of the state-of-the-art methods and open challenges. *Computers in Industry*, *134*, 103548. https://doi.org/https://doi.org/10.1016/j.compind.2021.103548

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, *133*, 285–296. https://doi.org/https://doi.org/10.1016/j.jbusres.2021.04.070

Dror, S. (2022). QFD for selecting key success factors in the implementation of quality 4.0. *Quality and Reliability Engineering International*, *38*(6), 3216–3232. https://doi.org/10.1002/qre.3138

Hein-Pensel, F., Winkler, H., Brückner, A., Wölke, M., Jabs, I., Mayan, I. J., Kirschenbaum, A., Friedrich, J., & Zinke-Wehlmann, C. (2023). Maturity assessment for Industry 5.0: A review of existing maturity models. *Journal of Manufacturing Systems*, *66*, 200–210. https://doi.org/https://doi.org/10.1016/j.jmsy.2022.12.009

Konstantinidis, F. K., Myrillas, N., Tsintotas, K. A., Mouroutsos, S. G., & Gasteratos, A. (2023). A technology maturity assessment framework for Industry 5.0 machine vision systems based on systematic literature review in automotive manufacturing. In *International Journal of Production Research*. Taylor and Francis Ltd. https://doi.org/10.1080/00207543.2023.2270588

Nenadál, J., Vykydal, D., Halfarová, P., & Tylečková, E. (2022). Quality 4.0 Maturity Assessment in Light of the Current Situation in the Czech Republic. *Sustainability (Switzerland)*, *14*(12). https://doi.org/10.3390/su14127519

Prashar, A. (2023). Towards digitalisation of quality management: conceptual framework and case study of auto-component manufacturer. *TQM Journal*, *35*(8), 2436–2454. https://doi.org/10.1108/TQM-09-2022-0289

Psarommatis, F., & May, G. (2023). A practical guide for implementing Zero Defect Manufacturing in new or existing manufacturing systems. *Procedia Computer Science*, *217*, 82–90. https://doi.org/https://doi.org/10.1016/j.procs.2022.12.204

Psarommatis, F., May, G., Dreyfus, P.-A., & Kiritsis, D. (2020). Zero defect manufacturing: state-of-the-art review, shortcomings and future directions in research. *International Journal of Production Research*, *58*(1), 1–17. https://doi.org/10.1080/00207543.2019.1605228

Psarommatis, F., Sousa, J., Mendonça, J. P., & Kiritsis, D. (2022a). Zero-defect manufacturing the approach for higher manufacturing sustainability in the era of industry 4.0: a position paper. *International Journal of Production Research*, *60*(1), 73–91. https://doi.org/10.1080/00207543.2021.1987551

Psarommatis, F., Sousa, J., Mendonça, J. P., & Kiritsis, D. (2022b). Zero-defect manufacturing the approach for higher manufacturing sustainability in the era of industry 4.0: a position paper. *International Journal of Production Research*, *60*(1), 73–91. https://doi.org/10.1080/00207543.2021.1987551

Spaltini, M., Acerbi, F., Pinzone, M., Gusmeroli, S., & Taisch, M. (2022). Defining the Roadmap towards Industry 4.0: The 6Ps Maturity Model for Manufacturing SMEs. *Procedia CIRP*, *105*, 631–636. https://doi.org/10.1016/j.procir.2022.02.105

Tricco, A., Lillie, E., Zarin, W., O'Brien, K., Colquhoun, H., Levac, D., Moher, D., Peters, M., Horsley, T., Weeks, L., Hempel, S., Akl, E., Chang, C., Mcgowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M., Garritty, C., & Straus, S. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. *Annals of Internal Medicine*, *169*. https://doi.org/10.7326/M18-0850

Zonnenshain, A., & Kenett, R. S. (2020). Quality 4.0—the challenging future of quality engineering. *Quality Engineering*, *32*(4), 614–626. https://doi.org/10.1080/08982112.2019.1706744