

Systematic Literature Review of Industry 4.0 Implementation Frameworks Focusing on Applicability in Manufacturing SMEs

Joshua DENNING¹ and Kapila LIYANAGE

College of Science of Engineering, University of Derby, United Kingdom

Abstract. Industry 4.0 (I4.0) is not an exceedingly new concept. Since the term was coined in Germany in 2011 it has come to encompass many enabling technologies around the digitalisation of manufacturing processes growing further into the service industry and beyond. The need for businesses to begin to explore these options to reap the benefits of I4.0 is growing and while many larger organisations are maturing in their adoption many SMEs are not. This paper conducts a systematic literature review (SLR) of the tools available to organisations looking to implement I4.0. The research will focus on tools are around the areas of readiness models, maturity models and frameworks that provide detail on how to begin the journey to I4.0 implementation. The key research questions to be answered are if these tools cater to the unique needs of manufacturing SME's and the challenges they face. What sets this SLR apart from other analysis is the identification of a research gap for a detailed framework for manufacturing SMEs to implement I4.0 in an agile and sustainable way. As the manufacturing world is changing and consumers are making more informed choices about what they buy with a view towards sustainability how can I4.0 help manufacturing SMEs operate in a sustainable way whilst remaining agile to changing economic conditions. This SLR will form the basis for further research into this area to support SMEs on their I4.0 adoption journey.

Keywords. Industry 4.0, Implementation Framework, Manufacturing SME, Sustainability, Agility

1. Introduction

The terms “industry 4.0” (I4.0) and “smart manufacturing (SM)” have come to mean many things to many people. Ultimately, they are umbrella terms that describe a vast amount of enabling technologies, theories and strategies that are allowing companies to harness technology to drive manufacturing performance and improve key areas such as quality, productivity, and efficiency.

As the area of I4.0 is so large many academics and practitioners have devised practical and theoretical frameworks to assist in the implementation of I4.0 within a business. The frameworks often consist of readiness models and maturity models used relatively interchangeably to understand, in a structured way, the start point for the business. The frameworks generally try to provide a pathway or methods to get from the current state highlighted in the readiness/maturity model to the proposed future state of I4.0 maturity the business desires.

¹ Corresponding Author. j.denning2@derby.ac.uk

1.1. Manufacturing SME Focus

In 2021 there are approximately 270,000 manufacturing businesses in the UK of which only 5353 are identified as being large enterprises that employ 500 people or more [1]. This leaves 98% of UK manufacturing businesses that do not fall into this category.

This SLR focusses on this area of SMEs in manufacturing due to their large population and limited resource availability in this type of business. Compared to large enterprises SMEs have less resources to invest in improvement activities and future expansion which is the type of benefit that I4.0 hopes to provide [2]. SMEs therefore need the support of research from academics and practitioners to understand how they can compete on a larger scale leveraging the benefits of I4.0 and how they can implement them.

1.2. Sustainability

By 2050 many countries have pledged to become carbon neutral in the fight against climate change. Manufacturing is often seen as a high polluting industry due to its history however in 2018 the climate change committee published the fact that manufacturing and construction account for 12% of the total UK emissions. 90% of this figure is from manufacturing and 86% of these emissions are from fuel combustion [3]. This figure is low as a percentage of the total contribution but there is still room for considerable improvement.

The technology revolution that I4.0 can provide is able to help businesses develop in their approach to sustainability and some studies exist as a guide on how to do this and what positive effect it can have. Within the climate change committee report are recommendations on how the industry can reduce its carbon footprint. Points include resource efficiency, material substitution, energy efficiency, fuel-switching and more. The key enabling technologies of I4.0 will allow for the better monitoring of resources, increases in efficiency and the ability to use data to predict usages and find the best solutions to energy requirements thus reducing carbon emissions.

1.3. Agility

Agility in business allows companies to react quickly to changing demands and fuels innovation and creativity. The introduction of I4.0 technologies if done incorrectly can impact a business's agility in a detrimental way. The implementation of centralised computer systems to manage data can make a business too rigid and adopt a 'computer says no' mentality.

Pulling these key ideas together highlights the need for further research into the area of implementation frameworks for manufacturing SMEs that include significant support and consideration towards sustainability and agility. This systematic literature review will focus on the applicability of existing I4.0 implementation frameworks for manufacturing SME's whilst also looking at how these frameworks offer methods to become more sustainable and more agile during the process.

It will critically assess the frameworks in a number of ways to understand what benefits they are bringing and what research gaps are missing.

2. Research Methodology

The SLR is a key research tool to discover current research and understand where that fits into wider research categories and how they all relate to each other in order to identify gaps and create a richer picture of the subject. The key point in the SLR is the systematic nature of it. By having a systematic approach to the literature review it ensures that it is repeatable and using a good methodology is rooted in good research practice.

The area of research around industry 4.0 is vast and by applying some filters to keywords, sources and timeframe the researcher can ensure a manageable area of literature to review. This allows deeper focus in the specific area of research relating to the subject of the research allowing for richer analysis and links that can be made between research.

2.1. Research Questions

It is important to structure the research around specific research questions to ensure research direction is continuous. For this SLR the following have been selected.

RQ1: Do current industry 4.0 implementation frameworks cater sufficiently to the needs of manufacturing SME's?

RQ2: Do current industry 4.0 implementation frameworks acknowledge the need for sustainability and agility?

RQ3: Does the current research go far enough in bridging the gap between academia and industry to make the research actionable by business leaders/practitioners?

2.2. Research Criteria & Source

By using the below specific search criteria the SLR ensures that the research stays within the defined area. By using the truncation method, the method ensures more applicable results are displayed and considered within the review. These specific search terms were as follows; "Industry 4.0" + "Manufacturing", "Industry 4.0" + "Manufacturing" + "SME's", "Industry 4.0" + "Implementation framework", "Industry 4.0" + "Agile", "Industry 4.0" + "Sustainable", "Industry 4.0" + "Readiness".

These search terms were input into Google Scholar and Scopus and all results were collected in their raw form for a later analysis of inclusion criteria as detailed below.

Inclusion and exclusion criteria have been created to further refine the search field of relevant papers. The area of research around industry 4.0 often generates a lot of result of implementing specific technologies such as a specific automation package, MES system or as granular as a specific RFID installation. For this research this level of detail into the enabling technologies is not applicable. Therefore, the exclusion criteria contain any papers that are specifically focussed on enabling technologies. As the research is also focussing on the agility and sustainability within manufacturing and industry 4.0 a significant amount of research around generic business agility and sustainability must be excluded as it is not applicable to the research.

Further defining the research period allows the SLR to ensure it is more up to date and applicable to the latest research. As research tends to build on previous research defining a period in the last 6 years from January 2016 to March 2022 allows the SLR to be up to date. Of the 222 papers collected 30 were removed due to duplication and a further 20 were excluded after a first pass due to relevancy as described above. This resulted in 172 papers being taken forward for the further analysis for this SLR.

3. Results/Findings

3.1. Metadata Analysis

The below graphs and charts show the distribution of research material by type, year, country, source and author. It illustrates that the majority of the material researched came from journal papers followed closely in second by conference papers. The peak of the distribution of the research was published in 2020 highlighting 15 countries with over 5 papers contributing to the research.

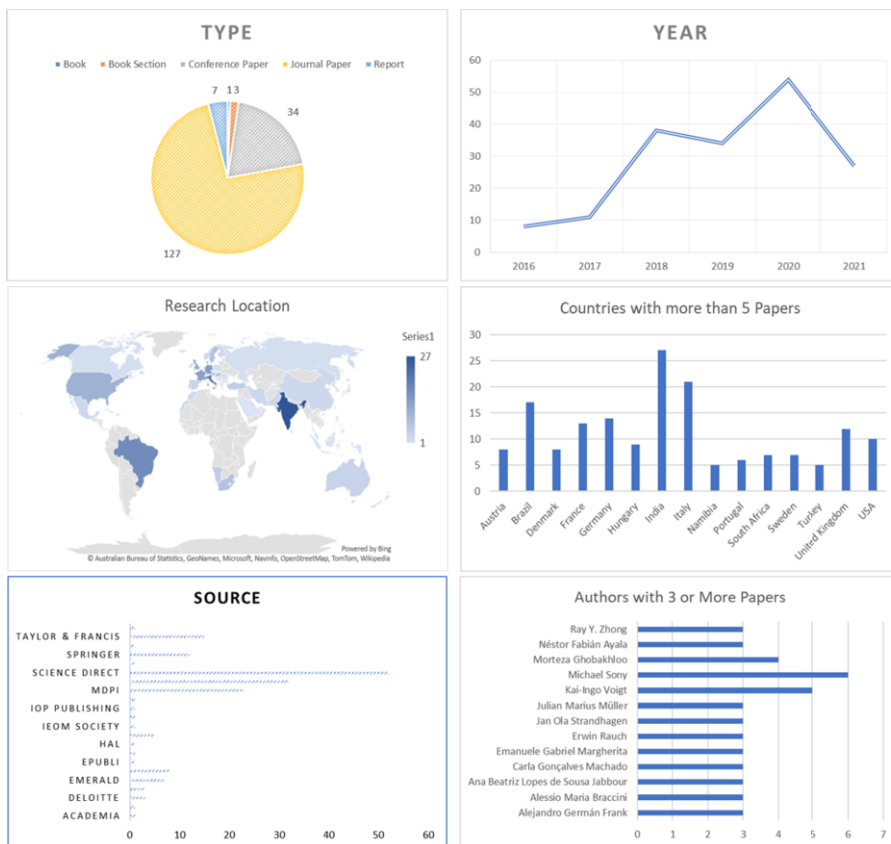


Figure 1. Metadata Analysis

3.2. Framework Comparisons

From the above broad meta-analysis from the literature search defined in the methodology 9 papers have been selected for comparison. This paper aims to understand the research and tools that will allow manufacturing SMEs to implement industry 4.0 as effectively as possible. This comparison includes readiness models, maturity models,

frameworks and roadmaps and looks to define the place of each within the journey an SME will take to implement industry 4.0.

The assessment will outline the key points of each paper in isolation then the discussion section will compare and contrast each paper on its merits, highlight its drawback and ultimately make suggestions around the research gaps identified.

Each Paper in some way or another tries to define industry 4.0 and touches on enabling technologies. Some go into a lot of detail on the enabling technologies and their implications. The purpose of this paper is to look at the structure of the model/framework/roadmap and analyse the impact from a business management point of view looking at how an SME could utilise is in an adaptive, agile and sustainable way. Therefore, the below analysis will exclude discussions about the impact of industry 4.0 and its enabling technologies.

3.2.1. Comparison Tables

Table 1 outlines briefly the title of the paper, the type of model, focus area, benefits and drawbacks of each of the 9 identified models. The benefits and drawbacks are based on the applicability to a manufacturing SME implementing industry 4.0 in an agile and sustainable way as identified previously.

Table 1. Framework Comparisons

Title & Author	Type	Focus Area	Benefits	Drawbacks
A Categorical Framework of Manufacturing for Industry 4.0 and Beyond [4]	Framework	Implementation based on manufacturing system	The model goes some way into breaking down the levels of industry 4.0 implementation and relates the cognition level to the manufacturing system.	Very little to no discussion around other areas of business such as culture, management, finance etc. No mention of agility or sustainability. Little benefit to the model other than defining a level in relation to the manufacturing system/method.
A Framework for Assessing Manufacturing SMEs Industry4.0 Maturity [2]	Maturity Model	Manufacturing SMEs Maturity	Highlights the needs of SME's and highlights the business processes and areas SME's need to focus on to achieve high levels of industry 4.0 implementation	It is quite complex with all 26 different sub dimensions being loosely defined and not so easy to score. No mention of sustainability or agility.
A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises [5]	Maturity Model	Generic manufacturing readiness	Useful software tool created to allow businesses and practitioners to utilise the model easier. Level of detail and inclusion of all business areas important.	No relation to the importance of agility and sustainability and not related to SME's unique needs.

A roadmap to achieve apparel 4.0; The apparel industry perspective of industry 4.0 [6]	Roadmap	Apparel industry	Some definition of an implementation strategy of assess, plan, act is used to make the most of the model.	No info on scoring system, no sustainability, no agility no real application.
A smart manufacturing adoption framework for SMEs [7]	Framework	SME's Adoption of Industry 4.0	Emphasis on creating a data driven culture. Focus on SME's. Detailed consideration given using different toolboxes to implement in different areas. This is more focused on the adoption of Industry 4.0 and is actionable and applicable to SME's	No mention of sustainability or agility. SME's can get worse if they implement complex IT systems that remove the agility which makes them so robust.
A strategic roadmap for the manufacturing industry to implement industry 4.0 [8]	Roadmap	Manufacturing industry	Good use of established techniques and focusses on creating value for the business. Focused on existing manufacturing excellence techniques to implement I4.0	It is not focused on SME's, agility or sustainability.
Agile requirement engineering maturity framework for industry 4.0 [9]	Framework	Agile requirement engineering	Combines agile methodology with industry 4.0 implementation and requirements engineering.	No minimum maturity levels. Need to enhance applicability but no methods of how for SMEs. Confusing architecture is difficult for practitioners to implement.
Roadmap industry 4.0 - Implementation guideline for enterprises [10]	Roadmap	Implementation strategy	Defines a real actionable set of steps to be able to implement industry 4.0 from start to finish. Focused on the strategy so it can be tailored and not a generalised solution.	Limited tools to guide SME's other than the overall 6 key steps. No mention of embedding sustainability or agility into the model.
Industry 4.0 Readiness Assessment: Comparison of Tools and Introduction of New Tool for SME [11]	Readiness Model	SME readiness assessment	Good scoring system is defined individually for each of the sub dimensions.	Little explanation of defining a map of where to go after and little detailed explanation of the tool. No mention of sustainability and agility and is very focused on data, software and hardware not things like people culture and processes.

3.2.2. Detailed Comparison

The above tables go some way to starting to highlight the benefits and drawbacks in the material available to businesses. The table pulls out details from maturity models, frameworks, roadmaps and implementation strategies to highlight some of the key elements of each approach with a view to finding the key elements that can contribute to the agile and sustainable implementation of industry 4.0 within manufacturing SME's.

The analysis of the tools is intended for a manufacturing SME and stresses the importance of agility and sustainability within the implementation. Of the 9 tools analysed in the SLR 8 of them have no mention of agility and 9 of them do not put any real focus on sustainability being a key factor.

There are range of application areas focusing on the distinct needs of SMEs and highlighting the importance of doing so [1], [2] and [7]. They all discuss the importance of SMEs to the global economy and how their size and position in the market offer specific challenges that any implementation or assessment tool must consider. Amaral & Pecas (2021) [2] go into much detail around the specific tailored needs of SMEs and what is critical to them for a good implementation.

Some researchers focus on the manufacturing industry and use standardised tools from manufacturing such as lean principals, six sigma, DMAIC and others then adapt them in the context of industry 4.0 implementation which is beneficial to the target audience of manufacturing companies [7] and [8]. If the companies are already familiar with the tools highlighted then the adoption of the industry 4.0 framework does not seem so daunting and they can apply tried and tested manufacturing principals to the implementation.

The scoring systems of all the models are very different with [4], [5] and [10] suggesting a 1 to 5 scale that gives a score to be used to develop the final outcome of the assessment. This is quite subjective in the analysis as little guidance is given to each of the 5 levels. Axmann & Harmoko (2020) [11] uses a specific system of scoring that is defined individually for each of the 12 sub-dimensions of the model. This allows for a more specific approach to scoring resulting in a more tailored and standardised approach that giving a score based on a 1 to 5 objective scale.

Software tools are used to deliver the research and apply the model in an easy and friendly way to practitioners [5]. Some employ the use of radar charts which are a great tool in understanding the current level of industry 4.0 implementation [5], [9] and [10]. They allow for the before and after stages to be produced. This allows practitioners in manufacturing SMEs to understand the gaps and create plans/strategies/project to fill these and achieve their required level of implementation/maturity.

4. Conclusions and Future Research

The SLR has highlighted 9 papers and has analysed many different aspects of their design such as focus area, dimensions, and sub-dimensions, scoring systems and applicability to manufacturing SMEs whilst looking at sustainability and agility as key areas for the implementation.

The research has shown a clear gap in the knowledge of how to implement industry 4.0 within manufacturing SMEs in an agile and sustainable way. The future of this research aims to expand on this comparison to develop a tool utilising some key areas highlighted. A lot of the work has already been started and by looking at the key benefits

of the models in this SLR a new tool can start to be developed. By highlighting key areas around the applicability of the models to manufacturing SMEs and how utilising existing tools within manufacturing can benefit the businesses utilising the tools a new tool can be developed including all of the key points from the above analysis.

The additional research into how to apply the agility and sustainability steps into these models needs to be comprehensively applied to the creation of a new model to support SMEs in their adoption of industry 4.0.

References

- [1] Clark, D. (2022). *Number of business enterprises in the manufacturing sector in the United Kingdom in 2021, by enterprise size*. Retrieved February 17, 2022, from <https://www.statista.com/statistics/677081/uk-manufacturing-businesses-by-size/#:~:text=In%202021%2C%20there%20were%20approximately,employed%20500%20or%20more%20people.>
- [2] Amaral, A., & Pecas, P. (2021). A Framework for Assessing Manufacturing SMEs Industry4.0 Maturity. *Applied Sciences*, 11.
- [3] Climate Change Committee. (2020). *The Sixth Carbon Budget - Manufacturing and construction*. London: TheCCC.
- [4] Qin, J., Liu, Y., & Grosvenor, R. (2016). A Categorical Framework of Manufacturing for Industry 4.0 and beyond. *Procedia CIRP*, 52, 173-178.
- [5] Schumacher, A., Erol, S., & Sihni, W. (2016). A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises. *Procedia CIRP*(161), 161-166.
- [6] Jayatilake, H. S., & Peter, S. (2016). A ROADMAP TO ACHIEVE APPAREL 4.0; THE APPAREL INDUSTRY PERSPECTIVE OF INDUSTRY 4.0. *SSRN Electronic Journal*.
- [7] Mittal, S., Khan, M. A., Purohit, J. K., Menon, K., Romero, D., & Wuest, T. (2019). A Smart Manufacturing Adoption Framework for SMEs. *Production REsearch*, 5(58), 1555-1573.
- [8] Butt, J. (2020). A Strategic Roadmap for the Manufacturing Industry to Implement Industry 4.0. *Designs*, 2(4), 1-31.
- [9] Elnagar, S., Weistroffer, H., & Thomas, M. (2019). Agile Requirement Engineering Maturity Framework for Industry 4.0. *Business information Processing*, 405-418.
- [10] Pessl, E., Sorko, S. R., & Mayer, B. (2017). Roadmap Industry 4.0 - Implementation Guideline for Enterprises. *International Journal of Science, Technology and Society*, 6(5), 193-202.
- [11] Axmann, B., & Harmoko, H. (2020). Industry 4.0 Readiness Assessment: Comparison of Tools and Introduction of New Tool for SME. *Tehnički Glasnik*, 2(14), 212-217.