Industry 4.0 assessment in agri-food and dairy sector: a literature review of Maturity Models

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Abstract: The agri-food industry and the dairy industry are undergoing a profound transformation due to the spread of new digital technologies. This digital transition is pushing for the use of enabling technologies indicated by the new Industry 4.0 paradigms, impacting on how companies typically provide their goods and services. Although companies are aware of the potential benefits of this transition, they have tackled the required task of adapting or reshaping their existing processes to the new era of digitalization. To do that, proper and accurate digital maturity models (MM) should be developed aiming at defining roadmaps to assist organizations in Industry 4.0 adoption. These models are necessary to both verify the technological level and to define the starting point of a path that can lead to an effective digital transition of manufacturing. The concept of MM has been widely investigated in literature, especially for medium and large companies while limited studies have been focused on its implementation in Small and Medium Enterprises (SMEs) context. Indeed, SMEs exhibit substantial constraints in terms of limited financial and human resources which may hinder the roadmaps adoption developed for large organizations making the definition of the Design Principles a complex and tailored task. This work proposes a critical review of the extant literature on MMs for the implementation of Industry 4.0 technologies in the SMEs context with emphasis on the food processing sector. Having realised the absence of specific MMs for the dairy industry, the main purpose is to identify, among the MMs currently available in the literature, the ones that can more effectively be adapted for the digital level assessment of companies operating in that sector. Results highlight how employing the MMs typically applied for manufacturing organizations may be a valuable tool for addressing the specific needs of the dairy industry.

Keywords: industry 4.0, maturity model, dairy industry, assessment, digital maturity models, agri-food

I. INTRODUCTION

The founding concepts of the fourth industrial revolution, or Industry 4.0, are spreading in the manufacturing industry sectors and numerous public and private institutions, bringing about a profound change in economic and social organizations. Institutions and companies that approach a digital transition process through the introduction of digital technologies into business processes face a series of challenges both in terms of costs and cultural aspects. The decision to face such transition is becoming an obligatory requirement for companies to remain competitive in an increasingly global and dynamic market, but also for careful exploitation of human resources. This can be done through the adoption of cyber-physical systems (CPS), big data, cloud computing, and the Internet of Things (IoT). In this scenario, data is considered the key enabler of digital transition as it provides useful insights along the entire production chain [1]. Therefore, it becomes important to understand how the collection and use of data and their interconnection can improve processes in all business aspects. All economic and social sectors are involved in this transition, including the agri-food sector. Despite the presence of large businesses characterized by highly automated processes targeted at large-scale distribution, the agri-food industry is dominated by small and medium enterprises (SMEs) and smallholder farmers where innovation-related activities as well as the adoption of digital technologies are still limited. To remain competitive, they have to face severe challenges such as the need to comprehend customer preferences and demands and to identify logistical concerns that might compromise product quality. Particularly, companies should be responsive to meet customer needs by implementing valuable strategies to ensure food quality and safety standards while improving their manufacturing practices and business performance [2]. Another crucial challenge concerns the logistic information systems in the agri-food supply chain. Indeed, if traditionally this system was merely based on tracking and storing orders and deliveries, the need to properly control the risks can affect the food quality and safety such as temperature and/or humidity control, incorrect physical handling, and delays, it is an essential requirement throughout the entire supply chain. To do this, traceability allows locating and keeping track of a product through the different stages a food has taken from production to consumption, i.e., its origin, production, manufacturing, processing, distribution, and handling [3]. In this case the enabling technologies of the 4.0 paradigm and in particular the Blockchain seems to be of great help and appear to be the standard of the future since data traceability, improves food safety and quality monitoring [4].

In the process of transition to new digital technologies, it is necessary to precisely understand the initial conditions of the company that wants to start this path. It is therefore essential to define the state of digital maturity that characterizes the company. For this purpose, Digital Maturity Models have been developed, and defined within specific frameworks based on specific criteria (Design principles). The MM guides businesses toward the most appropriate path for the deployment of the enabling technologies suggested by Industry 4.0 and aids them in clarifying the current state of process digitalization. There are many theoretical MMs in the literature. It should be emphasized that most of the models have been developed concerning medium and large companies, where it is possible to identify some large business common elements ranging from logistics to marketing and maintenance aspects. Thus, these models have to be modified and often specifically adapted for SMEs, since they appear to be highly focused on a limited number of employees due to their small scale of operations and organizational structure. Moreover, another challenge concerns the complexity of food systems so they require dedicated modelling approaches. Indeed, several aspects should be considered: (i) the intrinsic variability of food production systems due to their diffused and seasonal nature, (ii) the market concentration at the end of the supply chain, and (iii) the interrelations between production processes and food quality and safety requirements.

This work proposes a critical review of the extant literature on MMs for the digital assessment of agri-food SMEs, with an emphasis on the dairy sector. Since no MMs specifically adapted to dairies have not been found in the literature, the main research question that this work seeks to address is to discuss whether general MMs models might be suitable for that sector. Therefore, the main purpose is to identify and highlight potential similarities or peculiarities of existing MMs applied for the digital transition in companies' processes or generally in different manufacturing sectors.

II. Methodology

To understand the state-of-the-art of Industry 4.0 paradigm in agri-food and dairies, a literature review has been conducted, with two different focuses. The first one aimed at identifying existing MMs that can be suitable to assess the digital maturity level of companies in the agri-food and dairy industry, using Scopus as a reference platform. The second part of the analysis concerned an overview of specific issues characterizing the agri-food and dairy industry, which can be important factors to customize a MM based on peculiarity for the sector; Google Scholar has been used as a research platform for this scope. In the two following sections, the method used to conduct the two parts of the research has been detailed.

A. Research on Scopus

To identify papers in the literature and conduct the first part of the analysis the research moved on Scopus using the following query: *TITLE-ABS-KEY (("maturity model" OR "assessment") AND ("industr* 4.0" OR "I4.0")) AND (LIMIT-TO(PUBSTAGE, "final")) AND (LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (EXACTKEYWORD, "Maturity Model") OR LIMIT-TO (EXACTKEYWORD, "Maturity Assessments") OR LIMIT-TO (EXACTKEYWORD, "Assessment") OR LIMIT-TO (EXACTKEYWORD , "Case-studies") OR LIMIT-TO (EXACTKEYWORD, "Readiness Assessment") OR LIMIT-TO (EXACTKEYWORD, "Maturity Models") OR LIMIT-TO (EXACTKEYWORD, "Assessment Models") OR LIMIT-TO (EXACTKEYWORD, "Maturity Assessment") OR LIMIT-TO (EXACTKEYWORD, "Maturity Levels"))*

An amount of 272 papers has been found; a first screening was made to classify papers and find those concerning the explanation of a new maturity model, through several criteria such as title, abstract, and keywords; afterward, this selection has been adjusted through a quick read to have an overview of real contents developed and understand if the paper presented a structured new assessment model.

The selection covered 53 papers where a MM to assess the maturity level of digital transition in companies is presented with its structure. Different levels of granularity have been found in their approaches, starting from general models that can be used as a reference architecture to analyze businesses that belong to different kinds of industries, to MMs tailored on companies’ features as dimensions or specific industries. Results have been discussed in the following chapter, where section A details general MMs, section B relates models focused on SMEs’ peculiarities, and section C analyzes specific industry models.

B. Research on Google Scholar

To find papers focused on agri-food and food production, several specific keywords have been used on Google Scholar platform:

Agrifood industry 4.0 assessment model, Cheese factory industry 4.0 assessment model, Case study cheese factory industry 4.0 assessment model, Case-study cheese factory industry 4.0 assessment model, Application model industry 4.0, Application cheese factory model industry 4.0.

Papers selection has been conducted considering title, abstract, and a general overview; in particular, two articles have been taken into account and discussed in section D of the following chapter.

III. DISCUSSION AND RESULTS

A. General Maturity Models

Among the selected papers, 27 MMs general models have been explained: they represent theoretical structures that should be used to evaluate and enable innovation and digital transition in companies’ processes. The main part of these models is focused on the comprehension of the current status of a digital maturity level in order to assess the AS-IS situation of industrial processes; this approach follows a descriptive purpose, defined as the first phase of the MM life-cycle that at the same time, represents the starting point for implementing a digital transformation strategy to be integrated into company’s processes. Some MMs also include subsequent phases corresponding to a prescriptive purpose [5–12] which consists of the evaluation of a targeted maturity level that the company would achieve based on its resources, needs, and opportunities, through a tailored roadmap punctuated in timing, tasks, and action plans. Each MM refers to its own maturity scale to evaluate the company’s processes, made by a number of levels that may vary from 3 to 6: except [9,13–16] that use a quantitative score, other models declined the weighted average of dimensions in a qualitative gradient of attributes whose combination determines the current maturity situation. The overall evaluation is obtained as an average of specific sub-indexes calculated in different levels of granularity: dimensions, areas, and pillars, divided into sub-areas, and items, have been used to create a structure of elements thought to scan industrial and business processes, that allows to understand and know how each part of company’s organization is involved in I4.0 paradigm.

TABLE I. GENERAL MATURITY MODELS

Model	Authors	Ref
Acatech Industrie 4.0 Maturity Index	Zeller V., Hocken C., Stich V.	[5]
RAMI 4.0 Ontology Standard Readiness Assessment	Bastos A., Sguario Coelho De Andrade M.L., Yoshino R.T., Santos M.M.D.	[17]
Lean I4.0 Maturity & Technology Assessment (LI4MTA)	dos Santos V.A., Ramos L.F.P.	[18]
ECO Maturity Model	Bretz L., Klinkner F., Kandler M., Shun Y., Lanza G.	[19]
Industry 4.0 Collaborative Diversification	Ganzarain J., Errasti N.	[6]
SIMMI 4.0 - System Integration Maturity Model Industry 4.0	Leyh C., Bley K., Schaffer T., Forstenhausler S.	[20]
3D-CUBE Model	Felippes B., da Silva I., Barbalho S., Adam T., Heine I., Schmitt R.	[13]
DX-CMM Digital Transformation Capability Model	Gökalp E., Martinez V.	[7]
(name not specified)	Canetta L., Barni A., Montini E.	[14]
(name not specified)	Facchini F., Digiesi S., Rodrigues Pinto L.F.	[21]
I4.0CMM Competency Maturity Model	Maisiri W., Van Dyk L.	[22]
(name not specified)	Schumacher A., Erol S., Sihn W.	[15]
(name not specified)	Schumacher A., Nemeth T., Sihn W.	[8]
(name not specified)	Melnik S., Magnotti M., Butts C., Putman C., Aqlan F.	[9]
SMCMM Smart Manufacturing Capability Measurement Model	Xia Q., Jiang C., Yang C., Zheng X., Pan X., Shuai Y., Yuan S.	[23]
(name not specified)	Amaral A., Peças P.	[24]
	Amaral A., Jorge D., Peças P.	[25]

DREAMY Digital REadiness Assessment MaturitY model	De Carolis, A., Macchi, M., Kulvatunyou, B., Brundage, M. P., Terzi, S.	[10]
	De Carolis A., Macchi M., Negri E., Terzi S.	[11]
	De Carolis, A., Macchi, M., Negri, E., Terzi, S.	[12]
(name not specified)	Kırmızı M., Kocaoglu B.	[26]
SANOL 4.0	Ünal C., Sungur C., Yildirim H.	[16]
IMPULS 4.0	Lichblau, K, Sicht, V, Bertenrth, R, Blum, M, Bleider, M, Millack, A, Schmitt, K, Schmitz, E, Schroeter, M.	[27]
PIM 4.0	Azevedo A., Santiago S.B.	[28]
Manufacturing Value Modeling Methodology (MVMM)	Tonelli F., Demartini M., Loleo A., Testa C.	[29]
(name not specified)	Çınar Z.M., Zeeshan Q., Korhan O.	[30]
Maturity Model for Technological Integration	Widmer N, Hassan A, Monticolo D.	[31]
(name not specified)	Honorato C., de Melo F.C.L.	[32]
(name not specified)	Wagire A.A., Joshi R., Rathore A.P.S., Jain R	[33]
I4.0RAF - Industry 4.0 Readiness Assessment Framework	Ramanathan K., Samaranayake P.	[34]
(name not specified)	Santos R.C., Martinho J.L.	[35]

B. *Maturity Models for SMEs*

MMs presented above, give a general structure that can be used for assessing companies' maturity level, regardless of their specific industry and their dimension, even so, some of them [9–12,25] consider SME's scenario. To fill this gap, several authors focused their attention on companies' dimensions and theorized MMs thought specifically for SMEs, and tailored to their peculiarities.

TABLE II. MATURITY MODELS FOR SMES

Model	Authors	Ref
SME3E maturity model	Mittal S., Romero D., Wuest T.	[36]
(name not specified)	Brozzi R., Riedl M., Matt D.	[37]
(name not specified)	Ávila-Bohórquez J.H., Gil-Herrera R.J.	[38]
(name not specified)	Castelo-Branco I., Oliveira T., Simões-Coelho P., Portugal J., Filipe I.	[39]
(name not specified)	Castro H.F., Carvalho A.R.F., Leal F., Gouveia H.	[40]
Smart SMEs 4.0	Chonsawat N., Sopadang A.	[41]
	Chonsawat N., Sopadang A.	[42]
RAISE 4.0: A Readiness Assessment Instrument Aimed at Raising SMEs	Pan Nogueras M.L., Perea Muñoz L., Cosentino J.P., Suarez Anzorena D.	[43]
(name not specified)	Perea Muñoz L., Pan Nogueras M.L., Suarez Anzorena D.	[44]
(name not specified)	Pirola F., Cimini C., Pinto R.	[45]
(name not specified)	Rahamaddulla S.R.B., Leman Z., Baharudin B.T.H.T.B., Ahmad S.A.	[46]

C. *Industry-specific Maturity Models*

There is no specific model thought to dairies, but potential similarities can also be found in other sectors than agri-food, considering some peculiarities. Possible analogies can be related to the fact that the dairy industry also mainly has thermal processes of the raw material and processes related to the controlled transport of fluids, especially milk. Another common element to other productions is the maintenance of the cold chain, a fundamental aspect especially in the phase of acquisition of raw materials and in maintaining quality.

TABLE III. MATURITY MODELS BUILT FOR A SPECIFIC INDUSTRY

Sector	Authors	Ref
Banking	Bandara O., Vidanagamachchi K., Wickramarachchi R.	[47]
Smart Agriculture	Büyük A.M., Ateş G., Burghli S., Yılmaz D., Temur G.T., Sivri Ç.	[48]
Clothing	Dal Forno A.J., Bataglini W.V., Steffens F., Ulson de Souza A.A.	[49]
	Dal Forno, A. J., Bataglini, W. V., Steffens, F. Ulson de Souza, A.A.	[50]
Gas & Oil	Duque S.E., El-Thalji I.	[51]
Agri-food	Facchini F., Digiesi S., Mossa G., Mummolo G.	[52]
Service	Kampker A., Frank J., Emonts-Holley R., Jussen P.	[53]
Ceramic	Kellner T., Necas M., Kanak M., Kyncl M., Kyncl J.	[54]
Mining	Merma Y.P.C.	[55]
Equipment	Schroderus J., Lasrado L.A., Menon K., Kärkkäinen H.	[56]
Defence	Bibby L., Dehe B.	[57]
Shipyard	Woo J.H., Zhu H., Lee D.K., Chung H., Jeong Y.	[58]

Some similarities in industrial processes can be found in [30] and [33], tailored to the gas & oil sector and ceramic industry respectively, with analogous issues in terms of heat processing and timing management: however, in the first case the proposed model is focused only on maintenance issues without covering all business and industrial aspects, and the second one is still being developed and appears specifically designed for the ceramic industry.

D. Agri-food and dairies specific issues

Specific problems have emerged over the years in the agri-food industry, depending on the particularity of food production and the matching between quality and high-performance standards: the construction of a tailored model should take into consideration quality and risk in the measurement and evaluation systems, within the agri-food chain. The risks of food contamination, health risks, and many other seasonal factors, represent agri-food industry-specific issues that need to be taken into account with tailored indicators different from those used in the supply chain. Choosing the right measurement tools depends a lot on the type of products and the nature of the problems a researcher intends to address. The literature on supply chain performance measurement systems lacks specific frameworks that meet the performance criteria for agri-food supply chains. This research gap needs to be filled by developing a framework that includes performance measures that embody agri-business. An analytical framework for the performance and risk of the agri-food supply chain is implemented and validated through a study of the New Zealand supply chain. Although the proposed analytical framework is flexible and scalable to evaluate and compare agri-food chains, there could be cases of unreliable data, such as in the case of companies where there is no formal register of their commercial transactions, such as small farmers in developing. The creation of this framework was carried out in 2018 by the studies of Moazzam et al. [59]. Cross-sectional data from around 60 dairy companies were collected through an Internet survey. Before the collection of the main data, semi-structured interviews were conducted with farmers and dairy managers to test the items/questions. During the pilot, it was learned that the information needed to calculate the first metrics (level I and II) was readily available from farmers and farms. However, the information needed to calculate the higher level (level III) metrics was not readily available, without access to confidential company records, which was a limitation of this research. The carried-out research confirms the fact that the performance measurement systems used in agri-food supply chains are complex due to their unique characteristics. There are significant gaps in measurement and their suitability for agri-food supply chains. In particular, existing measurement systems and frameworks do not explicitly emphasize food quality and risk aspects. Research shows that more than 2500 performance indicators are embedded in such performance measurement systems and frameworks. The extensive review helped identify the specific knowledge gap on food quality and risk measures. The problem related to food quality, quality standards, etc was also analyzed by Zubair & Mufti in 2015 [60]. Their work focused on dairy farms in Pakistan. Thanks to this analysis, 18 risk perspectives in the dairy supply chains were identified, useful for the development of a risk matrix aimed at prioritizing the risk perspectives. In this case, the risk matrix was created through the analysis of the answers obtained from the questionnaire administered to 170 interviewees, obviously belonging to the reference sector. The risks were divided according to the average score, obtained through a Likert scale assessment. Among the first places, we find factors such as competition, product substitution, political problems, and transport problems. This research was conducted in a developing country and risk dynamics may vary in other countries due to variations in regional influencing factors. All issues related to indicators and risk factors need to be considered during data analysis and pre-MM creation and digital assessment within the dairy sector.

IV. Conclusions

The models currently presented, and analyzed in the previous paragraphs, confirm that at the moment there are models that are too general and not suitable for the dairy sector. The models of small companies do not fit all the problems related to the dairy sector while those of large companies are not adaptable. Thus, their potential adoption necessarily requires significant adjustments within the models themselves for the proposed application. The dairy sector, therefore, does not have a specific maturity model even though its production process can, by analogy, recall some sectors that have specific peculiarities linked to precise strategic and positioning choices which can include semi-artisan processing phases. Future research should therefore be firstly focused on the calibration of an MM suitable for the peculiarities of the dairy sector, trying to involve local businesses in such a way as to create ad hoc efficient models for each type of company. Then, the future research stream would include additional case studies to increase the generalizability of the MM and to perform a comprehensive and structured roadmap to assist dairy firms in visualizing their digital path and setting priorities for process optimization. The expected output will be the development of a basic model that can be applied according to company needs, given that within this sector each company has its characteristics.

ACKNOWLEDGMENTS

This work was supported in the framework of the research project "Assessment 4.0 and digital maturity evaluation for the digital transformation of Sardinian dairies" funded by Sardinia Regional Government, project n° F29J21014330002.

V. REFERENCES

[1] Masood, T. and Sonntag, P. (2020). Industry 4.0: Adoption challenges and benefits for SMEs. *Computers in Industry* 121,103261.

[2] Wicaksono, T., Hossain, M.B. and Illés, C.B. (2021). Prioritizing business quality improvement of fresh agri-food smes through open innovation to survive the pandemic: A qfd-based model. *Journal of Open Innovation: Technology, Market, and Complexity*,7.

[3] Ronaghi, M.H. (2021). A blockchain maturity model in agricultural supply chain. *Information Processing in Agriculture*, *8*, 398–408.

[4] Caro, M.P., Ali, M.S., Vecchio, M. and Giaffreda, R. (2018). Blockchain-based traceability in Agri-Food supply chain management: A practical implementation. *2018 IoT Vertical and Topical Summit on Agriculture - Tuscany, IOT*, 1–4.

[5] Zeller, V., Hocken, C. and Stich, V. (2019). Acatech Industrie 4.0 Maturity Index – A Multidimensional Maturity Model. *IFIP International Conference on Advances in Production Management Systems (APMS), Seoul, South Korea*, 105-113

[6] Ganzarain, J. and Errasti, N. (2016). Three Stage Maturity Model in SME's towards Industry 4.0. *Journal of Industrial Engineering and Management*, 9(5), 1119–28.

[7] Gökalp, E. and Martinez, V. (2021). Digital transformation capability maturity model enabling the assessment of industrial manufacturers. *Computers in Industry*, 132, 103522.

[8] Schumacher, A., Nemeth, T. and Sihn, W. (2019). Roadmapping towards industrial digitalization based on an Industry 4.0 maturity model for manufacturing enterprises. *Procedia Cirp*, 79, 409-414.

[9] Melnik, S., Magnotti, M., Butts, C., Putman, C. and Aqlan, F. (2020). Developing a Maturity Model and an Implementation Plan for Industry 4.0 Integration. In *2nd African International Conference on Industrial Engineering and Operations Management, IEOM 2020*, 1695-1707.

[10] De Carolis, A., Macchi, M., Kulvatunyou, B., Brundage, M. P. and Terzi, S. (2017). Maturity models and tools for enabling smart manufacturing systems: comparison and reflections for future developments. In *14th IFIP International Conference on Product Lifecycle Management (PLM), July 2017, Seville, Spain*, 23-35.

[11] De Carolis, A., Macchi, M., Negri, E., Terzi, S. (2017). A maturity model for assessing the digital readiness of manufacturing companies. In *IFIP WG 5.7 International Conference on Advances in Production Management Systems (APMS). The Path to Intelligent, Collaborative and Sustainable Manufacturing, September 2017, Hamburg, Germany*, 13-20.

[12] De Carolis, A., Macchi, M., Negri, E. and Terzi, S. (2017). Guiding manufacturing companies towards digitalization a methodology for supporting manufacturing companies in defining their digitalization roadmap. In *2017 IEEE International Conference on Engineering, Technology, and Innovation (ICE/ITMC)*, 487-495.

[13] Felippes, B., da Silva, I., Barbalho, S., Adam, T., Heine, I. and Schmitt, R. (2022). 3D-CUBE readiness model for industry 4.0: technological, organizational, and process maturity enablers. *Production & Manufacturing Research*, 10(1), 875-937.

[14] Canetta, L., Barni, A. and Montini, E. (2018). Development of a digitalization maturity model for the manufacturing sector. In *2018 IEEE International Conference on Engineering, Technology, and Innovation (ICE/ITMC)*, 1-7.

[15] Schumacher, A., Erol, S. and Sihn, W. (2016). A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises. *Procedia Cirp*, 52, 161-166.

[16] Ünal, C., Sungur, C. and Yildirim, H. (2022). Application of the Maturity Model in Industrial Corporations. *Sustainability*, 14(15), 9478

[17] Bastos, A., Sguario Coelho De Andrade, M.L., Dias Santos, M.M., De Freitas Rocha Loures, E. and Yoshino, R.T. (2021). Readiness assessment method based on the reference architecture model for industry 4.0-RAMI 4.0. Master's Thesis. Universidade Tecnológica Federal do Paraná

[18] dos Santos, V.A. and Ramos, L.F.P. (2020). Lean & Industry 4.0 integration: proposed roadmap to assess maturity and select new technologies. In: *American Society for Engineering Manage, editor. International Annual Conference of the American Society for Engineering Management*, 1–10.

[19] Bretz, L., Klinkner, F., Kandler, M., Shun, Y. and Lanza, G. (2022). The eco maturity model–a human-centered industry 4.0 maturity model. *Procedia CIRP*, 106, 90-95

[20] Leyh, C., Bley, K., Schäffer, T. and Forstenhäusler, S. (2016). SIMMI 4.0-a maturity model for classifying the enterprise-wide it and software landscape focusing on Industry 4.0. In *Federated Conference on Computer Science and Information Systems (FedCSIS), September 2016, Gdansk, Poland*, 1297-1302.

[21] Facchini, F., Digiesi, S. and Pinto, L.F.R. (2022). Implementation of I4.0 technologies in production systems: opportunities and limits in the digital transformation. *Procedia Computer Science*, 200, 1705-1714.

[22] Maisiri, W., and van Dyk, L. (2020). Industry 4.0 competence maturity model design requirements: A systematic mapping review. In *2020 IFEES World Engineering Education Forum-Global Engineering Deans Council (WEEF-GEDC)*, 1-6.

[23] Xia, Q., Jiang, C., Yang, C., Zheng, X., Pan, X., Shuai, Y. and Yuan, S. (2019). A method towards smart manufacturing capabilities and performance measurement. *Procedia Manufacturing*, 39, 851-858

[24] Amaral, A. and Peças, P. (2021). A framework for assessing manufacturing SMEs Industry 4.0 maturity. *Applied Sciences*, 11(13), 6127.

[25] Amaral, A., Jorge, D. and Peças, P. (2019). Small medium enterprises and industry 4.0: Current models' ineptitude and the proposal of a methodology to successfully implement industry 4.0 in small medium enterprises. *Procedia Manufacturing*, 41, 1103–10.

[26] Kırmızı, M. and Kocaoglu, B. (2022). Digital transformation maturity model development framework based on design science: case studies in manufacturing industry. *Journal of Manufacturing Technology Management*, 33, 1319–46.

[27] Lichblau, K., Sicht, V., Bertenrth, R., Blum, M., Bleider, M., Millack, A., Schmitt, K., Schmitz, E. and Schroeter, M. (2015). IMPULS - Industrie 4.0 Readiness, 0–77.

[28] Azevedo, A. and Santiago, S.B. (2019). Design of an Assessment Industry 4.0 Maturity Model: An application to manufacturing company. In *Proceedings of the International Conference on Industrial Engineering and Operations Management, Toronto, Canada*, 23-25.

[29] Tonelli, F., Demartini, M., Loleo, A. and Testa C. (2016). A novel methodology for manufacturing firms value modeling and mapping to improve operational performance in the industry 4.0 era. *Procedia CIRP*, 57, 122-127.

[30] Çınar, Z.M., Zeeshan, Q. and Korhan, O. (2021). A framework for industry 4.0 readiness and maturity of smart

manufacturing enterprises: a case study. *Sustainability*, 13(12), 6659.

[31] Widmer, N., Hassan, A. and Monticolo, D. (2022). Assessment Model to Support the Technological Integration within Industrial Companies in the Context of Industry 4.0. In *IEEE 28th International Conference on Engineering, Technology and Innovation (ICE/ITMC) & 31st International Association For Management of Technology (IAMOT) Joint Conference, June 2022*, 1-6.

[32] Honorato, C. and de Melo, F.C.L. (2022). Industry 4.0: the case-study of a global supply chain company. In *Towards Sustainable Customization: Bridging Smart Products and Manufacturing Systems: Proceedings of the 8th Changeable, Agile, Reconfigurable and Virtual Production Conference (CARV2021) and the 10th World Mass Customization & Personalization Conference (MCPC2021), Aalborg, Denmark, 2021*, 8, 483-498.

[33] Wagire, A.A., Joshi, R., Rathore, A.P.S. and Jain, R. (2021). Development of maturity model for assessing the implementation of Industry 4.0: learning from theory and practice. *Production Planning & Control*, 32(8), 603-622.

[34] Ramanathan, K. and Samaranayake, P. (2022). Assessing Industry 4.0 readiness in manufacturing: a self-diagnostic framework and an illustrative case study. *Journal of Manufacturing Technology Management*, 33(3), 468-488.

[35] Santos, R.C. and Martinho, J.L. (2020). An Industry 4.0 maturity model proposal. *Journal of Manufacturing Technology Management*, 31, 1023–43.

[36] Mittal, S., Romero, D. and Wuest, T. (2018). Towards a smart manufacturing maturity model for SMEs (SM3E). In *Advances in Production Management Systems. Smart Manufacturing for Industry 4.0: IFIP WG 5.7 International Conference, APMS 2018, Seoul, Korea, Proceedings, Part II*, 155-163.

[37] Brozzi, R., Riedl, M. and Matta, D. (2021). Key readiness indicators to assess the digital level of manufacturing SMEs. *Procedia CIRP*, 96, 201-206.

[38] Ávila-Bohórquez, J.H. and Gil Herrera, R.D.J. (2022). Proposal and validation of an industry 4.0 maturity model for SMEs. *Journal of Industrial Engineering and Management*, 15(3), 433-454.

[39] Castelo-Branco, I., Oliveira, T., Simões-Coelho, P., Portugal, J. and Filipe, I. (2022). Measuring the fourth industrial revolution through the Industry 4.0 lens: The relevance of resources, capabilities and the value chain. *Computers in Industry*, 138, 103639.

[40] Castro, H.F., Carvalho, A.R.F., Leal, F. and Gouveia, H. (2020). Importance of maturity assessments in promoting adoption of I4. 0 concepts in SMEs. In *Industry 4.0–Shaping The Future of The Digital World*, 35-40.

[41] Chonsawat, N. and Sopadang, A. (2019). The development of the maturity model to evaluate the smart SMEs 4.0 readiness. In *Proceedings of the international conference on industrial engineering and operations management*, *Bangkok, Thailand, March 2019*, 354-363.

[42] Chonsawat, N. and Sopadang, A. (2021). Smart SMEs 4.0 Maturity Model to Evaluate the Readiness of SMEs Implementing Industry 4.0. *Chiang Mai University Journal of Natural Sciences*, 20, 1–13.

[43] Pan Nogueras, M.L., Perea Muñoz, L., Cosentino, J.P. and Suarez Anzorena, D. (2022). RAISE 4.0: A Readiness Assessment Instrument Aimed at Raising SMEs to Industry 4.0 Starting Levels–an Empirical Field Study. In *Towards Sustainable Customization: Bridging Smart Products and Manufacturing Systems. Proceedings of the 8th Changeable, Agile, Reconfigurable and Virtual Production Conference (CARV2021) and the 10th World Mass Customization & Personalization Conference (MCPC2021), Aalborg, Denmark, 2021*, 8, 713-720.

[44] Perea Muñoz, L., Pan Nogueras, M. L. and Suarez Anzorena, D. (2022). An 'End to End' Methodological Framework to Assist SMEs in the Industry 4.0 Journey from a Sectoral Perspective-an Empirical Study in the Oil and Gas Sector. In *Towards Sustainable Customization: Bridging Smart Products and Manufacturing Systems: Proceedings of the 8th Changeable, Agile, Reconfigurable and Virtual Production Conference (CARV2021) and the 10th World Mass Customization & Personalization Conference (MCPC2021), Aalborg, Denmark, 2021*, 8, 705-712.

[45] Pirola, F., Cimini, C. and Pinto, R. (2020). Digital readiness assessment of Italian SMEs: a case-study research. *Journal of Manufacturing Technology Management*, 31(5), 1045-1083.

[46] Rahamaddulla, S.R.B., Leman, Z., Baharudin, B.T.H.T.B. and Ahmad, S.A. (2021). Conceptualizing Smart Manufacturing Readiness-Maturity Model for Small and Medium Enterprise (SME) in Malaysia. *Sustainability*,13, 9793.

[47] Bandara, O., Vidanagamachchi, K. and Wickramarachchi, R. (2019). A model for assessing maturity of industry 4.0 in the banking sector. In *Proceedings of the International Conference on Industrial Engineering and Operations Management Bangkok, Thailand, March 2017*, 1141-1150.

[48] Büyük, A.M., Ateş, G., Burghli, S., Yılmaz, D., Temur, G. T. and Sivri, Ç. (2021). Digital Maturity Assessment Model for Smart Agriculture. In *Digital Conversion on the Way to Industry 4.0: Selected Papers from ISPR2020, Turkey, 2020*, 289-301.

[49] Dal Forno, A.J., Bataglini, W.V., Steffens, F. and Ulson de Souza, A.A. (2023). Maturity model tool to diagnose Industry 4.0 in the clothing industry. *Journal of Fashion Marketing and Management: An International Journal*, 27(2), 201-219.

[50] Dal Forno, A.J., Bataglini, W.V., Steffens, F. and Ulson de Souza A.A. (2023). Industry 4.0 in textile and apparel sector: a systematic literature review. *Research Journal of Textile and Apparel*, 27, 95–117.

[51] Duque, S.E. and El-Thalji, I. (2020). Intelligent maintenance maturity of offshore oil and gas platform: A customized assessment model complies with Industry 4.0 vision. In *Engineering Assets and Public Infrastructures in the Age of Digitalization: Proceedings of the 13th World Congress on Engineering Asset Management*, 653-663.

[52] Boenzi, F., Digiesi, S., Mossa, G., Mummolo, G. and Romano V.A. (2015). Modelling workforce aging in job rotation problems. *IFAC-PapersOnLine*, 48(3), 604–9.

[53] Kampker, A., Frank, J., Emonts-Holley, R. and Jussen, P. (2018). Development of maturity levels for agile industrial service companies. *Advances in Production Management Systems. Smart Manufacturing for Industry 4.0: IFIP WG 5.7 International Conference, APMS 2018, Seoul, Korea, August 2018, Proceedings, Part II*, 11-19.

[54] Kellner, T., Necas, M., Kanak, M., Kyncl, M. and Kyncl, J. (2020). Assessment of readiness for Industry 4.0 implementation in ceramic industry. *Manufacturing Technology*, 20(6), 763-770.

[55] Merma, Y.P.C. (2019). Modelo de Madurez del Computer Integrated Mining (CIMG) Aplicado a la Gran Minería a Tajo Abierto del Perú: Estudio de Casos.

[56] Schroderus, J., Lasrado, L.A., Menon, K. and Kärkkäinen, H. (2022). Towards a pay-per-X maturity model for equipment manufacturing companies. *Procedia Computer Science*, 196, 226-234.

[57] Bibby, L. and Dehe, B. (2018). Defining and assessing industry 4.0 maturity levels – case of the defence sector. *Production Planning & Control*, 29, 1030–43.

[58] Woo, J.H., Zhu, H., Lee, D.K. and Chung, H. (2021). Assessment Framework of Smart Shipyard Maturity Level via Data Envelopment Analysis. *Sustainability*, 13, 1964.

[59] Moazzam, M., Akhtar, P., Garnevska, E. and Marr, N.E. (2018). Measuring agri-food supply chain performance and risk through a new analytical framework: a case study of New Zealand dairy. *Production Planning & Control*, 29(15), 1258-1274.

[60] Zubair, M., and Mufti, N. A. (2015). Identification and assessment of supply chain risks associated with dairy products sector. *Journal of Basic & Applied Sciences*, 11, 167.