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The interplay between industry 4.0 maturity of manufacturing processes and performance measurement and management in SMEs

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Abstract

Purpose – This paper proposes an SME oriented Industry 4.0 maturity framework to explore the interplay between manufacturing processes, performance measurement system and management practices (PMM). Given that the fourth industrial revolution, famously referred to as Industry 4.0, is a new paradigm for manufacturing firms, it is crucial to know the 'as-is' state or maturity of SMEs' manufacturing processes and link it with their PMM. Despite the availability of numerous maturity models, no previous study has tried to link the maturity of manufacturing processes with performance measurement and management.

Design/methodology/approach – Due to the exploratory nature of the study and the lack of theoretical base for Industry 4.0 maturity and PMM interaction, especially in the SME context, a multiple case study approach has been adopted due to its robustness and effectiveness under such circumstances.

Findings – There is a strong interplay between the maturity of manufacturing processes and PMM. The firms that have invested in their manufacturing processes have also developed performance measurements. Overall, performance measurement is more developed than performance management practices.

Originality/value – The characteristics of the interplay between the maturity of manufacturing processes and PMM are summarized in three main propositions. Moreover, the study provides practitioners with an assessment framework to help SMEs evaluate the current state of their manufacturing processes and PMM to highlight the areas of improvement towards the I4.0 expedition.

Keywords SMEs, Industry 4.0, Maturity assessment, Performance measurement and management

Paper type Research paper

1. Introduction

The manufacturing industries worldwide are experiencing a dramatic change due to alleged 'Industry 4.0' (I4.0). The term 'Industry 4.0' represents 'the fourth industrial revolution' and the strategic plan describing the impact of emerging technologies on maintaining the competitiveness in manufacturing (Kagermann *et al.*, 2013). A working group mandated by the Research Union Economy-Science of the German Ministry of Education and Research first presented this idea at the Hanover Fair in 2011. The elementary characteristics of I4.0 are process integration, real-time information transparency, a virtual representation of the real-world, autonomy and higher process integration within and across the firm's boundaries (Culot *et al.*, 2020). The commonest expectations from I4.0 are associated with higher flexibility and productivity (Culot *et al.*, 2020). But to reap the benefits, existing research

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(Bititci *et al.*, 2012; Nudurupati *et al.*, 2021) has emphasized developing performance measurement and management practices aligned with the dynamic business context characterized by novel business models and environmental issues, especially for small and medium enterprises (SMEs). Nudurupati *et al.* (2021), in particular, identified five key trends in this context and predominantly focused on the first, namely 'emerging technologies' (in line with the idea of I4.0) and argued that I4.0 requires a revision of the way organisations are measuring and managing performances.

Coping with the requirement of I4.0 can be challenging for many firms. Nevertheless, it offers numerous opportunities for both multinational firms and small and medium enterprises (Sommer, 2015; Moeuf *et al.*, 2020). Compared to SMEs, the driving forces of I4.0 are higher, and barriers are lower for multinational firms (Horváth and Szabó, 2019). But the financial performance and innovation benefits are prominent for SMEs (Lin *et al.*, 2019). These firms are the backbone and play a key role in several manufacturing economies (Schiersch, 2013). They represent over 99% of the European firms (European Commission, 2011) and 95% in the OECD member states (OECD, 2019). SMEs provided two-thirds of the total employment in the private sector and have created almost 85% of the new job in the EU (Commission, 2018). Therefore, their relevance is significant in the wake of I4.0. Industrial European countries like Germany, Italy, the UK and France have already accepted Industry 4.0 with particular initiatives. For example, according to the Italian Ministry of Economic Development (MISE, 2018), the investment in the machinery and equipment sector in 2017 reached 13%, increasing almost 11% from last year. Recent research shows that 18% of Italian companies have completed I4.0 related implementation projects, and another 19% are going through the execution process (Chiarini *et al.*, 2020). Although I4.0 seems to be the dawn of a new era for the European manufacturing sector, SMEs struggle to adopt modern technologies and production techniques in general (Sommer, 2015; Veza *et al.*, 2015; Schröder, 2017; Wuest *et al.*, 2018; Harris *et al.*, 2019). Due to its complexity, lack of unanimity and numerous technological components (Chiarello *et al.*, 2018), firms struggle to understand the idea of I4.0 (Bibby and Dehe, 2018; Ghobakhloo, 2018). "SMEs know that something has to be done, but they do not know how and where to start" (Eisert, 2014).

In light of this competitive and dynamic landscape of I4.0, recent studies have highlighted the critical role of performance measurement and measurement in adapting to the I4.0 scenario and fully exploiting their potential (Raffoni *et al.*, 2018; Nudurupati *et al.*, 2021; Sarti *et al.*, 2020). It is widely recognised that PMM would bring improvements in the form of efficiency and effectiveness in organisations (Neely, 1999), and digital technologies and tools are having a significant impact on performance measurement and performance management tools. I4.0 is not about a solo breakthrough invention. Instead, on the one hand, it involves numerous tech components evolving into new enabling technologies through mutual combination and convergence (Drath and Horch, 2014). On the other hand, the impact of the adoption of I4.0 technologies on organisational control of a firm (in terms of technical and social controls) and the alignment between the technological and organisational changes to achieve and sustain performance is not well-understood (Smith and Bititci, 2017; Nudurupati *et al.*, 2021; Sardi *et al.*, 2020). As highlighted by recent studies, the changes needed in softer people practices of performance measurement and management are insufficiently investigated, particularly in SMEs (Raffoni *et al.*, 2018; Sardi *et al.*, 2019; Nudurupati *et al.*, 2021).

Agreement on representative constructs and corresponding measurements is vital for a theoretically reliable approach to understanding I4.0 and driving its benefits. The research on assessment tools like maturity models and readiness indexes has made some preliminary efforts in this direction (Culot *et al.*, 2020). Several maturity models and assessment tools have been introduced by both academics and practitioners alike (Basl and Doucek, 2019). But very few of them are specifically developed for an SME context (Mittal *et al.*, 2018a). Additionally, none of the existing studies considers the link between the maturity of the manufacturing operations and organisational control in terms of technical and social controls (Smith and Bititci, 2017) as a way to track the relationship between the adoption of I4.0 technologies and the development of sustainable organisational practices (Biegler *et al.*, 2018; Nudurupati *et al.*, 2021).

To fill this gap, we aim to propose an assessment framework to help SMEs evaluate the current state of their manufacturing processes and their interplay with the PMM to highlight the areas of improvement towards the I4.0 expedition. The first segment of the framework consists of five manufacturing-related operations, namely product design and engineering, production management, quality management, maintenance management and supply chain management. The second part of the proposed framework addresses the PMM of firms considering the two main dimensions of organizational control: technical controls, that is rational and structural elements related to the performance measurement practices and social controls, that is, behavioural and cultural aspects of the firms impacting on how performance information is used.

2. Literature review

During the adoption of I4.0, SMEs encounter challenges like availability of trained technicians (Pinto *et al.*, 2019), absence of adequate digitisation facilities (Peillon and Dubruc, 2019), lack of intention to adopt digital technologies (Sommer, 2015) and lack of resources and skills inside the enterprises (Rauch *et al.*, 2017; Goerzig and Bauernhansl, 2018; Moeuf *et al.*, 2020). As the competencies of firm progress via several maturing phases (Kohlegger *et al.*, 2009), assessing their maturity is a topic of great attention in the age of I4.0. Oxford Dictionary (Stevenson, 2010) defines maturity as ‘the state, fact, or period of being mature’. Recognising the ‘as-is’ or maturity state of a process concerning I4.0 can help guide a firm through the maturing stages of transformation. Additionally, as highlighted by Bourne *et al.* (2018) and Bititci *et al.* (2012), performance measurement literature has evolved from what to measure (i.e., performance measurement) towards how to use these measures to manage the performance of organisations (i.e., performance management). To foreground salient manufacturing processes and create a link between their maturity and PMM, the following subsections present the contemporary literature on the assessment and maturity models developed especially for SMEs and the relevance of PMM in light of I4.0.

2.1 SME oriented industry 4.0 maturity models

We followed a systematic literature review approach to conduct a comprehensive review of the I4.0 maturity models explicitly developed for SMEs to identify dimensions related to manufacturing processes. To find the relevant literature, we searched Scopus until April 2020. We used the following keywords: “Industry 4.0” or “Industrie 4.0” or “smart factory” or “smart manufacturing” and “SME” or “small and medium” and “maturity model” or “readiness” or “assessment” or “index”. This search produced 66 articles in the first step. To conduct abstract scrutiny and the detailed paper reviews, authors then applied three exclusion and inclusion criteria, that is article has a maturity model, is SME oriented and is in the I4.0 context. This review helped identify 17 articles that either had a maturity model or some sort of maturity assessment of SMEs. Only 10 of these studies had a maturity or readiness assessment model, which featured both technology and/or organisational dimensions.

Table 1 contains a summary of these models. It shows that the most frequently used dimensions are ‘strategy’, ‘human resource’, ‘product’, ‘manufacturing’/‘production’ and ‘technology’. ‘Strategy’ and ‘human resource’ are part of seven models, ‘product’ is included in six studies and five authors consider ‘manufacturing’/‘production’ and ‘technology’ each. The frequent repetition of the dimension ‘product’ and ‘manufacturing’ or ‘production’ hints at the importance of these aspects of an enterprise. It is fair to argue that the maturity of product and operations related to its manufacturing are critical for SMEs to excel in and relish the benefits of I4.0. Other than manufacturing/production, there are generic dimensions like ‘processes’

Authors dimensions	Bittighofer *et al.* (2018)	Chonsawat (2019)	Trotta and Garengo (2019)	Hamidi *et al.* (2018)	Kolla *et al.* (2019)	Mittal *et al.* (2018b)	Modrak *et al.* (2019)	Pinto *et al.* (2019)	Sheen and Yang (2018)	Puchan *et al.* (2018)
Manufacturing/ Production	✓	✓	✓				✓			✓
Technology	✓	✓	✓		✓			✓		
Product	✓		✓	✓	✓	✓				✓
Strategy		✓	✓	✓	✓	✓		✓	✓	
Process	✓					✓		✓		
Human resource		✓	✓	✓	✓	✓		✓		✓
Operations				✓	✓					
Smart factory				✓					✓	
Maturity levels	Six	Five	Five	Six	–	Five	–	–	Five	Five
Focus of Model	Practitioners' perspective	Readiness evaluation	Maturity scale	Maturity assessment	Lean and Industry 4.0 assessment	Maturity model	Readiness assessment and roadmap	Digital readiness level	Readiness assessment	Maturity assessment

Table 1.
SME oriented Industry 4.0 maturity and assessment models

(Bittighofer *et al.*, 2018; Kolla *et al.*, 2019; Pirola *et al.*, 2019), operations (Hamidi *et al.*, 2018; Kolla *et al.*, 2019) and smart factory (Hamidi *et al.*, 2018; Sheen and Yang, 2018). But no specific dimension other than ‘smart logistics’ (Modrak *et al.*, 2019) addresses manufacturing-related activities.

To keep it concise, we excluded all such dimensions from Table 1, which appeared only once. The excluded dimensions were smart devices and steering and control (Bittighofer *et al.*, 2018), digital support (Chonsawat and Sopadang, 2019), data-driven services (Hamidi *et al.*, 2018), customers, leadership, suppliers and culture (Kolla *et al.*, 2019), finance (Mittal *et al.*, 2018b), smart logistics and organisational and managerial models (Modrak *et al.*, 2019), integration (Pirola *et al.*, 2019) and key elements (Puchan *et al.*, 2018).

Most authors have developed their models, while some studies (Bittighofer *et al.*, 2018; Hamidi *et al.*, 2018) adopt the models developed by practitioners and consulting firms like.

Gimélec - Industrie 4.0, IMPULSE and Rüßmann *et al.* (2015). The number of dimensions in the existing models ranges from a minimum of two up to nine. Sheen and Yang (2018) have the simplest models with two dimensions, whereas Kolla *et al.* (2019) propose nine dimensions based on their literature review. Most models have featured five or six dimensions measured on five or six maturity levels. An interesting observation here is that the criteria to assess SME’s maturity and dimensions to be evaluated hinges on authors’ perception and understating of I4.0. Interestingly, all the models in Table 1 were developed during 2018 and 2019. Only one study (Pirola *et al.*, 2019) is published in a journal, whereas the remaining nine are in conference proceedings. It indicates the novelty of the field and the room for improvement of SMEs focused I4.0 maturity framework. Another significant gap in the prevailing maturity models is that none of the studies has attempted to link the proposed maturity dimensions and the organisational control dimensions. This highlights scant attention to the management and understanding of the sustainability of the I4.0 investment.

2.2 Performance measurement and management

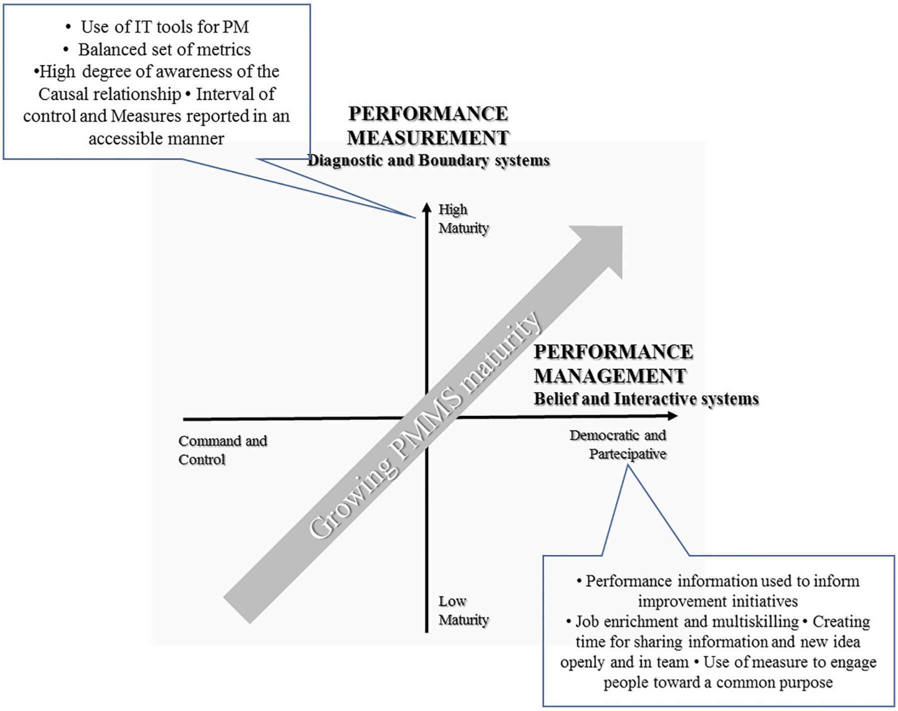
Since the publication of the seminal book titled ‘Relevance Lost: The Rise and Fall of Management Accounting’ by Johnson and Kaplan (1987), numerous researchers and practitioners have investigated performance measurement and management as essential to implement firm strategy, promoting innovation, firm’s performance leveraging on effective organisational control (Neely, 1999; Nudurupati *et al.*, 2011; Bititci, 2015; Bititci *et al.*, 2018). Numerous studies of the theoretical foundation of PMM identify two complementary dimensions of organisational control named technical and social control (Child, 1973; Ouchi, 1979; Cardinal *et al.*, 2004; Tessier and Otley, 2012). Technical control pertains to rational, bureaucratic and structural elements of the organization and, consequently, performance measurement practices. Social control refers to the organisation’s cultural and behavioural aspects that impact performance management practices using performance information (Smith and Bititci, 2017).

Performance measurement literature has evolved from *what to me*asure (i.e., performance measurement) towards *how to use these measures* to manage the performance of organisations (i.e., performance management) (Bititci *et al.*, 2012; Bourne *et al.*, 2018). Earlier studies focused on what to measure, paying particular attention to performance measurement in general and performance measurement systems in particular (see, for instance, Neely, 1999; Melnyk *et al.*, 2014). Performance management refers to the use of performance measurement systems for managing the performance of an organisation (Bititci, 2015), and it should be complementary to performance measurement. Measuring performance alone is insufficient to improve performance and therefore underlines the necessity for performance management to effectively manage an enterprise (Melnyk *et al.*, 2014).

Researchers have highlighted the significant role of operations management in general and performance measurement and measurement in particular (Nudurupati *et al.*, 2016; Raffoni *et al.*, 2018) to adapt to this new competitive and dynamic I4.0 landscape. On the one hand, digital technologies and tools have a growing impact on performance management practices. On the other hand, the changes needed in softer people practices of performance management cannot be ignored.

Organisational management control and performance measurement theories have highlighted that social and technical controls should be considered simultaneously to improve company efficiency and effectiveness in the new business environment (Bititci *et al.*, 2012; Tessier and Otley, 2012). Consequently, to implement and properly use performance measurement system and performance management practices, an organisation should effectively balance the structural characteristic of performance measurement systems (i.e., what we measure) and the development of effective performance management practices (i.e., how we use these measures). Smith and Bititci (2017) synthesize this concept in the conceptual framework shown in Figure 1 that also include Simons' (1995) four levers of control (Belief systems, Interactive systems, Diagnostic systems and Boundary systems). Using this framework, PMM maturity can be described as a combination of performance measurement (or technical control) maturity and performance management (or social control) maturity. The first levels range from low maturity (or basic) to high maturity (or diagnostic) (Wettstein and Kueng, 2002; Speckbacher *et al.*, 2003; Van Aken *et al.*, 2005; Garengo, 2009). The second level can be described as a continuum of practices spanning command and control to democratic and participative management (for additional information, see Smith and Bititci, 2017).

The effective implementation and use of PMM is recognized as essential for managing the processes innovation promoted by I4.0 and improving organisational and process performance (Melnyk *et al.*, 2014; Nudurupati *et al.*, 2021). Research acclaims that organisations managed through measures perform better (Bititci *et al.*, 2011). However, SMEs rarely develop a PMM due to the lack of managerial skills, financial resources and human resources (Garengo, 2009;



Source(s): Smith and Bititci, 2017 (Adapted)

Figure 1. Conceptual framework with dimensions typifying PMMS

Sardi *et al.*, 2021). Commonly, in these companies, the technical excellence in products and operational processes is perceived as the only critical factor and insufficient attention is given to the managerial activities (Garengo *et al.*, 2005). In recent years, the changes in the business scenario are creating new opportunities for SMEs (Nudurupati *et al.*, 2021), and there is a growing need for further development of social control and major intangible asset for PMM improvement, particularly in SMEs (Jardioui *et al.*, 2019; Sardi *et al.*, 2019, 2021). At the same time, recent IT innovations offer substantial opportunities for SMEs as they require limited use of financial and human resources (Haug *et al.*, 2020).

Based on the above premises, this paper investigates the interplay between the maturity of manufacturing processes and the PMM in SMEs investing in I4.0 technologies. In particular, the research aim at answering the following question;

RQ. In the context of Industry 4.0, how does the maturity of SMEs' manufacturing processes interplay with performance measurement system and performance management practices –(PMM)? How could these be improved?

3. Research design for the development of industry 4.0 maturity framework

To analyse the interplay between PMM and maturity of the manufacturing processes and propose a framework, we needed to identify suitable manufacturing-related processes. Regarding PMM maturity, we used Smith and Bititci (2017) framework (Figure 1) due to its suitability for SMEs and also because it has already been tested in such firms (Jardioui *et al.*, 2019; Sardi *et al.*, 2019, 2021). For the maturity of manufacturing processes in the I4.0 context, the development of a new framework was required. For this, we adopted a stepwise approach based on Hevner *et al.* (2004) and Becker *et al.* (2009) due to their strong theoretical background of design science research. This methodology of developing a framework comprises a multi-methodological style consisting of literature review, comparison of prevailing models, interviews with experts, conceptual design and modelling, testing the developed model and finally, validating the model in real-life application. This methodology follows an iterative approach that helps evaluate, refine and improve the framework. In short, our model was developed in the following steps.

3.1 Review of existing maturity models

We conducted a detailed literature review of existing maturity models and compared the dimensions and maturity levels used by them (section 2.1, Table 1). The identified models are thoroughly analysed and compared for their utility for manufacturing SMEs in terms of the model's complexity and applicability. The literature review helped us develop an inventory of the most frequently used dimensions in the existing maturity models. As presented in Table 1, the most commonly used dimensions are 'strategy', 'human resource', 'manufacturing'/'production', 'product' and 'technology'. These dimensions were later used to complement the discussion with our experts, consultants and researchers' panel. This detailed review helped us identify the structural components necessary to build a maturity framework like assessment method (qualitative or quantitative), mode of assessment (external or self-assessment), dimensions (two in the simplest model and nine in the most complex one), maturity levels (1 being lowest and 5 or 6 being highest maturity) and presentation style (numerical or graphical or both).

3.2 Expert interviews

Apart from the literature review, for triangulation, we held interviews with experts' panel comprising six consultants and three researchers to identify the key dimensions which characterised I4.0 maturity in manufacturing SMEs. To ensure the importance and relevance for SMEs, we shared and discussed the dimensions highlighted by the literature with the group of experts, consultants and researchers. Although the experts agreed on the importance of frequently used dimensions pooled up from the literature review, they disputed their relevance for a maturity model developed specifically for manufacturing SMEs. Considering the limited resources and higher costs for SMEs in implementing broader changes, the focused group and experts contended to restrict the dimensions closely related to the manufacturing processes. The input was in line with the literature as ‘product’ and manufacturing/production were among the recurrent maturity dimensions. This research focuses on the firms that have invested in I4.0 technologies; experts unanimously excluded the ‘strategy’ dimension as it was implicitly incorporated in the research setting. ‘Human resource’ was part of the performance management and therefore was deemed redundant in this section and therefore was not recommended as a separate dimension in maturity analysis. After several iterations, consultants and academic experts proposed the five most relevant manufacturing dimensions: design and engineering, production management, quality management, maintenance management and supply chain management.

3.3 Development of model structure

With the help of the triangulation method, we developed the structure of our maturity framework, including maturity dimensions, items to measure these dimensions and maturity levels. A refined maturity assessment framework was proposed based on the insights from the literature, interaction and discussion sessions with industry experts, consultants and academicians, on the manufacturing processes and their sub-processes. A case study approach was adopted to test the developed framework, and two SMEs were involved in testing the usability and usefulness of the model.

3.4 Testing and implementation of maturity framework

Finally, the proposed model is tested in a real-life setting, and the feedback regarding its practicability is collected. The group of experts was also engaged during framework testing on two SMEs. All the comments and difficulties in the understanding framework by the users and the practitioners were recorded and used to improve the usability of the initial version of the model. The improved version of the framework is then empirically tested and applied in 12 SMEs involved in this study.

4. Proposed maturity and PMM framework

The first part of our proposed framework is related to the maturity of the most significant manufacturing dimensions identified using the above methodology. The recognized dimensions were five manufacturing-related processes, that is, design and engineering, production management, quality management, maintenance management and supply chain management. For each of the five investigated processes, PMM maturity was assessed. Using Smith and Bititci (2017)’s conceptual framework, data was collected considering eight main dimensions, four for performance measurement, that is use of IT tools, balanced set of measures, causal relationship, the interval of control and four for performance management, that is performance information for improvement initiatives, job enrichment and multi-skilling, openly share information, measures for engaging. The existing models in the literature have used five or six maturity levels. We follow the accepted and tested norms and include six maturity levels in our framework. The framework assesses the maturity of the proposed dimensions on six maturity levels divided into four categories: Table 2 lists all the dimensions and sample measurement items and questions. Table 3 consists of the maturity levels of the framework.

Company	No of employees	Revenue (million €)	Core business activity	Strengths	Industry 4.0 oriented initiatives	
C1	21	4.15	Metal sheet products	Customer orientation Cost competitiveness	Digitisation of the production process to improve quality and delivery time	Small-sized firms
C2	25	6.07	Prototyping and production of slewing cranes' components	Research and development	Digitisation of operations, specially design process	
C3	26	1.60	Cold rolling mill	Relationship with suppliers and distributors	Detailed overhauling and digitisation to meet customers' needs	
C4	31	27.50	Interior design and furniture	Lean manufacturing	Digital monitoring of quality management	
C5	33	6.303	Dental products	Quality of the finished products	Transformation phase of digitising design and production processes	
C6	39	4.10	B2B mechanical machining	Use of design and engineering software	Digitised order acquisition and processing	
C7	60	6.01	manufacture and assembly of precision components	Standardisation of operations	Digitisation of product, quality and maintenance	Medium-sized firms
C8	55	13.09	Decorative and composite panels and furniture	Product range	Planning to digitise production line	
C9	75	26.87	Semi-continuous agri-food processes	Control over manufacturing process Knowledge base of lean manufacturing	Automation and digitisation of processes to reduce cost	
C10	90	20.44	Production of packaging and metal closures	Market leader Range of products and materials	integration with katana engineering software in production and assembly phase	
C11	140	46.45	Water treatment	Market leader Cross-functional design development Technological solution and services	Implemented a complete dematerialisation process to eliminate paper procedures	
C12	142	18.39	Mixer sinks, ovens and hoods for domestic kitchens	Operational excellence Long term with suppliers and customers	Investment of € 2.3 million in I4.0 plants	

Table 2.
Profile summary of SMEs

Dimension	Sample of measurement items	Sample question
Manufacturing dimensions		
Design and engineering	Kaizen	With Industry 4.0 technologies, the quality of new product development projects is measured and shows continuous improvement
Production management	Production planning	The production planning system is Industry 4.0 oriented
Quality management	Types of control	The quality controls have been defined and carried out according to Industry 4.0 strategy
Maintenance management	Department interaction	The maintenance department is virtually connected with the production department
Supply chain management	Demand planning	Digital applications are used to support the demand planning process
Performance measurement dimensions		
Use of IT tools	BI software	Does the company use BI software? How is used for performance measurement?
Balanced set of measures	Processes indicator	Could you list the most relevant indicators related to the manufacturing process?
Causal relationship	Horizontal Relationships	How do you investigate the relationship between the performance of the manufacturing process?
Interval of control	Performance review	How often do you review the manufacturing performance report?
Performance management dimensions		
Improvement initiatives	Improvement plan	Do you use performance information to design improvement plans?
Job enrichment and multi-skilling	Training (on the job)	How are employees acquiring the new competencies required by process digitalization?
Information sharing	Performance meeting	Is the information on performance shared in periodic departmental meetings?
Measures for engaging	Job engagement	Which measure do you use to favour engagement to engage people towards a common purpose?

Table 3. Dimensions of maturity framework, samples of measurement items and questions

The maturity of each dimension and the overall firm was calculated by taking the average scores of the maturity levels identified for each dimension.

4.1 Methodology

Due to the exploratory nature of this study, a qualitative research design involving multiple case studies was adopted to answer the research questions (Meredith, 1998; Eisenhardt and Graebner, 2007). Multiple case studies are considered one of the most powerful strategies for inductive research (Voss *et al.*, 2002; Eisenhardt and Graebner, 2007). This approach is particularly appropriate due to the distinct lack of research exploring the relationship between I4.0 manufacturing processes and PMM maturity (Barratt *et al.*, 2011). On the one hand, the studies on I4.0 and PMM are in their early research stages, particularly in the SME context. On the other hand, case studies are described as a robust and appropriate methodology when theoretical bases are not consolidated (Eisenhardt, 1989; Meredith, 1998; Voss *et al.*, 2002; Yin, 2017). Moreover, several authors describe case studies as a proper method for understanding the dynamics of an entire process and evaluating this process in its natural context (Meredith, 1998; Barnes, 2001; Eisenhardt, 1989; Voss *et al.*, 2002; Yin, 2017).

The unit of analysis in our study was SME. In total, 12 SMEs were involved in this research. Table 2 presents a brief profile of each of the 12 SMEs of this study. To define both the characteristics of the population from which the research sample was drawn and the boundaries for the transferability of the findings (Eisenhardt, 1989; Yin, 2017), the investigated SMEs were identified using the criteria below. SMEs;

- Employing between 20 and 250 employees. Micro-companies and small enterprises with fewer than ten people were excluded because of the diversity of their organisational complexity (Storey, 1994; Garengo *et al.*, 2005). Combining this definition with the EU definition, we could split the companies into two groups; six small enterprises (i.e. having up to 50 employees and €10 million turnovers) and six medium-sized enterprises (i.e. having up to 250 employees and €50 million turnovers).
- Operating in the manufacturing sector. Service companies were not included in the study as scholars and practitioners have highlighted their different approaches in facing both performance measurement and management and I4.0 (Garengo *et al.*, 2005)
- Implementing at least three of the nine I4.0 technologies (Rüßmann *et al.*, 2015) during the last five years.
- Involved by industrial SME associations in I4.0 competitions as they started smart I4.0 projects in the last three years.

4.2 Data collection

Two separate and independent approaches were used to collect and analyse data. First, two consultants and a researcher conducted business reviews with each company individually. Researchers and consultants were experts in the field of I4.0 and SMEs. These reviews helped the panel apprehend SMEs' understandings of the idea of I4.0 and the implementation of I4.0 oriented strategies. This exercise helped ensure the suitability and the alignment of the selected SMEs with the scope of this study. As the literature suggests that I4.0 is a difficult and broader concept to grasp easily, especially by SMEs, the consultants and the researcher explored whether the practices explained by the SMEs as I4.0 oriented actually fell in the I4.0 domain or not. These reviews were critical to ensuring that the maturities we calculated were related to manufacturing processes in the I4.0 context. They then used the identified maturity self-assessment framework to evaluate five dimensions of maturity framework and eight PMM dimensions. To ensure consistency and repeatability, they used a predefined protocol to conduct the initial semi-structured face-to-face interviews of approximately two hours to collect information from senior management teams. It allowed creating a welcoming environment to talk freely about the investigated issues. An additional research person joined the group to analyse data and write a company report.

Three to six management team members were involved in collecting data required by the maturity assessment of PMM and the five processes. This required two half-day workshops with the management teams (typically the managing director/general manager and the managers of the investigated processes). Additional supporting data related to businesses was collected in the form of internal reports and media publications. The results of the maturity assessments were then presented to the management teams to validate the scores of each item and the overall maturity (Eisenhardt, 1989; Miles and Huberman, 1994).

The PMM was assessed considering the eight dimensions shown in Figure 1. The six points Likert scale, '1' for absence and '6' fully portrayed (Smith and Bititci, 2017; Sardi *et al.*, 2019), for the maturity assessment, a six-point Liker scale, '1' for unaware '6' for digitally intelligent, is adopted to record the responses. The maturity dimensions of the framework, the measurement items and questions are presented in Table 3.

4.3 Calculating the maturity scores

Along with the overall maturity of an organization, it is imperative to measure the maturity of each dimension separately since each dimension has a different level of contribution in the

I4.0 maturity measurement. The maturity score of each dimension and the overall firm is measured in the following step.

Each maturity dimension has several items. The responses against each item are separately recorded from the respondent firm. The members of the research team assessed each score and discussed it together. In the case of discrepancies between the assessments, the average of the values was calculated. At the end of the process, scores were validated with at least two informants for each company. The maturity score of each dimension was calculated by taking the average of the responses of its measurement items. The calculated scores are then used to describe the maturity of each dimension and the overall firm.

4.4 Industry 4.0 maturity levels

The calculated maturity scores are ascribed to different maturity levels and categories presented in Table 4. Based on the six maturity levels, the interviewed firm can show different levels of I4.0 aspirations ranging from maturity 'Level 1' of unaware to 'Level 6' as digitally intelligent. In terms of categories, a firm can be classified as 'insufficient' if it is barely aware of I4.0 related technologies but does not have the required infrastructure to support I4.0 implementation and execution. The highest category is the expert and is ascribed to a firm whose maturity ranges from digitally connected to digitally intelligent, meaning that the required infrastructure is in place and the proper implementation of I4.0 strategies has been achieved.

5. Findings

This section presents in detail the results of the interplay between manufacturing processes maturity and PMM of one SME and a summary of all 12 SMEs involved in this study.

As an example, we report the analysis of a case C12. As synthesized in Table 4, it is a medium-sized firm that employs 142 people and has a revenue of over € 18 million. It produces mixer sinks, ovens and hoods for domestic kitchens. It has adopted a lean approach in the organisation of the business and pursuits operational excellence with an efficiency that support long-term partnerships with customers and suppliers. Since 2017, C12 has invested more than € 2.3 million in I4.0 based plants. For the five identified manufacturing and eight PMM dimensions of the I4.0 maturity framework, we assess the maturity score of each constitutive activity (see Figure 2).

Dimension-wise maturity scores indicate that the overall maturity of the firm exhibited with an orange line, and an average score of 4 falls in the 'experienced' category. The highest maturity score for the case firm is 4.9, and the lowest is 2.7. C12 is relatively well equipped and established in two dimensions; design and engineering and supply chain management with a maturity score of 4.9, whereas it lacks maintenance management and falls in the 'insufficient' category (2.7). Our proposed I4.0 maturity framework has helped indicate the points of concern and the opportunities for improvement for C12. For example, the maturity score of

Maturity levels	Description	Maturity levels and categorizations
1	Unaware	$1 \leq$ Maturity <3 Insufficient
2	Aware	$3 \leq$ Maturity <3.5 Established
3	Aware but not ready	$3.5 \leq$ Maturity <5 Experienced
4	Digital ready	$5 \leq$ Maturity ≤ 6 Expert
5	Digitally connected	
6	Digitally intelligent	

Table 4. Industry 4.0 maturity levels

Figure 2.
Maturity of manufacturing processes and PMM in C12. (a): Industry 4.0 maturity scores of manufacturing dimension. (b): Performance measurement and performance management

nearly 5 shows that C12 is doing well and is nearing expert level in design and engineering and supply chain dimensions. But it is not performing that well in production management (3.7) and quality management (3.7) as it is near the lower bound of being experienced. Overall, C12 has nearly achieved the ‘expert’ level of maturity in 2 dimensions and experienced maturity level in 2 others. These results are substantiated by the fact that C12 has an investment worth € 2.3 million in I4.0 plants. Additionally, one of the strengths of C12 is the strong relationship with its suppliers, which ultimately translates into the highest average score of 4.9 for supply chain management among five maturity dimensions.

Alongside supply chain management, C12 also scores the highest maturity in design and engineering dimension (4.9). One attribution of I4.0 technologies is developing and producing otherwise tricky and complicated products. C12 specialises in home decor, which usually requires very personalised designs and products. Massive investments might have boosted the firm's ability to cater to a broader customer base by developing customised products. The firm seems to be still in the learning phase of operating I4.0 plants and has yet to gain quality management and production management, especially in maintenance management. It is worth noticing that investment in I4.0 technologies does not automatically increase a firm's I4.0 opportunities. Instead, the alignment between other components, especially human resource training, is crucial in extracting the benefits from these technologies.

The second part of the proposed I4.0 maturity framework addresses performance measurement and management in five manufacturing dimensions of SMEs. The radar chart in Figure 2(b) presents the results of eight PMM dimensions (4 for performance measurement and 4 for performance management) for C12. The dark green line represents performance measurement, and the light green represents performance management. It is interesting to note that the shape of the performance measurement radar chart is very similar to that of manufacturing dimensions' maturity. The highest performance measurement value (5) is for design and engineering, followed by supply chain management (4.7), quality management (3.8), production management (3.8) and maintenance management (2.6). The hierarchy of values and the shape of the radar chart of performance management follows a similar trend but with relatively lower values. Design and engineering have the highest performance management value (4.8) and second-best is for the supply chain management (3.9). All the remaining dimensions, that is production management, quality management and maintenance management, score the same and are very low (2.8).

These results are very intriguing in several ways. First, a similar trend but different magnitude shows an interplay between the maturity of manufacturing dimensions and PMM. Especially, the radar chart of manufacturing maturity and performance measurement are almost identical. It means that the improvement in one can cause a similar change in the other. For example, if a firm's manufacturing operations mature in the I4.0 context, it is more likely to take its performance measurement initiatives seriously to keep itself competitive. It shows a powerful interplay between the PMM and I4.0 maturity of manufacturing dimensions. Secondly, the four dimensions of performance management also scored the highest for design and engineering (4.8), followed by a comparatively lower score for supply chain management (3.9) and the lowest for maintenance management (2.8). Performance management values in production and quality management are lagging by a considerable margin, that is. 2.8 for both production and quality management, which are 3.7 and 3.8 for maturity dimensions and performance measurement, respectively. Although C12 has made a decent effort in developing its performance measurement system, it has not advanced in pursuing a performance management system.

It can be concluded here that C12 does give attention to its performance measurement, but it is not addressing all the dimensions with similar intensity. A very similar trend between maturity dimensions and performance could be due to the lack of trained and skilled workers. As human resources cannot utilise the new I4.0 plant to its maximum utility due to lack of training and technical knowledge, the benchmark for measuring the performance is missing. That is why C12 is not able to differentiate between what it has achieved and what it can achieve. Additionally, even if the firm is putting efforts into measuring its performance, it will be less valuable if it does not take enough initiative to use the gathered information to manage its performance.

To provide an overview of all the SMEs of this study, Tables 5 and 6 respectively presents the summary values of manufacturing dimensions' maturity and PMM. Moreover, during the study of the cases, additional qualitative empirical evidence was collected on the maturity of

Company Name	Design and engineering	Production management	Quality management	Maintenance	Supply chain management	Average	
C1	4.20	3.30	3.50	3.10	3.20	**3.46**	Small-sized firms
C2	3.36	2.45	2.61	2.33	2.80	**2.71**	
C3	3.91	3.32	3.39	2.91	3.70	**3.45**	
C4	3.70	3.50	3.10	2.90	3.80	**3.40**	
C5	3.00	2.55	2.88	2.50	2.78	**2.74**	
C6	2.40	2.60	2.40	2.60	2.40	**2.48**	
C7	4.40	4.40	4.30	3.80	4.10	**4.20**	Medium-sized firms
C8	3.09	3.38	3.50	3.10	3.44	**3.30**	
C9	3.90	4.20	4.00	3.90	4.10	**4.02**	
C10	4.00	3.90	3.10	3.00	3.30	**3.48**	
C11	4.40	3.30	4.20	3.30	3.20	**3.70**	
C12	4.9	3.7	3.7	2.7	4.9	**4.00**	

Note(s): Insufficient (Red): 1 ≤ Maturity < 3; Established (Yellow): 3 ≤ Maturity < 3.5; Experienced (green) 3.5 ≤ Maturity < 5

Table 5.
I4.0 maturity of manufacturing processes of the 12 SMEs

		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	average
		Small-sized firms						Medium-sized firms						
Performance measurement	Design and eng. *	4.25	3.00	4.00	3.75	3.25	2.50	4.25	3.00	3.93	4.25	4.25	4.95	**3.79**
	Production mng.**	3.18	2.09	3.38	3.36	2.64	2.86	4.29	3.66	4.07	4.45	3.11	3.79	**3.40**
	Quality mng.	3.63	2.50	3.29	3.41	3.26	2.55	**4.19**	**3.59**	2.96	3.22	4.21	3.75	**3.38**
	Maintenance mng	3.00	1.25	2.88	3.03	2.50	2.50	3.88	3.25	4.38	3.00	3.13	2.63	**2.95**
	SCM ***	3.13	2.68	3.30	3.90	2.15	2.31	3.68	3.10	3.63	3.67	3.23	4.70	**3.29**
	average	**3.44**	**2.30**	**3.37**	**3.49**	**2.76**	**2.54**	**4.05**	**3.32**	**3.79**	**3.72**	**3.58**	**3.97**	
Performance management	Design and.	4.25	4.00	3.25	3.50	2.25	2.25	4.75	3.25	3.96	4.00	4.25	4.75	**3.75**
	Production mng.	3.00	2.75	2.75	2.88	2.00	2.63	4.38	3.13	4.00	2.38	2.88	2.75	**2.96**
	Quality mng.	3.06	2.38	2.88	2.89	2.23	2.05	4.03	3.57	3.50	3.00	3.82	2.75	**3.01**
	Maintenance mng.	3.03	2.75	3.00	2.31	2.13	2.40	3.70	3.03	3.00	3.00	3.25	2.75	**2.86**
	SCM	3.06	2.18	2.18	3.44	2.57	1.99	3.53	2.61	4.75	3.22	2.50	3.88	**2.99**
	average	**3.28**	**2.81**	**2.81**	**3.00**	**2.24**	**2.26**	**4.08**	**3.12**	**3.38**	**3.34**	**3.12**	**3.84**	

*engineering **management ***supply chain management

Note(s): Insufficient (Red): 1 ≤ Maturity < 3; Established (Yellow): 3 ≤ Maturity < 3.5; Experienced (green) 3.5 ≤ Maturity < 5

Table 6.
Performance measurement and management in I4.0 manufacturing processes' maturity

manufacturing processes and PMM and their evolution. Table 7 shows an extract of some quotes that help the understanding of the evolutionary trend of the digitalization of the manufacturing processes and PMM.

	Performance measurement	Performance management
Design and engineering	"The Design and Engineering processes are managed using high performing product design software (as solidworks) that are common to other production companies . . .. A product configurator named Siemens Rulestream further automates engineering processes . . .. **plenty of data are available but we are not able to use these data** to plan improvement actions . . ." (C4)	"The level of digitization is uneven and where the activities have been undertaken they are in any case at a basic level. Design and engineering is an exception. Here we have a competitive advantage as a **motivated team uses advanced technologies** that allow integration with suppliers and good control over performance." (C2)
	"After the digitalization of the design and engineering **process,** data abounded in our department, but we did not know what to do with them . . . we had to **redefine our objective** and structure data collection and analysis before going on." (C3)	"Initially even if we introduced a new PMS we could **not achieve our objectives** (such as increase sales, reduce internal operating costs, improve delivery times for customized products . . .) due to the **wrong use of the performance data** . . .. our managers adopted a command and control approach that obstruct the teamworking and the sharing if information . . . people did understand the new objectives as they were not rightly explained to them" (C3)
Production management	"The main objective of our production process is the achievement of efficiency and quality combined with the shortest possible delivery time. To guarantee these objectives, **firstly numerous design and production activities have been digitalized then** to eliminate any possible execution errors, guarantee the repetition of series production, **performance data were integrated into the overall PMS**. Without this integration, we could not properly analyse data and use them for improvement" (C1)	"Our company has recently carried out several digitization interventions of particular importance, especially in the areas of design, production and quality management . . .. we have a high degree of standardization of the various production operations which allows the homogeneous control of each production operation onboard each machine . . .. .thank you the use of advanced and innovative technologies the performance information of the production management are well integrated into the PMS and available to all the employees for control of operations and decision making . . .. **this require a couple of years** and a couple of coaching projects to change company culture. Now several of our managers adopt a participative approach that favour information sharing, job enrichment and multi-skilling of our employees" (C7)
	"The tools for managing production flows are not advanced, particularly the production scheduling system which currently does not consider the finite capacity of the plants and the association of the plants themselves with the skilled labour force. This fact implies that the most important parameters of the production process can only be analysed in the final balance and with specific manual *a posteriori* analyses. We **need to improve the digitalization of the process and then we plan a new PMS, but we lack resources to manage this . . . we did a recruitment campaign to recruit skilled employees but there are few skilled employees on the market and they are engaged by larger companies** " (C2)	"In the production department, the use of paper is reduced to a minimum. All the main information are digitalized and ad hoc software provide information on performance at all stages of production and assembly processes. A year later the lunch of the I4.0 project we started to work also to a new PMS. In a few months, the new PMS was planned but the lead-time is still too high . . .. to achieve our objective **we should not work only on the manufacturing process and PMS design . . .. we need to enrich our soft skills** . . .. We are trying to push the person to share information and develop multi-skilling, but these changes require more time than the simple implementation of new digital technology " (C11)
	"Important investments must be evaluated to integrate tools into the flow that are currently being tackled mainly based on experience. In particular, we know the need to develop a value analysis, a set of tools for better digital integration between different areas, especially that of production and logistics, the need for rescheduling of production, a guide to interventions on production processes by anticipating the exit of critical quality parameters from the set control thresholds . . ..but to manage these issue we needed a new PMS supporting data collection, data analysis (C10)	"The company is developing internally an ad-hoc technology for production control that allows the digitally revamping of its machines and workstations. The custom solution should guarantee flexibility to employees. **Reliable data are required for** favouring **decision-making autonomy and empowerment** shortly" (C8)
Quality management	"The processes relating to the product area and quality management have had a homogeneous development under the aspect of the introduction of digital technologies thank the introduction of BI software. We collect plenty of data on performance and we use it to identify improvement areas . . . suitable data support the casual relationship analysis and they drive our improvement plans. **After an information crisis due to information overload, the performance data has been integrated into an overall PMS,** however much needs to be done to change people's behaviour in their use of data. " (C6)	"Particular attention is dedicated to the management of any customer complaints. We collect electronically many performance information to verify that the corrective actions have given the required results and to update all the information necessary to ensure that the problem encountered no longer occurs. **However, we do not have the culture of date. People do not share information they use it to defend their position"** (C1) "Our a company that has been able to seize the opportunity of digitalization processes not only in the production area but also in the other areas from which we collect plenty of data . . ..**we have some difficulty in managing data properly due to the lack in data culture and people knowledge**" (C2)

(*continued*)

Table 7. Extract of the interviewee's quotes

	Performance measurement	Performance management
Maintenance	The maintenance process, while making use of competent support from the plant suppliers, is not optimal in terms of fault analysis and remote surveillance. These elements are particularly important to ensure optimal process efficiency as the company aims to maximize unmanned production activities to ensure product and delivery tenders. **However, our data are not completely integrated into an overall PMS** and this obstructs the effective digitalization of the process" (C1) "Important investments must be evaluated to integrate tools into the flow that are currently being tackled mainly based on experience. In particular, we started to develop a value analysis, a set of tools for better digital integration between different areas, especially that of production and logistics, the rescheduling of production, a guide to interventions on production processes by anticipating the exit of critical quality parameters from the set control thresholds, a guide to maintenance interventions connected to spare parts management, also considering the use of sensors aimed at controlling critical plant components . . .. **we are facing some difficulties doing all this because we do not have a PMS yet**" (C10) "We must introduce tools and processes that facilitate the analysis of the amount of data managed on the performance of the processes to address the main improvement actions, but given our small size we do not have the necessary resources (both human and financial)" C4	"The use of big data are favouring act towards predictive and other optimization functions, however, we have still not enough knowledge on data analysis . . ..we have plenty of data but **people still struggle in sharing information and/or use them to activate improvement processes"** (C9) Our product has been enriched with functions and applications related to the electronics on the machine that allow interconnection of the same, but we have not enough skilled persons to manage properly remote maintenance process as people are not able to manage huge amount of data . . .. **These data are not helping us they are creating problems for us …. we do not have enough time to manage data …. We changed our recruitment process to engaged skilled employees but we had not enough time and money to manage it properly "**C6 "A mention of merit should be addressed to the new codification of maintenance operations and the monitoring of the operator's skills by digitized supports . . .. **Good management is improved by the adoption of an employee's oriented policy** of typical "lean" inspiration" (C7) "Downstream of the database collection, the introduction of predictive maintenance could consolidate the leadership position on the market. However, **we faced some difficulty in managing performance due to the lack of data analytics knowledge**" (C10)
Supply chain management	"We have recently purchased a new software that represents the first key step towards the digitization of our manufacturing process that encompasses design, production, product quality and the key steps of the supply chain . . .. .**we could think about PMM only after the digitalization process will be completed**" (C4) "The Plant Manager was fundamental for the digitization of the production areas and in the supply chain to"pull "the flow even more. He highlighted that attention must be paid to a deeper integration of the different areas along with the entire flow of the Supply Chain value chain to monitor production efficiency thanks to new tools for detecting bottlenecks and performance. Machines to integrate more efficiently with the new target group. But to manage this change it is **now necessary to invest in data analysis and create an adequate PMS, but we do not know how we can manage it as we do not have skilled persons** " (C9) Thanks to the competencies developed in the treatment of big data, and its **subsequent integration into the PMS**, the quality is constantly monitored throughout the supply chain also with the support of lean logic.(C4)	"We digitalized several key processes, we have plenty of data integrated into the overall PMA and now we are engaging of a new manager for digital transformation today almost entirely entrusted to the logistic manager. Until now the focus was on data, at this stage, to increase digital development we need to focus on people . . .. The logistic manager has a too **command and control approac**h to further drive the digital transformation (C9) "The further digitalization of the SCM represents one of the next development projects of the company without significant investments, but we **need to create time for sharing information and promote engagement**" (C11) "To overcome the lack in the digitalization of SCM we need to e**ngage a enhance skills for digital transformation** by perhaps resorting to a temporary manager in the industrial information systems area" (C6) "Almost all our main processes have a high digitalization, the supply chain management should be improved especially on the organizational front, but we do not **have skilled persons and they struggle to work as a team**" (C11) "A current project aims primarily at completing the digitization for all the manufacturing process leveraging on human resource training and performance management project . . ..we have a good PMS, but we need to further improve how people use the plenty of data available. Above all, **we need to introduce new managerial processes that facilitate the analysis of the amount of data managed** and the sharing of ideas" (C7)

Table 7.

As shown in Table 5, the medium-sized SMEs fare much better than the small-sized SMEs. Considering the medium value of the investigated processes, none of the small-sized SMEs has managed to make it to the 'experienced' category. In contrast, four medium firms have maturity scores close to or more than 4. The design and engineering dimension is the most developed process. At the same time, maintenance is the most neglected process, so that among all 12 firms, only C7 and C9 scored 3.8 and 3.9, respectively, but in most of the investigated cases, SMEs score just over or less than 3. Despite a mixed trend in production management and quality management, medium-sized firms appear more mature than small ones. Surprisingly, supply chain management is reasonably mature in two small SMEs.

Although none of them has a maturity value greater than four, and the outlook of medium firms is more promising, three small firms also produced values on the higher side of 3 (C1, C3 and C4). Based on the average maturity values of all five manufacturing dimensions, four firms can be categorised as 'experienced', five 'established' and three 'insufficient'.

Table 6 is related to the PMM section of our proposed I4.0 maturity framework for SMEs' manufacturing processes. Some key observations can be made from this table. In smaller SMEs, the maturity of performance measurement of the manufacturing processes is moving in the same direction as the maturity of digitalization of the manufacturing processes themselves. Company C2, C5 and C6 were positioned as 'insufficient' in the I4.0 maturity assessment, and here, these three firms score even lower and remain insufficient concerning performance measurement. Regarding performance management, four small SMEs fall under the three maturity level, whereas the remaining two also scored less than their maturity level and performance measurement. For medium-sized firms, there is a much better trend in the PMM values. For the performance measurement, there are 4 out of 5 at the level of 'experienced' level and only one firm at the 'established' level. The scenario worsens if we look at performance management. There are only two 'experience' firms and the other three 'established' here. However, even here, the scenario is much better than the smaller firms.

6. Discussion and conclusion

As shown by the empirical findings, the maturity level of the five investigated manufacturing processes is highly consistent with the maturity level of PMM enacted for measurement and management processes themselves. The companies with the highest score in the manufacturing processes also have the highest PMM maturity (see C7, C9, C11, C12). Design and engineering is the most mature manufacturing process in the investigated companies and the most mature regarding PMM. At the same time, the maintenance process has the lowest level of maturity and the lowest level of PMM maturity (Tables 5 and 6). Nevertheless, the empirical investigation shows a temporal misalignment between the maturity of manufacturing processes and the development of PMM. Tables 5 and 6 highlight the fact that the PMM maturity is lower than the manufacturing processes in the investigated processes. This further confirms a previous study that highlights how technical excellence in operational processes is perceived as the most relevant factor in SMEs, and less attention is given to managerial processes such as performance measurement and management (Garengo *et al.*, 2005). All the 12 SMEs perceived the digitalization of manufacturing processes as essential to compete in the current business environment, and they initially focused their attention on such processes.

In the early stage of the I4.0 projects, all the SMEs' efforts focused on increasing the digitalization of the manufacturing process. Later on, they perceive the relevance of proper use of the data available. Most of them had to face the problem of data overload. The quick introduction of new high-performing technology made a massive amount of data available. And the organization had to face absences of skills in data analytics, lacks knowledge on how to use data and shortages of plans on how to integrate data in the overall company performance measurement system (see Table 7). The fact that the availability of big "unstructured" data - that is not organized in such a way as to support the decision-making process adequately - hinders good management is not a new matter. Pascale (1999) describes that the importance of organizational development and the managerial system is emphasized by improvement in the technology of processes. Garengo and Bernardi (2007) pointed out that adopting new technology in managing processes often leads to increased managerial complexity. As a consequence, the development of a performance measurement system is favoured. The PMS implementation and use enhance the capacity to acquire, distribute, interpret and store knowledge to support decision-making and promote organizational learning. Moreover, SMEs usually behave in a reactive approach to improve managerial processes. Traditionally these firms have not developed their operational systems simultaneously with organizational capability (Harvey and Jones, 1992).

These pieces of evidence could be synthesized in the proposition below:

P1. In the context of Industry 4.0, the maturity of manufacturing processes is strictly related to the maturity of performance measurement system and performance management practices, even if their evolution is not concomitant. The digitalization of manufacturing processes requires improvement in the performance measurement system and facilitates its development.

Established that change in the manufacturing process pushes the development of performance measurement system, the role of performance management practices cannot be ignored for very long. In all the investigated processes, the medium score of performance measurement is higher than the performance management one (Tables 5 and 6). As highlighted by recent literature, the purpose of performance measures and the motivation behind their use greatly influence manufacturing processes and the performance outcomes of organizations (Koufteros *et al.*, 2014). In other words, in the investigated cases, after the first development of the manufacturing processes and PMS (technical control), attention moves to performance management practices (social control).

Some recent research highlights that measuring performance is necessary but not enough to improve performance, stating the relevance of performance management practices (Smith and Bititci, 2017; Bourne *et al.*, 2018; Franco-Santos *et al.*, 2012). When performance measurement systems become more mature, there is a tendency for technical control to dominate over social control, becoming less personal, more focused on the performance data and less effective, with a negative impact on performance. Hence the need to improve performance management practices to increase motivation, involvement, empowerment, teamwork, etc (Smith and Bititci, 2017; Bourne *et al.*, 2018; Sardi *et al.*, 2021).

The data collected during the empirical study show that the increase in participative and democratic approaches in the investigated organisations is not the engine of change but an implicit consequence of the digitalization of the operational processes (Table 7). The change in the manufacturing process makes SMEs perceive firstly the potential of data to support decision-making and secondly the lack of managerial approaches consistent with the new business context. The delay in the development of performance measurement practices is mainly due to the lack of knowledge and culture of data (Smith and Bititci, 2017; Bourne *et al.*, 2018; Sardi *et al.*, 2021). As shown in Table 7, performance measurement practices for improving motivation, empowerment and teamwork are not enough exploited. This negatively affects the development of both performance measurement and digitalization of the manufacturing process.

These pieces of evidence could be synthesized in the proposition below:

P2. The change in the manufacturing processes promotes firstly the improvement of the performance measurement system and, subsequently, underlines the need to develop democratic and participative performance management practices.

The empirical data highlight a clear difference between small and medium firms (Tables 5 and 6). The SMEs dimension influences the development of manufacturing processes and PMM maturity. The firms with the highest revenue and/or the number of employees demonstrated higher levels of maturity across all processes as well as demonstrating a higher maturity PMM around these processes. This further confirms the strong influence of the companies dimensions on the development of managerial practices, also due to the lack of financial and human resources available (Garengo *et al.*, 2005; Fuller-Love, 2006; Sardi *et al.*, 2021).

I4.0 would appear to have the capacity to allow a range of routine tasks to be done by automation and digitalization, but a new specialised and skilled workforce is required. The acquisition of new competencies and skills required by new technology is one of the main problems highlighted both by literature (Carmeli *et al.*, 2009) and this empirical research. The introduction of new HRM policies that attract and retain skilled workers are required (Carmeli *et al.*, 2009) and introduced in some of the investigated organizations. However, currently, the market is high demanding skilled workers, and bigger firms are more attractive for highly skilled employees. Moreover, while technical skills and methodological skills are considered as being important for Industry 4.0, social skills and personal skills are higher demanding and specific investments (financial and human) are necessary for their development (Maisiri *et al.*, 2019; Sardi *et al.*, 2021). The investigated SMEs have a lack of financial and human resources, and employees are mainly focused on manufacturing activities, as often happens when investing in the development of SMEs manufacturing processes (Garengo *et al.*, 2005). Moreover, Industry 4.0 requires teamwork, communication and sharing of idea to support innovation (Wood and Wall, 2007). Still, once again, they are not adequately developed in the investigated SMEs due to a lack of resources and a suitable managerial approach. This could summarise in the proposition below.

P3. The smaller the firms, the lower the efficiency of investments in the digitalization of production processes due to their delay in adopting participatory and democratic performance management practices.

To conclude, this research makes practical and theoretical contributions to the field of PMM. In developing these contributions, a maturity model and three propositions have emerged from the discussions, with implications to theory and practice. Having studied the complex nature of the interplay between digitalization of manufacturing process, performance measurement system and performance management practices, our main theoretical implication is that the interaction and relationship between these concepts should be considered to support Industry 4.0 projects effectively. Failing to do so is likely to provide incomplete insights and potentially.

From a practical perspective, the paper identifies an assessment framework to help SMEs in evaluating the current state of their manufacturing processes and PMM to highlight the areas of improvement towards the I4.0 expedition. Secondly, it shows the need to properly manage the interplay between manufacturing processes and PMM, reducing the gap between changes in the manufacturing processes and improvement in performance measurement system and performance management practices. In era 4.0, the effective management of I4.0 projects requires overcoming the delay in the development of PMM that currently characterize SMEs.

Concerning limitations, our findings are based on case studies. Additional longitudinal research could be useful to understand further the role of each dimension in the interplay between PMM, manufacturing processes and company performance considering 3 to 5 years. The longitudinal study will allow a better investigation of the misalignment between the development of managerial process, performance measurement system and performance management practices.

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