The industrial management of SMEs in the era of Industry 4.0

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Industry 4.0 provides new paradigms for the industrial management of SMEs. Supported by a growing number of new technologies, this concept appears more flexible and less expensive than traditional enterprise information systems such as ERP and MES. However, SMEs find themselves ill-equipped to face these new possibilities regarding their production planning and control functions. This paper presents a literature review of existing applied research covering different Industry 4.0 issues with regard to SMEs. Papers are classified according to a new framework which allows identification of the targeted performance objectives, the required managerial capacities and the selected group of technologies for each selected case. Our results show that SMEs do not exploit all the resources for implementing Industry 4.0 and often limit themselves to the adoption of Cloud Computing and the Internet of Things. Likewise, SMEs seem to have adopted Industry 4.0 concepts only for monitoring industrial processes and there is still absence of real applications in the field of production planning. Finally, our literature review shows that reported Industry 4.0 projects in SMEs remained cost-driven initiatives and there in still no evidence of real business model transformation at this time.

Keywords: production control; Industry 4.0; smart manufacturing; operational improvement; SME; SMB

1. Introduction

The future of SMEs, which are major contributors to most industries and countries (Li et al. 2016), depends largely on their capacity to respond to their clients' expectations while maintaining a competitive advantage on their market. To achieve this, SMEs need to work to constantly improve their industrial management processes, i.e. planning, using resources, controlling production, and measuring and evaluating operational performance (Apics 2005).

Several production planning and control management methods already exist, such as (JIT) *Just-In-Time* stemming from the *Toyota Production System* whose purpose is to synchronise flows via production lines with the flows pulled by the client (Ohno 1988). Although it has proven itself in many factories (Liker 2007; Womack and Daniel 2003), this approach seems too rigid or difficult to apply in SMEs due to a lack of expertise and leadership (Achanga et al. 2006; Moeuf et al. 2016). In a similar manner, MRP (Petroni 2002) and MRPII (McGarrie 1998; Sum and Yang 1993), driven by the deployment of computer tools such as ERP (Deep et al. 2008), are complex and costly methods to implement in SMEs, and can be extremely rigid once installed (Cullinan, Sutton, and Arnold 2010).

More recently, the concept of Industry 4.0 has emerged. However, this concept is complex to define. The German telecommunications association BITKOM reveals more than 100 different definitions of Industry 4.0 (Bidet-Mayer 2016). For instance, Trappey et al. (2016) defined Industry 4.0 as a general concept enabling manufacturing with the elements of tactical intelligence using techniques and technologies such as Internet of things, cloud computing and big data. For Schumacher, Erol, and Sihn (2016), Industry 4.0 refers to recent technological advances where the internet and supporting technologies (e.g. embedded systems) serve as a backbone to integrating physical objects, human actors, intelligent machines, product lines and processes across organisational boundaries to form a new kind of intelligent, networked and agile value chain. The CEFRIO has adopted, based on an extensive literature review, a more global definition by defining Industry 4.0 as a set of initiatives for improving processes, products and services allowing decentralised decisions based on real-time data acquisition (Danjou, Rivest, and Pellerin 2016).

As our goal in this paper is to analyse the production planning and control practices of SMEs, we have limited the scope of our review to the Industry 4.0 definition by Kohler and Weisz (2016) which is *a new approach for controlling production processes by providing real time synchronisation of flows and by enabling the unitary and customised fabrication of products.*

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In all cases, the Industry 4.0 concept is based on the emergence of new technologies such as cloud computing, Internet of things, cyber-physical-systems and big data. Such technologies should improve the transmission of information throughout the entire system, which enables better control and operations to be adapted in real time according to varying demand.

Despite the fact that Industry 4.0 tools may require a large investment and a high level of expertise (Ruessmann et al. 2015), it appears to be more flexible as it decentralises information and decision-making. Such initiatives are therefore more accessible to SMEs. In Europe, SMEs are defined as firms employing fewer than 250 persons and that have a total turnover that does not exceed 50 million euros (European Commission 2008).

Torres (1999) notes that the organisational structure of SMEs is characterised by proximity management, which results in strong involvement of managers in all of the company's decisions. Most SMEs also have a short-term strategy, which prevents significant long-term investments (Mintzberg 1982). In addition, there is a lack of expert support functions in SMEs such as a supply chain manager, information technologies, or financial manager. Unlike large firms, SMEs have lower productivity, higher costs and less on-time delivery performance.

As the business strategy of SMEs is often based on flexibility, reactivity and customer proximity, the Industry 4.0 concept appears appealing with regard to potentially providing a more streamlined flow of information (and thus better planning and control processes). Previous works have shown a limited but positive impact of Industry 4.0 in SME operational performance, with little investment and little expertise when it relates to cloud computing (Radziwon et al. 2014). However, the introduction of new technologies and practices is always risky in SMEs.

Since it is presently the beginning of the Industry 4.0 era, its real benefits and requirements for SMEs are still not fully known. The objective of this paper is to fill part of this gap by conducting an analysis of Industry 4.0 empirical cases reported in the scientific literature that aimed at transforming the production planning and control management processes within SMEs. As such, we propose an analytical framework which aims at classifying the existing research reporting case studies in SMEs. The proposed framework allows identification of the targeted performance objectives, the required managerial capacities and the selected group of technologies for each selected case.

Note that Industry 4.0 concepts may also be applied for transforming the nature of products and services provided by organisations (Porter and Heppelmann 2014). However, the intent of this paper is to focus solely on the impact of Industry 4.0 on the production planning and control functions that is also referred by some researchers to the concept of *Smart Factory* or *Digital Manufacturing*.

The reminder of the paper is organised as follows. First, we present the analysis framework and the strategy used to review the literature. Using the proposed framework, the selected papers are then summarised in Section 4. New paths of research are then discussed in Section 5 before the paper is concluded in Section 6.

2. Analytical framework

Industry 4.0 introduces new possibilities that may disrupt the traditional approach to production planning and control. Porter and Heppelmann (2014) exposed how smart connected objects may transform the current process control system. As such, they demonstrate that different levels of performance may be achieved. In the basic case, setting up simple monitoring tools can help achieve the objectives sought. A large share of Lean Manufacturing JIT initiatives, such as Kanban (Abdul-Nour, Lambert, and Drolet 1998), allow for this type of process to be set up at a low cost. Some objectives nonetheless require the development of more extensive and more sophisticated managerial capacities (Koh and Simpson 2005). As each level of capacity requires different investments and competences, it is essential to classify Industry 4.0 initiatives in terms of the desired performance objective and the corresponding managerial capacity that needs to be put in place.

In addition, the CEFRIO group (2016) demonstrated that Industry 4.0 initiatives can be implemented through various technological groups, such as the Internet of objects, big data or Cloud Computing. Each group of technologies represents different means of implementing the desired capacity. Thus there is a close relationship between the targeted objectives, the levels of managerial capacity sought and the technical resources required to achieve them. Our analytical framework, as shown in Figure 1, illustrates these three elements that were used to guide the analysis of the scientific literature. Each of these elements is described further in the following subsections.

2.1 *Industrial performance objectives*

Operational performance indicators often express a corporate strategy. Raymond (2005) listed the performance indicators that an SME can hope to improve after investing in new technologies: lower costs, improved quality, improved flexibility, improved productivity. Likewise, in his study of new technologies adoption in enterprises, Bayo-Moriones, Billón,

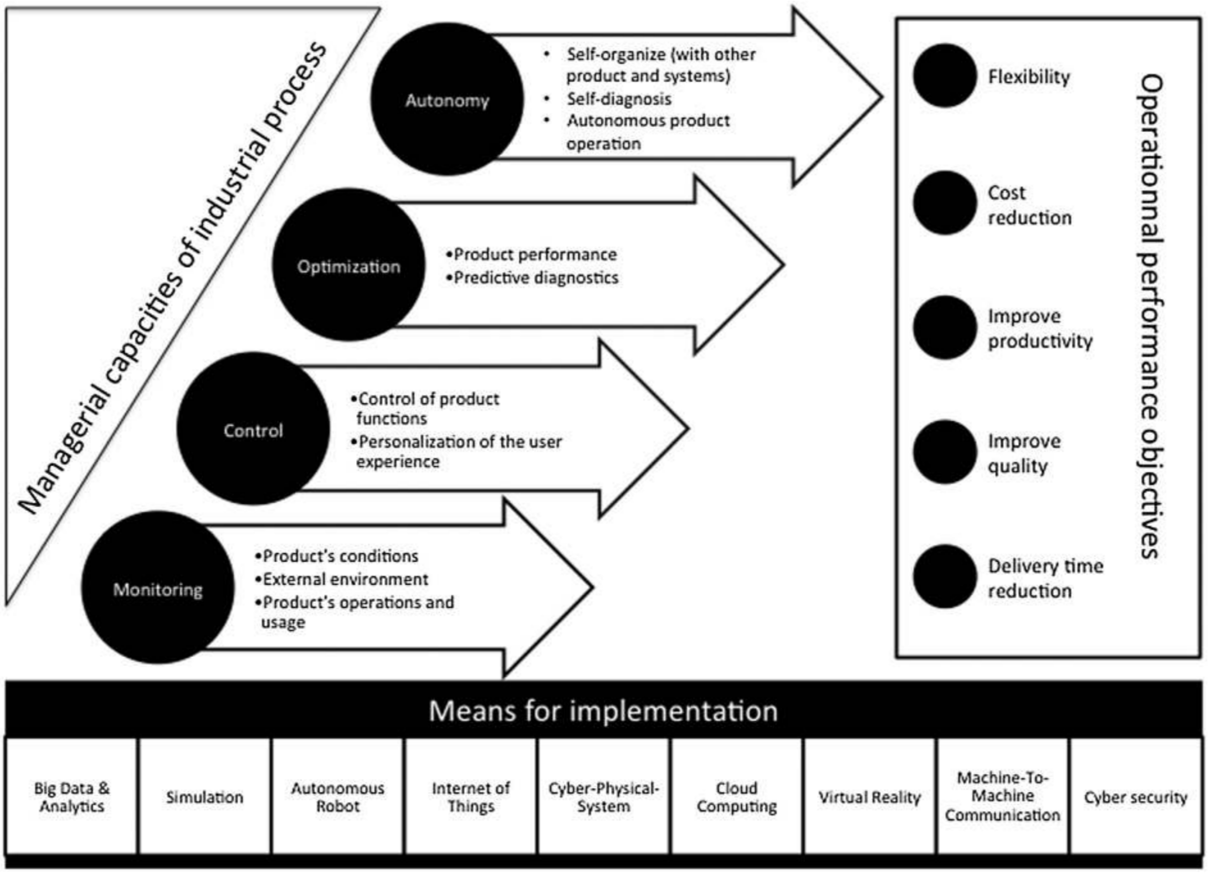

Figure 1. Analytical framework.

and Lera-López (2013) proposed a list of similar indicators with the addition of the criterion of reducing delivery lead times to this list. We therefore use the following performance indicators to measure the imp act of Industry 4.0 on SMEs:

- flexibility;
- costs;
- productivity;
- quality; and
- lead times.

These performance objectives may be obtained by the development of a new set of managerial capacities, which are described in the following subsection.

2.2 *Managerial capacities of industrial processes*

Reaching performance objectives requires specific investments and the use of specific expertise. These efforts will likely result in new managerial and production capacities aligned with the organisation's strategy. As such, we have adapted the works of Porter and Heppelmann (2014), initially proposed for measuring the capacity of new smart connected products and services, to establish a list of four distinct managerial capacities aligned with the concept of Industry 4.0:

- Monitoring: the global monitoring of the production system and its environment can be achieved today by using various connected objects (Wang, Törngren, and Onori 2015). For example, different elements of a production system can issue warnings if a situation changes or if there is an inconsistency in terms of achieved performances. The monitoring function can also take the form of a historical analysis used to clarify decision-making (Segura Velandia et al. 2016).

- Control: based on historical data, the ‘standard’ behaviours of the system and the performance thresholds defined, algorithms can be used to detect situations requiring a decision via an alert (Aruväli, Maass, and Otto 2014). The control therefore demands man–system interaction (Cao et al. 2011).
- Optimisation: using monitoring data, system models and simulation systems, production systems and resources can be optimised in real time (De Ugarte, Pellerin, and Artiba 2011). Furthermore, synchronising all the actors around the value chain can lead to superior performance both locally and over the entire network of partners (Horbach et al. 2011; Mauricio-Moreno et al. 2015).
- Autonomy: monitoring capacities, control and real-time optimisation of current systems can be combined to ensure reach new levels of autonomy (Khalid et al. 2016). Production resources can also act in coordination with other systems. Ultimately, it is now possible to develop systems capable of learning autonomously from their own behaviour and adapting themselves as a function of the results obtained (Bagheri et al. 2015).

All of these levels of managerial capacities can be materialised through the implementation of various technologies, described in the following subsection.

2.3 *The means of realisation for Industry 4.0*

Recent advances and development of new methods and technologies are largely responsible for the emerging popularity of the Industry 4.0 concept and its potential use by SMEs (Danjou, Rivest, and Pellerin 2016). According to Ruessmann et al. (2015), these means can be divided in nine main groups of methods and technologies:

(1) Big data and analytics: multiple tools and techniques are now available for exploiting a large mass of production data. Processing large quantities of data has always been seen as a major challenge for production planning and control functions as well as a necessity for achieving the Industry 4.0 goals (Babiceanu and Seker 2016; Denkena, Schmidt, and Krüger 2014; Kushiro, Matsuda, and Takahara 2014; Rago 2015);

(2) Simulation: the integration of different computer tools allows managers and designers to simulate the performances of all aspects of a production system (Caggiano, Caiazzo, and Teti 2015; Caggiano and Teti 2013; Luo et al. 2011). Modelling tools enable the analysis of product behaviour, production lines performance and multisite network coordination, thus leading to the optimisation of all industrial processes and operations (Azevedo and Almeida 2011; Matsuda, Sudo, and Kimura 2016, 2012; Mehrsai et al. 2014; Veza, Mladineo, and Gjeldum 2015)

(3) Internet of things (IoT): new technologies can now provide communication capabilities to physical objects (Kopacek 2015; Wang, Törngren, and Onori 2015). Real-time communication of physical objects can in turn be exploited to monitor various products and system states in real time and to facilitate the decentralisation of decision-making;

(4) Cyber-physical systems (CPS): these mechanisms permit controlling and monitoring via algorithms directly integrated in the systems and users around them. This allows objects to communicate with their environment and reconfigure in real time in response to new needs (Yue et al. 2015);

(5) Cloud computing: communication and exchange of information can be expanded easily with the use of cloud computing technologies by providing easy means of network connectivity. With reaction time of a few milliseconds and large bandwidths, information sharing across multiple systems and networks in real time can now ensure that data and applications are available everywhere, all the time and from any terminal (Gupta, Seetharaman, and Raj 2013; Wu et al. 2015);

(6) Virtual reality: the availability of data in an embedded system provides new means of information access to users. Smart glasses and other Augmented (AR) and Virtual Reality (VR) technologies are increasingly being used in manufacturing processes. As such, they can be used to simulate an environment containing real and simulated objects that can be used to enhance the design and manufacturing processes (Lee, Han, and Yang 2011);

(7) Cyber security: securing larger numbers of communication channels without reducing the performance of networks is vital for ensuring the deployment of Industry 4.0 strategies (Airehrour, Gutierrez, and Ray 2016);

(8) Collaborative robots: robots and embedded sensor technologies are becoming increasingly flexible, communicative and cooperative (Michniewicz and Reinhart 2014). Connectivity with products and proper collaboration mechanisms with humans will eventually favour the reduction of batch sizes to a single item at a reasonable cost (Caggiano, Caiazzo, and Teti 2015; Constantinescu et al. 2016); and

(9) Machine-To-Machine communication: communication technologies are rapidly growing with the use of a larger number of autonomous machines. Based on standard protocols, this communication mode allows the autonomous management of industrial organisations (Wang et al. 2016).

Recognising the importance of all these elements in developing new production planning and control practices adapted to the real context of SMEs, we elaborate upon our strategy for conducting the literature review in the next section.

3. Literature review strategy

To meet the research objective, it is necessary to carry out a full investigation of the bibliography. To do this, we applied a systematic bibliographical research method as exposed by Tranfield, Denyer, and Smart (2003). The selection of this method is justified on the grounds of reproducibility and formality. Contrary to other methods of doing a literature review (Adolphus 2015; Seuring and Gold 2012), Tranfield, Denyer, and Smart (2003) has extended the method of literature review from the medical sector to the management sciences, so the method is clearer and guides the user in the bibliographic search and analysis. Finally, the Tranfield method has been exploited and validated in other research on SMEs (Garengo, Biazzo, and Bititci 2005).

This literature review focuses on papers dealing exclusively with empirical Industry 4.0 cases in SMEs, as exposed by researchers. The Elsevier, Emerald, Springer and Taylor and Francis databases were surveyed. We considered publications, which followed the formal introduction of Industry 4.0 (i.e. after 2011) and used the following keywords to perform our research in *abstracts*, *keywords* and *titles*:

- 'Industry 4.0' and 'Small and medium'
- 'Digital production' and 'Small and medium'
- 'Digital manufacturing' and 'Small and medium'
- 'Internet of things' and 'Small and medium'
- 'Cyber Physical System' and 'Small and medium'
- 'Cyber Factory' and 'Small and medium'
- 'Production Planning and Control' and 'Small and medium'

We have observed in our preliminary readings that many authors describe uses of the Industry 4.0 technologies in production processes without referring specifically to 'planning and control' in their abstracts, keywords or title. In a similar manner, some authors reported uses of Industry 4.0 related technologies without using the work 'Industry 4.0'. Consequently, we decided to perform separated queries on 'production planning and control' and on 'Industry 4.0' to identify all empirical uses of Industry 4.0 tools within SMEs.

Figure 2 describes the article selection process. Among the applied cases found, 54% of the publications not specifying the size of the enterprise were omitted. We excluded articles that were not in English, which did not address a case

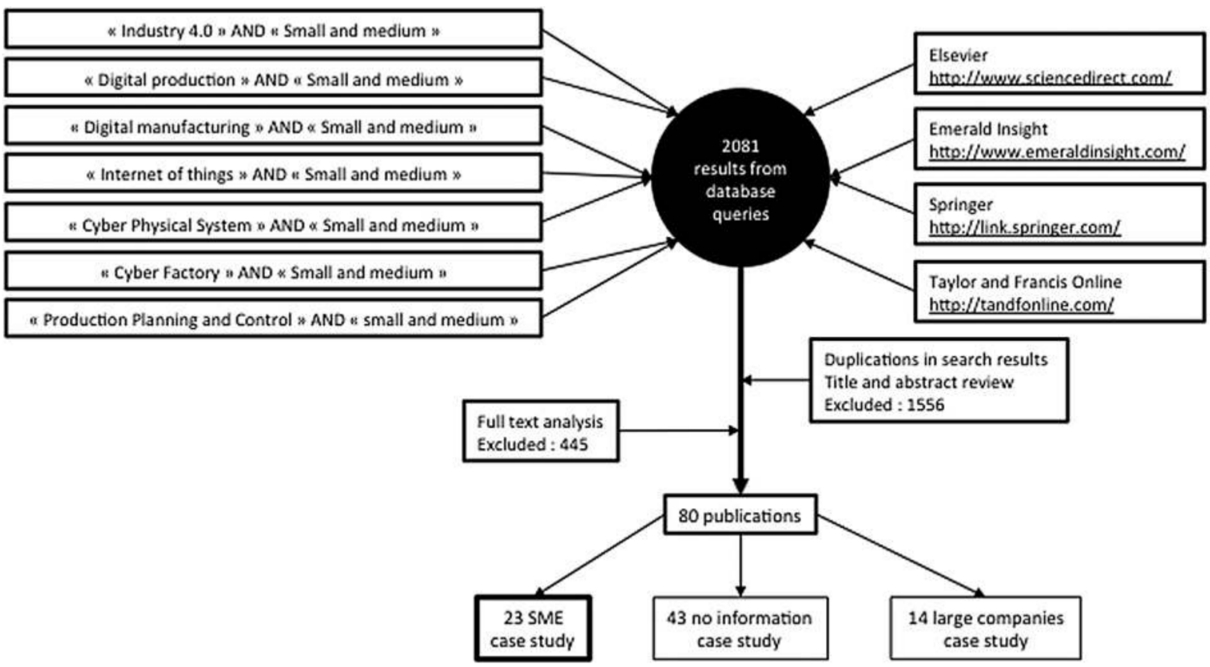

Figure 2. Mapping the scientific literature research.

of applications of Industry 4.0 in an SME. As a result, 23 empirical case studies were identified. These publications are analysed in the following section.

4. Literature analysis

4.1 *Industrial performance objectives*

In the reviewed papers, we first analysed the performance objective targeted in each paper. As shown in Table 1, flexibility and improved productivity are the two main paths of targeted improvements.

4.1.1 *Flexibility*

Industry 4.0 aims at the synchronisation of flows throughout the supply chain. To achieve this, enterprises must be flexible enough to respond to rapid market fluctuations. The use of Cloud Computing platforms, which permit collaboration between enterprises, favours reaction to new demands from the market (Ren et al. 2015; Shamsuzzoha et al. 2016). Ren et al. (2015) underlined that SMEs must focus on their expertise and core trade within a network, satisfying all the needs of the client.

The use of production planning optimisation algorithms can improve the reactivity of enterprises. For example, Peng et al. (2012) used real-time production flow data to modify the production plan when changes in demand or if flows disruption occurs. Likewise, Chalal, Boucher, and Marques (2015) split the flow simulation model into two subsystems, namely a subsystem modelling demand and one modelling production, in order to optimise reaction to client demands.

Wang and Xu (2013) proposed a solution to aid data sharing between partners on a Cloud Computing platform. They observed that the interoperability of systems raised problems and designed a 'Smart Cloud Agent' that facilitated searching for a solution to users by making interoperability more reliable.

4.1.2 *Cost reduction*

The use of digital tools by artisans in Italy led to significant manufacturing cost reduction through the deployment of a 3D digital model (Bonfanti, Del Giudice, and Papa 2015). Internet-based client relations management led to increased demand for production and thus favoured the organisation of artisans.

Table 1. Articles dealing with different objectives of industrial performance.

	Flexibility	Cost reduction	Improve productivity	Improve quality	Delivery time reduction
Shamsuzzoha et al. (2016)	X				X
Ren et al. (2015)	X		X		X
Bonfanti, Del Giudice, and Papa (2015)	X	X			X
Huang et al. (2013)	X				
Song et al. (2014)	X		X		
Denkena, Dengler et al. (2014)			X		X
Barenji et al. (2016)			X		
Peng et al. (2012)	X		X		
Masood, Weston, and Rahimifard (2013)	X				
Sena Ferreira et al. (2012)	X				
Herdon, Várallyai, and Péntek (2012)	X				
Chalal, Boucher, and Marques (2015)	X	X			
Fornasiero and Zangiacomi (2013)	X				
MacKerron et al. (2014)		X			
Wang and Xu (2013)	X	X			
Xia et al. (2016)			X		
Givehchi, Haghighi, and Wang (2015)			X		
Constantinescu et al. (2014)	X				
Dombrowski and Ernst (2013)			X		X
Segura Velandia et al. (2016)				X	
Hao and Helo (2015)			X		X
Constantinescu, Francalanza, and Matarazzo (2015)	X				
Holtewert et al. (2013)	X				

Other authors reported a cost reduction linked to improved flow synchronisation (Chalal, Boucher, and Marques 2015; MacKerron et al. 2014). Better information sharing between suppliers and customers coupled with real time management of flows also led to reduce stock costs.

4.1.3 *Improving productivity*

Givehchi, Haghighi, and Wang (2015) presented a machining process sequencing improvement method by exploiting a revised enriched machining feature concept. However, the data format needed to be addressed first.

At the plant level, Dombrowski and Ernst (2013) simulated different growth scenarios and the resulting production flows to optimise fabrication by reconfiguring production lines. Barenji et al. (2016) also proposed an algorithm for calculating production plans that take into account internal flow disturbances and variations of client demands. In a similar manner, Ren et al. (2015) presented an algorithm for optimising production flows based on data from the Internet of Things, thereby improving the productivity of the entire production network of partners on a Cloud Computing platform.

Improving productivity is often targeted at the level of CPS, enterprises and multi-site networks. We did not identify any papers dealing with all levels in a single model or architecture.

4.1.4 *Improving quality*

Segura Velandia et al. (2016) described the use of RFID on a part to control the quality of an entire production process. It was shown that the utilisation of historical data helped improve product quality.

4.1.5 *Delivery time reduction*

The use of Cloud Computing platforms shortens design time by favouring collaboration between all partners of a network (Ren et al. 2015; Shamsuzzoha et al. 2016) as well as facilitating the synchronisation of all production processes.

Digitising customer orders also reduces processing and execution times. Bonfanti, Del Giudice, and Papa (2015) showed that Italian artisans relied on digital parts models from their customers to produce products. The conservation of customer data also sped up the execution of future orders.

Denkena et al. (2014) used the IoT in addition to Lean Manufacturing to improve production flows. Data on waiting time and bottlenecks facilitated the targeting of improvement initiatives. Thus, the enterprise shortened its delivery lead times.

In conclusion, Industry 4.0 has a positive impact on several operational performance measures. However, improving quality and reducing costs were achieved in only a few cases, contrary to the improvement of productivity, lead times and corporate flexibility. In the following subsection, we pursue our analysis to the four levels of managerial capacities that had been identified previously.

4.2 ***Industrial managerial capacity***

In Table 2, we identify the industrial managerial capacity observed or developed in the selected papers. This table clearly shows the lack of use of real autonomous production systems in SMEs as of now.

4.2.1 *Monitoring*

Monitoring production processes is by far the easiest level of managerial capacity that can be achieved with technologies and resources related to Industry 4.0. For example, Denkena et al. (2014) used the IoT to map parts flows in real time by positioning sensors all along a production line. This information provided alerts in the case of bottlenecks and ultimately served to identify systematic blocking points, which could be overcome by continuous improvement initiatives. They stated, however, that RFID and sensors are expensive, which limits the number of measurement points. The works of Segura Velandia et al. (2016) also presented the use of RFID directly embedded in parts in contact with machine tools. This allowed recording data during the entire production process and not simply sampling data collected at different steps in the production process.

For Sena Ferreira et al. (2012), monitoring capacity can provide several performance indicators. Used within a *Virtual Enterprise (VE)* and shared with all partners, share of monitoring data can increase trust between partners. Likewise, monitoring data provided by connected objects was used by several researchers to manage collaborative processes

Table 2. Articles dealing with different capacities of managerial industrial processes.

	Monitoring	Control	Optimisation	Autonomy
Shamsuzzoha et al. (2016)	X			
Ren et al. (2015)	X			
Bonfanti, Del Giudice, and Papa (2015)	X			
Huang et al. (2013)	X			
Song et al. (2014)		X		
Denkena, Dengler et al. (2014)	X			
Barenji et al. (2016)			X	
Peng et al. (2012)			X	
Masood, Weston, and Rahimifard (2013)			X	
Sena Ferreira et al. (2012)	X			
Herdon, Várallyai, and Péntek (2012)	X			
Chalal, Boucher, and Marques (2015)			X	
Fornasiero and Zangiacomi (2013)	X			
MacKerron et al. (2014)		X		
Wang and Xu (2013)	X			
Xia et al. (2016)		X		
Givehchi, Haghighi, and Wang (2015)			X	
Constantinescu et al. (2014)		X		
Dombrowski and Ernst (2013)			X	
Hao and Helo (2015)	X			
Segura Velandia et al. (2016)	X			
Constantinescu, Francalanza, and Matarazzo (2015)		X		
Holtewert et al. (2013)	X			

(Fornasiero and Zangiacomi 2013; Huang et al. 2013; Ren et al. 2015; Shamsuzzoha et al. 2016). This data was processed and then used in the form of a real-time dashboard.

4.2.2 *Control*

Control favours the interaction of employees with the system by using historical data and predetermined thresholds. MacKerron et al. (2014) presented an e-Kanban system that monitors supply processes by using RFID technology. Changes in quantities consumed would then alert managers.

Xia et al. (2016) proposed using production data to compare the performance of different production resources and thus define expected levels of performance. When the targeted level is not reached, a new design project is launched to modify the production system.

The works of Constantinescu et al. (2014), Constantinescu, Francalanza, and Matarazzo (2015) focused on making information available for aid decision-making. Different data acquired from sensors were linked to specific tasks and transmitted operators for decision-making.

4.2.3 *Optimisation*

Optimisation aims at improving systems and processes and can be achieved through numerous approaches. However, all the selected works on optimisation within SMEs were achieved by performing simulation of current industrial processes (Barenji et al. 2016; Chalal, Boucher, and Marques 2015; Dombrowski and Ernst 2013; Givehchi, Haghighi, and Wang 2015; Masood, Weston, and Rahimifard 2013; Peng et al. 2012).

4.2.4 *Autonomy*

No applied case of autonomy could be found in the literature. This is not a surprise as this managerial capacity requires the implementation and the use of multiple methods and technologies (Brad and Murar 2015).

4.3 *Realisation means*

The reviewed publications show that not all the groups of technology related to Industry 4.0 are present in the SMEs setting. As shown in Table 3, Cloud Computing and the Internet of Things are the most used technologies to implement Industry 4.0 initiatives. A more detailed analysis is provided in this section.

4.3.1 *Big data & analytics*

Only one paper dealt with the use of big data for planning or controlling production processes in SMEs. Ren et al. (2015) proposed a Cloud Computing platform dedicated to SMEs which exploits data from the Internet of Things via MapReduce algorithms (Dean and Ghemawat 2008) and the Hadoop platform (Bao et al. 2012). However, their proposal was not implemented. The lack of research in this area confirms the observation of Bi and Cochran (2014) that showed the weakness of SMEs regarding research and development activities and their difficulties in managing complex computer solutions. They emphasised that Cloud Computing is a viable solution for SMEs for providing analytical services and the data structuring means for using big data.

4.3.2 *Simulation*

We identified two main categories of simulation approaches: operation scheduling and scenario-based simulation. In the first category, simulation is mostly used for generating operation schedules on-line. In the second category, simulation models are used for analysing and modifying current production systems. Table 3 presents reported cases of simulation according to this classification.

According to Chalal, Boucher, and Marques (2015), some SMEs want to improve their commercial offering by adding services in addition to their current products. They proposed two connected simulation models to replicate each offering. The first subsystem modelled demand and the second control the production plan in response to the demand of the first generated by the first subsystem.

Barenji et al. (2016) proposed using the PROMETHEUS method to develop a planning simulation software application. The author observed that usual methods consisted in taking into account only the dynamic demand of customers or production variations. Barenji presented a method that considered both at the same time to better suit the needs of SMEs.

Peng et al. (2012) reported the deployment of a Cloud Manufacturing platform. They presented an algorithm designed to optimise distributed resource management in a collaborative situation. They use a hybrid algorithm that combines VNS (Variable Neighbourhood Search) and PSO (Particle Swarm Optimisation). This combination permits optimising multi-objective problems for flexible planning in a job shop working in a collaborative network of SMEs (Srai et al. 2016).

Givehchi, Haghighi, and Wang (2015) presented a simulation to optimise the machining of a part. In their approach, the authors enhanced the data from the numerical design of the part by defining new data recorded by CPS.

Masood, Weston, and Rahimifard (2013) observed that the planning of SMEs is complex due to the many processes and competences involved in response to a great variety of products. So, they presented the concept of DPU (Dynamic Producer Unit) intended to model the 'role' of a resource in order to carry out a coherent breakdown between employees, machines and information systems. The DPU concept can be used to facilitate the modification of system models by changing only the 'roles' involved in the simulation. In this way, it is possible to simulate different scenarios of production systems and predicting the behaviours of the future system.

Lastly, Dombrowski and Ernst (2013) presented an approach to perform a simulation of potential production scenarios in 6 steps: the development of different scenarios, the design of possible changes of production lines, modelling alternatives, experimentation and optimisation, the evaluation of alternatives, the implementation of the alternative chosen.

Among all papers identified, only Dombrowski and Ernst (2013) presented a practical guide for SMEs for implementing their approach. In other cases, research teams used action research as their research methodology.

4.3.3 *Internet of things (IoT)*

As we can see in Table 3, several researchers use the IoT coupled with RFID technology to obtain production feedback in real time (Huang et al. 2013; MacKerron et al. 2014; Ren et al. 2015; Song et al. 2014). They showed how using IoT could enhance collaboration between SMEs in distributed production networks.

Table 3. Articles dealing with different resources of implementation.

		Simulation		IoT			Cloud computing								
	Big data & analytics	Scheduling optimisation	Scenario-based simulation	RFID	Smart glasses	CPS	Sharing documents	Servitisation	Collaboration	Distributed production	Optimisation resources	Virtual reality	Cyber security	Machine to machine	Collaborative robot
Shamsuzzoha et al. (2016)				X			X	X	X						
Ren et al. (2015)	X			X			X	X	X						
Bonfanti, Del Giudice, and Papa (2015)								X							
Huang et al. (2013)				X			X	X	X						
Song et al. (2014)															
Denkena, Dengler et al. (2014)				X											
Barenji et al. (2016)		X													
Peng et al. (2012)		X					X	X	X	X	X				
Masood, Weston, and Rahimifard (2013)			X												
Sena Ferreira et al. (2012)				X			X		X						
Herdon, Várallyai, and Péntek (2012)								X							
Chalal, Boucher, and Marques (2015)		X													
Fornasiero and Zangiacomi (2013)							X	X	X	X					
MacKerron et al. (2014)				X									X		
Wang and Xu (2013)							X	X	X	X					
Xia et al. (2016)				X						X					
Givehchi, Haghighi, and Wang (2015)		X				X					X				
Constantinescu et al. (2014)		X									X				
Dombrowski and Ernst (2013)			X												
Hao and Helo (2015)					X						X	X			
Segura Velandia et al. (2016)				X											
Constantinescu, Francalanza, and Matarazzo (2015)		X									X				
Holtewert et al. (2013)							X	X	X				X		

In this regards, Sena Ferreira et al. (2012) proposed several indicators to measure and validate the performance of the collaborative system. They suggested indicators focusing on individual operational performance criteria as well as global performance indicators for measuring the success of the partner's network.

Denkena et al. (2014) observed that most SMEs do not have reliable data. They proposed using the IoT associated with RFID technology to manage flows and to facilitate the implementation of Lean Manufacturing. This system made the data flow reliable and made it possible to target improvement initiatives more quickly than with the use of classical Value Stream Mapping.

Xia et al. (2016) used the IoT to recover data from a production machine and to analyse its performance and variance. The approach was also associated with a continuous improvement programme. Segura Velandia et al. (2016) use a similar approach to gather data from the produced parts. In both cases, the aim was to use the IoT to acquire data and to evaluate the performance of the production system.

Constantinescu et al. (2014, 2015) observed that the IoT gives too much data for humans to process. They developed the concept of JITIR (Just In Time Information Retrieval) consisting of three steps: the analysis of needs through interviews with the employees, the recovery of information, and the periodic review of the employee's environment to track any need for change to improve the quality of decision-making.

Hao and Helo (2015) observed that most research focused on using the IoT to improve automation and flexibility in organisations. Their work uses a different approach by focusing on the man–machine link through connected objects. Used in parallel with cloud computing and virtual reality, their approach connects employees with each other to optimise access to expert functions. The main research approaches in these papers followed an action research method (Cappelletti 2010).

4.3.4 *Cyber-physical-systems (CPS)*

The works of Givehchi, Haghighi, and Wang (2015) are the only found case reporting the use of cyber physical system applied in SMEs for production planning and control. They showed that adding connectivity to a production machine and defining a new data format for parts produced makes it possible for the machine to control and optimise its operations.

As CPS are complex systems that incorporate processing algorithms, it is not surprising to note the lack of in-house competences in SMEs is a major barrier for implementing CPS (Evangelista, Mckinnon, and Sweeney 2013).

4.3.5 *Cloud computing*

Cloud Computing is the most used means of implementation of Industry 4.0 practices in SMEs as we found that 65% of our selected publications reported its use. We identify five types of utilisation of Cloud Computing (as shown in Table 3): sharing documents, servitisation, collaboration, distributed production and resource optimisation.

Several works used Cloud Computing with the goal of building *Virtual Enterprises* between SMEs (Fornasiero and Zangiacomi 2013; Holtewert et al. 2013; Huang et al. 2013; Peng et al. 2012; Ren et al. 2015; Shamsuzzoha et al. 2016; Song et al. 2014; Wang and Xu 2013). Based on the observation that SMEs do not possess all the knowledge and capacities to satisfy complex clients' needs, the proposed models favour the development of industrial collaboration between several partners. Cloud Computing platforms allow the *servitisation* of the products, i.e. a change from the vision of 'What I have' to 'What I can achieve' (Ren et al. 2015) and how it can be shared in the network of partners.

The creation of such a network does not only depend on the availability of a Cloud Computing platform. Hao, Helo, and Shamsuzzoha (2016) outlined the first steps of building a *Virtual Enterprise*: find partners and then contractualise the commitments and risks. Once these steps have been taken, it is then possible to progress to collaboration and operational optimisation.

Shamsuzzoha et al. (2016) presented a concept of a Cloud Computing platform based on the Net-Challenge Framework responding to the Make to Order and to Engineering to Order strategies. Collaboration between partners is achieved for the specific needs of each customer. Once the need has been satisfied, the virtual organisation is dismantled.

However, Herdon, Várallyai, and Péntek (2012) observed that SMEs have internal information systems that do not permit direct connection with Cloud Computing systems. They proposed transferring ERP data to the Cloud Computing platform free of charge to promote the appropriation of their solution by enterprises.

Bonfanti, Del Giudice, and Papa (2015) showed that Cloud Computing allows Italian artisanal enterprises to offer products and services online. Creating a new product or service via Web interfaces and Cloud Computing platforms strengthens client loyalty, while providing access to new markets.

In conclusion, we note that Cloud Computing platforms favour the planning and utilisation of shared resources, control over processes and the evaluation of performance.

4.3.6 *Virtual reality*

Hao and Helo (2015) showed the advantage of using IoT, Cloud Computing and virtual reality simultaneously. The use of smart glasses allows for information to be displayed directly in the user's field of vision in real time. Disturbing events appear more visible, which causes employees to be more reactive. Likewise, maintenance of production resources is facilitated by the availability of the data required to restore faulty equipment to operational condition.

4.3.7 *Cyber security*

MacKerron et al. (2014) and Holtewert et al. (2013) studied cyber security in the production environment where the Internet of Things and Cloud Computing are both used. However, readers should note that cyber security was not central to their works.

4.3.8 *Collaborative robots and machine-to-machine communication*

Collaborative robots and communication between machines permit decentralising decision-making at the heart of the production processes. Unfortunately, we could not report any cases on the implementation of these technologies in SMEs.

5. Discussion

Flexibility is the most observed performance objective targeted by researchers, as shown in Figure 3. This could be surprising for practitioners, as flexibility is a common characteristic of SMEs that allows them to be differentiated from other firms. As Industry 4.0 encourages decentralised decisions, this objective should be highlighted in the literature covering larger firms, as flexibility is often seen as a weakness in such organisations.

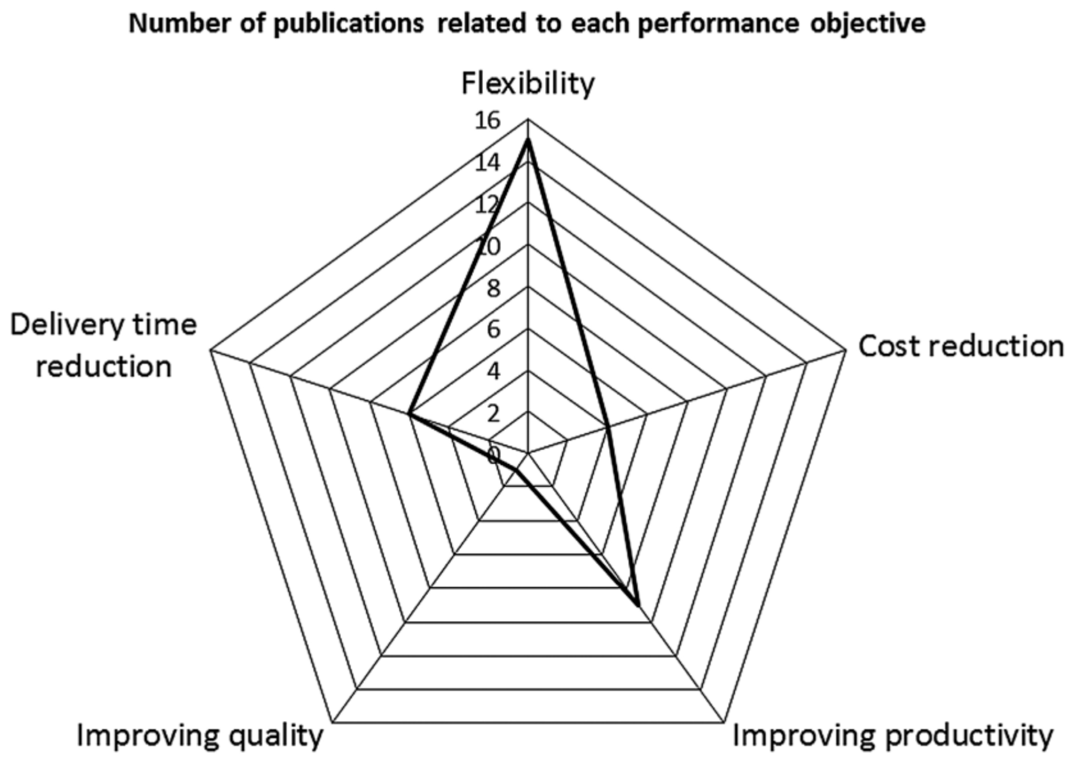

Figure 3. Number of publications related to each performance objective.

Fewer researchers have proposed a solution to reduce lead time (6 publications) or to reduce cost (4 publications). We believe that these two performance objectives could strengthen the business model of SMEs by improving current weaknesses. Research in this area is expected to grow rapidly.

Surprisingly, to date Industry 4.0 does not appear to be a way to increase quality in SMEs. This will probably change as techniques such as automatic fault detection will evolve with new tools and technologies developed around the concept of Industry 4.0 (Cayiroglu and Demir 2012).

This literature review also highlighted a major change in the way of integrating production planning and control systems. Many researchers have already shown that Industry 4.0 can be implemented using an iterative and continuous improvement approach such as Lean manufacturing (Denkena et al. 2014; Kolberg and Zühlke 2015). As Industry 4.0 aims at speeding up flows of information and Lean Manufacturing focuses on the elimination of waste to speed up physical flows, the synergy between the two methods should be considered to target operational excellence. Future research is this area is also expected in the near future.

From a capacity point of view, the literature review clearly demonstrated that current Industry 4.0 initiatives in SMEs focus on monitoring industrial processes, as shown in Figure 4. While simulation appears to be a way to optimise production processes, there appear to only be a few cases that use data to determine warning thresholds and permit decision-making or try to exploit collected data to optimise operations in real time. We also noted that all simulation models were reported to have been developed by researchers rather than the personnel at SMEs. Indeed, it has been shown in previous works that SMEs lack experts devoted to areas other than production processes (Achanga et al. 2006; Moeuf et al. 2016) and that optimisation models should be made more accessible to SMEs.

Among the selected papers, monitoring capabilities are developed by transferring information from the shop floor systems in the form of alert or deviation signal from expected targets. In a similar manner, simulation models are now being exploited by using shop floor information. Both cases are examples of vertical system integration similar to the

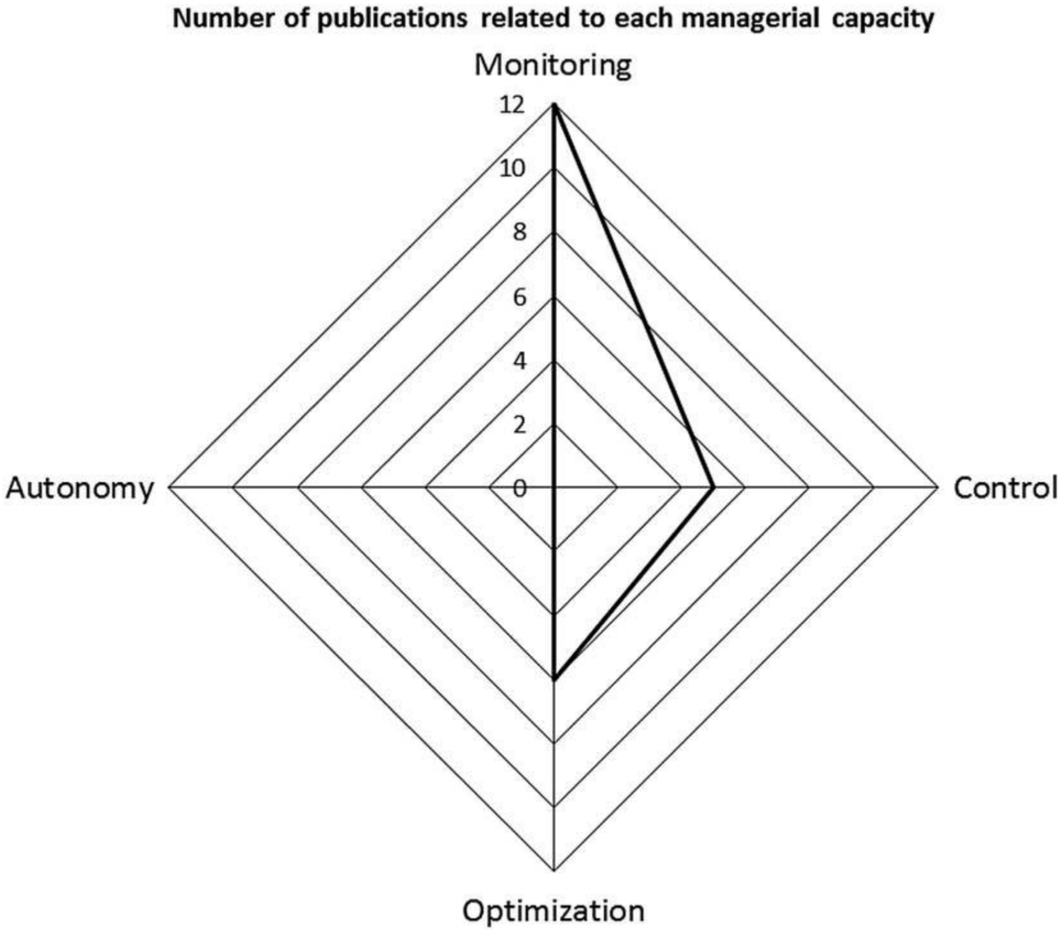

Figure 4. Number of publications related to each managerial capacity.

traditional MES-ERP integration adopted by many large organisations (Saenz De Ugarte, Pellerin, and Artiba 2009). However, this literature review has not found reported cases of horizontal system integration (for example, machine-to-machine communication) as we could expect by adopting Industry 4.0 strategies. Such integration is required to accelerate decision-making processes (possible automating decision-making processes) and reconfiguration of production systems.

In terms of means of realisation, Figure 5 shows great disparity between the use of each group of technology and methods linked to Industry 4.0. Clearly, researchers have proposed many Cloud Computing platforms and their use appears to be within reach of SMEs.

The development of the network of a virtual organisation, supported by Cloud Computing and other technologies, has also brought forward by many researchers. Cloud Computing platforms appeared to improve the cooperation between companies by sharing information and knowledge which in turn create better partnerships between SMEs.

However, none of the authors addresses the confidential issues attached to customer and production information shares between different systems. While only few articles discuss cyber security in SMEs in a general sense, they rarely provide means of protecting computer systems and confidential information when adopting Industry 4.0 technologies. This observation might suggest that there is a lack of awareness, or simply, some SME executives might consider that cyber security is already provided by cloud computing platforms and other modern communication platforms.

Unfortunately, our literature review did not report any use of big data methods in SMEs, despite the fact they have been largely recognised as highly regarded methods for optimising the uses of resources in other organisations (Lee, Kao, and Yang 2014; Mousannif et al. 2016). Some authors argued that SMEs still do not consider data as a source of added value (Bi and Cochran 2014). However, the exploitation of Internet of Things, or another source of data like

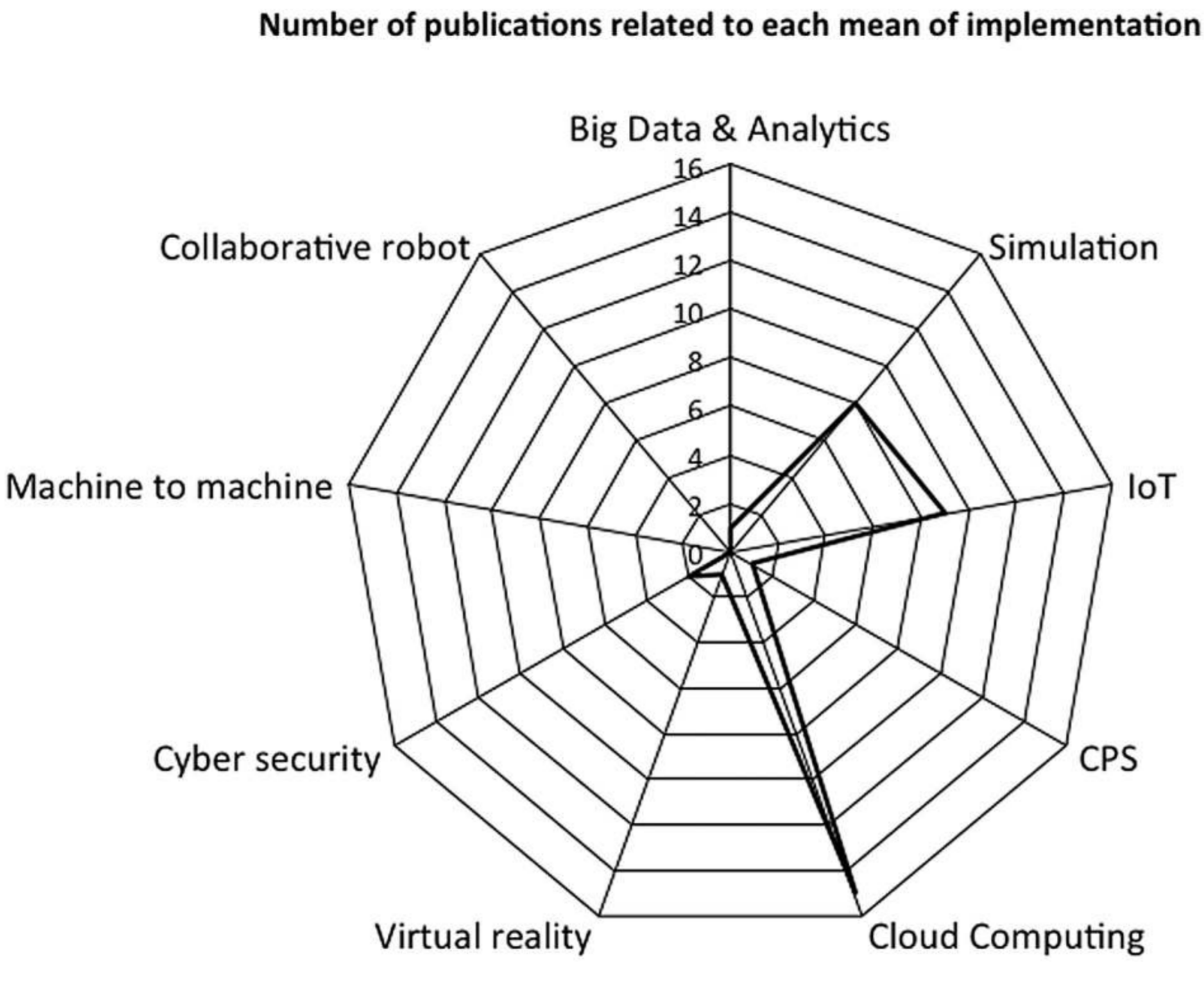

Figure 5. Number of publications related to each mean of implementation.

RFID technologies, will increase the number of data sources. SMEs will eventually exploit this data to optimise the production process and the customer demand at low cost. Clearly, research is still necessary to make big data analysis more accessible to SMEs by formulating clear and practical methods that clearly describe implementation steps, required techniques and tools as well as clearly state the roles and competencies required.

We also noted that the penetration of Cyber Physical Systems in SMEs is complex, though two paths for improvement can be considered: the purchase of new equipment and the upgrading of existing equipment. As proposed by Becker and Wagner (2016), SMEs should target the most critical machines to be upgraded and thus limit investment costs. In a similar manner, Machine-To-Machine communication is not exploited by SMEs, nor the use of collaborative robots. These three realisation means are very expensive with a long return on investment. In addition, these technologies are mostly aimed at improving flexibility, which is not necessarily the current objective of most SMEs. Research and case studies are still required to demonstrate the real benefits SMEs can obtain from this group of technologies.

The implementation of Industry 4.0 initiatives and the evaluation of their impact on internal processes need to be further investigated. As with many other Industry 4.0 strategies, it seems that most researchers have focused so far on the development and the validation of different technologies. As this approach relies on a large number of tools, methods and technologies, there is a clear need for researchers to propose and validate paths and methods of implementation. As was the case with previous production planning and control systems, such as MRP, ERP and MES information systems, we can expect that methodologies developed for large organisations will not fit the needs and constraints of SMEs.

Furthermore, we recognise that Industry 4.0 projects can be an opportunity to change processes (not only improving) and to seize new opportunities in the marketplace. In order to really embrace all the potential benefits behind the Industry 4.0 concept, SMEs managers must stop seeing the production system as a cost but as a vector of opportunities for transforming their business models. Unfortunately, this literature review reveals that this cost view has largely favoured the adoption of low cost technological groups, such as cloud computing, to achieve faster and cheaper production processes improvements without really transforming exchanges between manufacturers and customers. Indeed, CPS and Machine-To-Machine communication, which offer new opportunities for personalised production and customer service, have not been adopted yet in SMEs.

6. Conclusion, perspectives and limitations

This paper studied the current fields of research addressing new changes brought to the production planning and control functions in SMEs in the era of Industry 4.0. The proposed literature review strategy was carried out using an innovative process which consisted in the execution of two separate queries (*production planning and control* AND *Industry 4.0*) followed by the analysis of the papers obtained in order to identify intersections between both concepts. We also proposed a framework for analysing the selected papers based on the targeted performance objectives, the required managerial capacities and the different means of realisation associated with the Industry 4.0 concept. This framework is applicable to other works aiming at classifying uses of other information systems or technologies to monitor, control or optimise production systems.

Our survey identified 23 applied cases in which Industry 4.0 was used in SMEs. The reviewed publications show that applications of Industry 4.0 to SMEs are mostly related to monitoring of production processes and to the improvement of current capabilities and flexibility. Several use cases of Cloud computing and RFID tools are noted.

Despite the growing number of new tools and technologies, most of them are under-exploited, if not ignored by SMEs. Our study shows that the least expensive and least revolutionary technologies (simulation, cloud computing) are the most exploited in SMEs whereas those allowing profound business transformations (CPS, Machine-To-Machine, big data, collaborative robot) are still neglected by SMEs.

Despite a current lack of expertise to make use of these recent trends, Industry 4.0 should be considered a part of an SME strategy, as it provides means for connecting with partners, achieving autonomous processes, synchronising flows and customising products. Several authors highlighted some important weaknesses of SMEs that can explain this: SMEs lack resources to invest in research and development activities; they have difficulties managing complex computer solutions, and they lack experts that are not devoted solely to the production process.

Our literature review has some limitations. First, we found only 23 applied cases to analyse, which involve eight different means of realisation. In most cases, the implementation processes of Industry 4.0 technologies at SMEs are not clearly described. Indeed, in order to take an exhaustive look at the real cases and their success, it would be pertinent to supplement this type of approach with field surveys. Second, there is a subjective bias in the reading and selection of papers in a review. In our case, we have ignored commercial types of journals and focused on scientific journals only. Delays between the acceptance and publication of such papers may certainly impact the number of selected papers and underestimate the real level of Industry 4.0 adoption within SMEs. Third, case studies sometimes describe qualitative results and not quantitative results. It is therefore difficult to judge the real benefits achieved by SMEs in exploiting new technologies and practices.

Further research should also be conducted to demonstrate whether or not Industry 4.0 initiatives could bring benefits other than flexibility. In a similar manner, robot, machine-to-machine communication and CPS may appear to be too expensive for SMEs at this point, and qualitative research is required to clarify the real advantages that SMEs can get from their use.

As discussed earlier, the definition of new business models as well as the implementation process of Industry 4.0 initiatives need to be further investigated. In all reported cases, authors have some operational results without discussing the implications on the current business models of the SME.

Disclosure statement

No potential conflict of interest was reported by the authors.

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