Industry 4.0 and the SME: a technology-focused review of the empirical literature

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Abstract— The concept of Industry 4.0 has many advantages for Small and Medium-sized Enterprises (SME) in relation to other industrial management methods such as Just-In-Time or MRPII. Its adoption can be achieved through the use of many technologies. However, these technologies are not well mastered by SMEs. In order to identify the difficulties encountered by SMEs, this article presents an analysis of the exploitation of the different means of realization of the industry 4.0. From a scientific literature review, we show disparities in the exploitation of different technological group. Among the important elements, we note a sub-consideration of the data generated as a source of added value for SMEs, an under-exploitation of certain means of realization and a lack of expertise in SMEs that slows penetration of certain technological groups. The exploitation of the different technologies is often approached individually and targeted, which leads us to conclude that the concept of industry 4.0 is not approached from the angle of industrial management strategy.

Keywords— SME, Industry 4.0, Production Planning and Control.

I. Introduction

As major industrial players, SMEs have to meet ever more complex customer needs. Therefore, they are working on improving operations management: production planning and execution, production control, operational performance measurement and evaluation [1].

Just-In-Time (JIT), which stems from the Toyota Production System [2], [3], is one of several existing industrial management methods. It consists in standardizing tasks and processes, creating continuous process flows, and adopting a market-driven pull production strategy. Though it has produced some excellent results [4], [5], it has also proved difficult to implement in SMEs, for lack of leadership and expertise [6], [7]. Likewise, the MRP and MRPII methods, which are supported by the deployment of computer software such as ERPs [8], are complex methods and costly to implement in SMEs. They quite often proved too rigid a system once installed [9].

The concept of industry 4.0 emerged more recently as a new approach for controlling production processes by providing real time synchronization of flows and by enabling a make-to-order, customized, fabrication of products [10].

This concept relies on emerging technology such as cloud computing, Internet of Things, cyber-physical systems, and Big Data. These technologies foster information sharing all along the managed system; this allow for streamlined processes as well as real time synchronization to meet fluctuation in demand. This concept appears more flexible and less expensive, but relies on many technological means that SMEs struggle to deploy.

This article aims to identify and analyze the different means of Industry 4.0 deployment for production planning and control in SMEs. We will first describe more formally what Industry 4.0 is as a concept in the next section, and proceed to describe the means of realization that it relies on. We will the present a literature review of production planning and control in the Industry 4.0 era. This article ends with a discussion of the results obtained.

II. Industry 4.0

Groups of technologies such as the Internet of Things [11], [12], Big Data [13], as well as Cloud Computing and networks improvement [14], [15], recently entered the industrial landscape fostering the emergence of new concepts for process management. Consequently, several strategic initiatives emerged across the world, including “Industry 4.0” in Germany, “Industry of the future” in France, “Smart Manufacturing” in the United States, or “Internet +” in China. The concept of Industry 4.0 appears to be dominant and we will use this term in the remainder of this paper [16]. The concept of Industry 4.0 arose in the German Hanover Fair from a discussion between representatives of industry, academic institutions, trade unions, and state authorities. The term of Industry 4.0 refers to the fourth industrial revolution, fallowing mechanization (1^{st} revolution), the creation of production lines taking advantage of new energy sources such as electricity (2^{nd} revolution), and PLCs in manufacturing (3^{rd} revolution). Industry 4.0 aims to all objects and stakeholders within tomorrow’s factory. Communication between objects, machines and people promotes the integration and synchronization of all resources along the value chain. Industry 4.0 allows 3 types of integration:

- Horizontal integration along the value chain, fostering collaboration among enterprises and connecting remote units.
- Vertical and hierarchical integration helps in the management of subsystems through the flexibility and reconfiguration of manufacturing networks.
- Temporal integration throughout the product life-cycle allow for customization and make-to-order manufacturing while capitalizing data from design, manufacturing and product use.

To achieve the aforementioned forms on integration, Industry 4.0 relies on several characteristics [17]:

- the interoperability of objects, machines, people and computers systems which communicate with one another;
- the virtualization of the physical world through a copy in the virtual world based on data collected by sensors;
- the decentralization of decision-making which could happen directly on in-the-field cyber-physical systems;
- the real-time management of load and capacity through data collection and analysis;
- a service-focused approach to enhance customer offers; and
- the modularity of production systems allowing for increased.

Underlying this concept and its characteristics are the emergence of new technologies that we group together under the term of means of Industry 4.0 realization [18]. These technologies require significant investments and strong expertise for their deployment, but seem to respond to the need for flexibility in SMEs. We present the technologies in the next section and proceed in section 5 to analyze real deployment cases o these means of realization within SMEs.

III. Groups of technologies in Industry 4.0

The concept of Industry 4.0 is based on the emergence of a set of several groups of technologies. We adapted the list of the Boston Consulting Group© which includes 9 means of realization [18]:

- Big Data: a large amount of data becomes available for use. Real-time or delayed analysis of large data sets is a source of added value both commercially and industrially. Processing this massive amount of data is one of the major issues of industry 4.0 [13], [19]–[21];
- Simulation: modeling products, production lines and multi-site networks allows to evaluate different scenarios using computer software [22]–[25]. Thus, designers and decision-makers can stimulate decision outcome and evaluate its performance [26]–[28];
- Internet of Things: new technologies allow for physical objects to have communication capabilities [29], [30]. This approach makes it possible to capture the state of the system in real time while decentralizing decision-making. These data can be used in massive data analysis to predict system behaviors;
- Cyber Physical Systems: these are in-system mechanisms to algorithmically control and monitor systems and their surrounding users. It allows objects to communicate with their environment and reconfigure in real time according to needs [15];
- Cloud computing: network connectivity, reactions times of a few milliseconds, and increased bandwidth allow for real-time information sharing. Thus, data and software are available anywhere, at any time and from any terminal [31], [32];
- Virtual reality: using systems such as Google’s smart glasses, data become available directly into the field of view of employees [33];
- Cyber security: an increase in data transfer between businesses and services must not be to the detriment of industrial information safety. Cyber security aims to protect physical and intangible assets of companies as well as networks [34];
- Collaborative Robots: robots are becoming more flexible, better able to communicate and cooperate [35]. Product connectivity reduces batch sizes, and embedded sensor technologies allow for better collaboration with humans on the most meticulous tasks [36]; and

- Machine-to-Machine communication: with the increase in number of autonomous machines, communication machines are developing. This communication based on standard protocols and technologies allows the autonomous management of machines fleets.

Before assessing each group of technologies, we briefly describe in the following section the review strategy we used to select empirical Industry 4.0 cases in SMEs.

IV. Literature review strategy

The objective of our research is to identify the articles describing the use of the means of Industry 4.0 realization for production planning and control in SMEs. To do this, we applied Tranfield's systematic review method [37]. The selection of this method is justified on the grounds of reproducibility and formality, and this method has already shown its relevance in other literature reviews regarding SMEs [38].

The fallowing databases have been used:

- Elsevier (http://www.sciencedirect.com/)
- Emerald (http://www.emeraldinsight.com/)
- Springer (http://link.springer.com/)
- Taylor and Francis (http://tandfonline.com/)

We performed the requests on April 4, 2016 using the fallowing queries:

- "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 systems" AND "small and medium";
- "cyber factory" AND "small and medium"; and
- "production planning and control" AND "small and medium".

We obtained 2081 articles from the different queries. We excluded non-English language literature and the duplicate paper. We selected articles describing at least one empirical case of Industry 4.0 or one of its means of realization, for production planning and control in SMEs.

Among the 80 articles describing empirical cases, 54% do not specify the size of the company and 17% concern large companies. We found 23 items that match our criteria, which we analyze in the next section.

V. Literature analysis

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 1, 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.

A. Big Data & Analytics

The use of data in the sense of Big Data is discussed in the paper of Ren et al. [39] without giving case of application. Through the design of a cloud computing platform for SMEs, they propose to exploit data coming from the Internet of Things via MapReduce algorithms and the Hadoop platform [40], [41].

The lack of research in this area confirms the observation of Bi and Cochran [42] that showed the weakness of SMEs regarding research and development activities and their difficulties in managing complex computer solutions. They emphasized that Cloud Computing is a viable solution for SMEs for providing analytical services and the data structuring means for using Big Data.

B. Simulation

Barenji et al. [43] observed that the planning of SMEs had several limits: these systems are centralized and not distributed, nor do they allow parallel queries or respond to the need to reconfigure production lines. Masood et al. [44] observed that the planning of SMEs is complex due to the many processes and competences involved in response to a great variety of products. Finally, several Cloud Computing simulation platforms have emerged to support distributed production on several sites and the optimization of multi-site resources [45].

According to Chalal et al. [46], some SMEs want 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 modeled demand and the second control the production plan in response to the demand of the first generated by the first subsystem.

Barenji et al. [43] 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. The author presented a method that considered both at the same time to better suit the needs of SMEs.

Peng et al. [47] reported the deployment of a Cloud Manufacturing platform. They presented an algorithm designed to optimize distributed resource management in a collaborative situation. They use a hybrid algorithm that combines VNS (Variable Neighborhood search) and PSO (Particle Swarm optimization). This combination permits optimizing multi-objective problems for flexible planning in a job shop working in a collaborative network of SMEs.

Givehchi et al. [48] presented a simulation to optimize the machining of a part. In their approach, the authors enhanced the data from numerical design of the part by defining new data recorded by CPS.

Table 1 : Articles dealing with different means of realizations

	Big Data & Analytics	Simulation		IoT		CPS	Cloud Computing					Virtual reality	Cyber security	Machine to machine	Collaborative Robot
		Scheduling optimization	Scenario-based simulation	RFID	Smart glasses		Sharing documents	Servitization	Collaboration	Distributed production	Optimization resources				
[49]				X			X	X	X						
[39]	X			X			X	X	X						
[50]								X							
[51]				X			X	X	X						
[52]															
[53]				X											
[43]		X													
[47]		X					X	X	X	X	X				
[44]			X												
[54]				X			X		X						
[55]								X							
[46]		X													
[56]							X	X	X	X					
[57]				X									X		
[58]							X	X	X	X					
[59]				X						X					
[48]		X				X					X				
[60]		X									X				
[61]			X												
[12]					X						X	X			
[62]				X											
[63]		X									X				
[64]							X	X	X				X		

Masood et al. [44] 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.

Lastly, Dombrowski and Ernst [61] 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, modeling alternatives, experimentation and optimization, the evaluation of alternatives, the implementation of the alternative chosen.

Among all papers identified, only Dombrowski and Ernst [61] presented a practical guide for SMEs for implementing their approach. In other cases, research teams used action research as their research methodology.

C. Internet of Things

Several research use the IoT coupled with RFID technology to obtain production feedback in real time [39], [51], [57], [54], [49], [52].

In this regards, Sena Ferreira et al. [54] 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. [19] observed that most SMEs do not have reliable data, the data not being considered as a source of added value by the manager of this kind of company. They proposed using the IoT associated with RFID technology to manage flows and to facilitate implementation of Lean Manufacturing. This system made the data flow reliable and made possible to target improvement initiatives more quickly than with the use of classical Value Stream Mapping.

Xia et al. [59] used the IoT to recover data form a production machine and to analyze its performance and variance. The approach was also associated with a continuous improvement program. Segura Velandia et al. [62] use a similar approach to gather data from the produced parts. In both cases, the aim was to use IoT to acquire data and evaluate the performance of the production system.

Constantinescu et al. [60], [63] 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 need 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 [12] observed that most research focused on using the IoT to improve automation and flexibility in organizations. 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 other to optimize access to expert functions.

The main research approaches in these papers followed an action research method [65].

D. Cyber physical systems

The works of Givehchi et al. [48] 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 optimize 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 [66].

E. Cloud Computing

Cloud Computing is the most used means of realization of Industry 4.0 practices in SMEs as we found that 65% or our selected publications reported its use.

Several works used Cloud Computing with the goal of building *Virtual Enterprises* between SMEs [39], [47], [51], [49], [52], [56], [64], [58]. Based on the observation that SMEs do not possess all the knowledge and capacities to satisfy complex clients’ needs, the proposed models favor the development of industrial collaboration between several partners. Cloud Computing platforms allow the *servitization* of the products, i.e. a change the vision of “What I have” to “What I can achieved” and how it can be shared in the network of partners [39].

The creation of such a network does not only depend on the availability of a Cloud Computing platform. Hao et al. [67] outlined the first steps of building a Virtual Enterprise: find partners and then contractualize the commitments and risks. Once these steps have been taken, it is possible to progress to collaboration and operational optimization.

Shamsuzzoha et al. [49] presented a concept of a Cloud Computing platform based on the Net-Challenge Framework responding to make-to-order and engineering-to-order strategies. Collaboration between partners is achieved for the specific needs of each customer. Once the need has been satisfied, the virtual organization is dismantled.

However, Herdon et al. [55] 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 et al. [50] 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 favor the planning and utilization of shared resources, control over processes and evaluation of performance.

F. Virtual reality

Hao and Helo [12] 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 users' 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.

G. Cyber Security

MacKerron et al. [57] and Holtewert et al. [64] 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.

H. Collaborative robots and Machine-to-Machine communication

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

VI. Discussion

SMEs are companies recognized for their flexibility and proximity to customers [68]. Their size ease communication and adjustments between employees, thereby enabling quicker reconfiguration in the event of change in demand [69], [70]. However, SMEs are weak on investment capacity and operational performance, with high costs and subpar on-time delivery compared to large companies. Finally, SMEs manly have short-term strategies, which do not favor long-term investments.

From our analysis, three groups of means of realization are emerging: collaborative tools, production tools, and optimization tools.

The first group, the collaborative tools, is strongly present in the identified articles; it is cyber security and Cloud Computing that promote exchanges and their security between companies through the creation of *virtual enterprise*. Cloud Computing is in the form of PaaS (platform as a service), which does not require high skill and investment. However, this mean of realization push SMEs towards concentrating on their core business activities, at the risk of being increasingly dependent on their external value chain. A more detailed analysis is needed to estimate the optimal exploitation strategy of Cloud Computing.

The second group, the production tools, concerns the cyber physical systems, the virtual reality, collaborative robot and the communication between machines. These means of implementation bring a capacity to the physical systems to become more flexible. SMEs do not need to improve their flexibility for they are already recognized for this. Moreover, these means require heavy investment, which may hamper the reconfiguration capacity of SMEs and does not favor the deployment of these means of realization. This group of technologies thus appears ill suited to SMEs and unable to meet their specific needs.

The third group, the optimization tools, combines the Internet of Things, Big Data analysis and simulation. These tools are inexpensive compared with collaborative robot for example. The Internet of Things ease the acquisition of data from the whole production system; some authors relied on this mean to realize a VSM in a Lean Manufacturing implementation project. The Big Data analysis can be exploited to consider predictive maintenance or predictive planning with ERP [71]. Likewise, all of these data can be used to design a simulation model and thus make a decision between scenarios. However, these means of realization require a strong expertise, which is usually not present in SMEs. While the cost of these solutions seems to be compatible with SMEs investment capacity, the required expertise is not. Research should focus on the definition of methods / tools available to SMEs, taking into account the specific characteristics of these enterprises.

In our analyses, the cases of application are described in terms of the use of one or more means of Industry 4.0 realization. However, we have not identified an article discussing industry 4.0 as a concept supporting the company's strategy. Geographic growth, growth throughout the value chain or growth through diversification of activity, Industry 4.0 provide help according to the strategy chosen, the research must extend the study of industry 4.0 in this sense.

Our literature review has some limitations. First, we found only 23 applied cases to analyze, which involve eight different means of realization. In most cases, the implementation processes of Industry 4.0 technologies within 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 adoptions 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.

VII. Conclusion

The aim of this paper was to analyze the exploitation of the means of realization of Industry 4.0 within SMEs for production planning and control.

Our study has been limited to the analysis of empirical cases concerning SMEs since 2011. The concept of Industry 4.0 is recent, but the penetration of new technologies within companies has existed for many years. In order to complement our research, we should analyze the articles with the same objectives using ICT (Information and Communication Technology) or AMS (Advanced Manufacturing System) [72], [73]. Moreover, an extension to industrial documents (reports, white papers) describing concrete cases could enrich the analysis.

SMEs are recognized for their flexibility and proximity to customers, and are also recognized for their low investment capacity and short-term strategy. In this sense, some means of realization cannot support the strategy of SMEs. Production tools require too much investment, while collaboration tools and optimization tools seem less expensive. Research should focus on adapting optimization tools to the characteristics of SMEs, mainly exploiting massive data to improve operational performance.

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