Managing Complexity in Industry 4.0 Based Systems: A Qualitative Analysis

Managing Complexity in Industry 4.0 Based Systems: A Qualitative Analysis[1]

Rebecca Castagnoli, Giacomo Büchi, Monica Cugno, Julie Le Cardinal

Abstract Modelling a System is a challenging task, especially if integration and interoperability between branches, machines, products and people are almost overarching as in Industry 4.0. However, engineering and managerial literature little analyze SMEs' readiness to handle barriers and complexity in Industry 4.0 based systems. The paper analyzes the perceived barriers faced by manufacturing SMEs adopting Industry 4.0 and the ways to manage complexity in Industry 4.0 based systems. The research is carry out through a focus group and an in-depth interview with selected organizations in Italy and France. The expected findings are that: (1) there are five macro-categories of barriers related to cultural aspects, ecosystems role, firms' characteristics, human resource management, business model innovation; (2) there are two main unsatisfied needs that limit the benefits of Industry 4.0 adoption. The theoretical contribution of the paper is to open up future research lines both in managerial and engineering literature to identify solutions to these barriers and unsatisfied needs. The paper suggests to managers and policy makers some interesting cues to maximize Industry 4.0 opportunities.

Keywords Industry 4.0, Barriers, Complex systems, SMEs, Manufacturing.

1. Introduction

Since 2011, the Fourth Industrial Revolution or Industry 4.0 (Kagermann et al., 2013) is tremendously changing the world inside and outside firms (Schwab, 2016). Despite the visible impacts of Industry 4.0 on firms, societies and complex systems in general, there is no clear nor unique definition of this neologism. However, focusing on firms, some scholars define Industry 4.0 as an integrated, adapted, optimized, service-oriented, and interoperable manufacturing process which is correlate with algorithms, big data, and high technologies (Lu, 2017).

[1] This work is supported by a public grant overseen by the French National research Agency (ANR) as part of the « Investissements d'Avenir » program, through the "ADI" project funded by the IDEX Paris-Saclay, ANR-11-IDEX-0003-02.

Rebecca Castagnoli
Università degli Studi di Torino, Management Department,
C.so Unione Sovietica, 218 bis, 10134 Torino, Italy
rebecca.castagnoli@unito.it

Giacomo Büchi
Università degli Studi di Torino, Management Department,
C.so Unione Sovietica, 218 bis, 10134 Torino, Italy
giacomo.buchi@unito.it

Monica Cugno
Università degli Studi di Torino, Management Department,
C.so Unione Sovietica, 218 bis, 10134 Torino, Italy
monica.cugno@unito.it

Julie Le cardinal
Centrale Supélec, Laboratoire de Génie Industriel,
9 rue Joliot-Curie, F-91192 Gif-sur-Yvette Cedex, France
julie.le-cardinal@centralesupelec.fr

Scholars have analyzed Industry 4.0 from diverse perspectives identifying that it enables companies to achieve: greater competitiveness and productivity (Xu, Xu & Li, 2018); better value chain (Saucedo-Martínez et al, 2018; Kinzel, 2017) and supply chain efficiency (Barz et al., 2019; Rosin et al., 2020; Merino et al., 2020); improved business activities (Schneider, 2018); highest performance (Dalenogare et al., 2018). In particular, some studies show that the more technologies 4.0 adopted, the more benefits obtained (Büchi, Cugno & Castagnoli, 2020; Vogel-Heuser & Hess, 2016) through economies of scale, scope and networking (Büchi, Cugno & Castagnoli, 2018). Last but not least is the role of Industry 4.0 on firms' sustainability favoring the circular economy (Machado, Winroth & Da Silva, 2020; Kiel et al., 2017).

As can be seen, the impact of Industry 4.0 on firms is analyzed by several studies, however, some key elements related to its adoption remain uncovered. At present, there are few studies investigating the barriers perceived by firms in Industry 4.0 adoption (Horváth & Szabó, 2019; Moeuf et al., 2020; Raj, Dwivedi, Sharma, and de Sousa Jabbour, 2020; Stentoft, Adsbøll, Wickstrøm, Philipsen, and Haug, 2020). Moreover, the existing literature is still in an early phase and presents a knowledge gap on how firms deal with complexity in Industry 4.0 based systems.

The paper is part of these two research stream and investigates how small and medium-sized enterprises (SMEs) perceive barriers to Industry 4.0 adoption (Stenoft et al., 2020; Moeuf et al., 2020) and manage the complexity of Industry 4.0 based systems. The research is carried out through a qualitative analysis divided into three phases. The first phase reconstructs the theoretical background through a literature review of the main barriers perceived by SMEs. The second phase validates and integrates the results of the theoretical background through a focus group with experts having a wide experience on the phenomenon. The third phase compares the results obtained through a semi-structured in-depth interview with an expert on the subject, and investigates how SMEs manage complexity in Industry 4.0 based systems.

Focus groups and interviews are carried out with leading figures of public-private partnerships in Industry 4.0, trade associations, centers and/or poles dealing with applied research, technology transfer and training active in accompanying manufacturing SMEs in the transition 4.0 in Italy and France.

The analysis focuses on the manufacturing sector because Industry 4.0, although it is a cross-sector phenomenon, initially started within the manufacturing sector (Kagermann et al., 2013). The later expansion to other industries is also reflected in the evolution of the Italian industrial plan name, first referring to Industry 4.0 (MISE, 2017), then to Enterprise 4.0 (MISE, 2017) and finally to Transition 4.0 (MISE, 2020).

The analysis is carried out cross countries on the two European countries competing for second place in Europe, after Germany, for the total value of manufacture. From 2017, in fact, France is second (with 889.4 billion euros) and Italy is third (with 883.7 billion euros), Eurostat, (2017). The cross countries analysis is carry out to identify whether two countries – having similar manufacturing rate and not so different socio-economic conditions and firms' characteristics – have similar barriers to Industry 4.0 adoption and similar solutions to manage Industry 4.0 complexity.

The article offers an original contribution identifying the barriers to Industry 4.0 adoption and finding how SMEs manage complexity in Industry 4.0 based systems.

The research identifies SMEs' perceived barriers and key points concerning corporate governance and suggests proposals for improvement for industrial policy actions in support to Industry 4.0.

The paper is structured as follows: the second section identifies the barriers that may hinder the Industry 4.0 adoption; the third section illustrates the methodology adopted; the fourth section reports the main results; the fifth section discusses the results focusing on SMEs readiness to Industry 4.0 adoption; the conclusion describes the main limitations, highlights the implications and suggests future research lines.

2. Theoretical background

The theoretical background comes from an analysis of the literature carried out on Web of Science (WoS) database, selecting English language academic journals and applying three search criteria: period (from January 2011 – introduction of the German National Industrial Plan – to June 2020); research terms (Industry 4.0 synonyms and barriers synonyms); research areas (economic, business and management). The literature review allows the identification of several barriers able to hinder Industry 4.0 adoption classified into 11 types.

The first barrier identified concerns Few information on the potential offered by technologies 4.0 (Basl, 2017). The conceptual literature show that many companies do not intend to develop research on the economic feasibility of technologies 4.0 because of the limited information on the potential offered. Similar results are highlighted by an empirical survey on German companies (Müller, Buliga & Voigt, 2018) which highlights how entrepreneurs estimate Industry 4.0 as a high investment process due to the change of machinery, the formation of new skills and the transformation of business activity.

The second perceived barrier concerns Insufficient know-how within companies. The literature on Industry 4.0 seems to agree that companies need new knowledge and skills to manage new technologies (Wei, Song, & Wang, 2017; Karre et al., 2017; Kiel, Arnold & Voigt, 2017; Kiel et al., 2017).

The third barrier identified in the literature is related to Few skills on the labor market (Liboni et al., 2019) also referring to the types of profiles formed by educational institutions at various levels (Baygin et al., 2016; Motyl et al., 2017; Benešová & Tupa, 2017).

The fourth perceived barrier concerns Insufficient financial resources within the company (Kiel, Arnold & Voigt, 2017; Kiel et al., 2017).

The fifth barrier identifies that the shortcomings in financial resources may affect a Scarcity of external financing further worsening the situation of the previous barrier.

The sixth perceived barrier is Insufficient economic infrastructures. Industry 4.0 is enabled through the Internet of things that requires the need for several economic infrastructures, primarily broadband connection, which allow communication between connected elements based on sensory, communication, networking and information processing technologies.

The seventh perceived barrier concerns the Legal uncertainties that the company may encounter following the adoption of Industry 4.0. This barrier is related to the responsibility of the company's data, trade restrictions, intellectual property protection and differences between the regulations of different countries.

The eighth barrier concerns Difficulties in alliances with universities, polytechnics and research centers. This barrier is due to the high need for research and development and for new knowledge to adopt and manage technologies 4.0 (Mittal et al., 2018).

The ninth perceived barrier is linked to Lack of unambiguous standards. This barrier is due to a low security of data transmission in both inter and intra-organizational relationships (Kiel, Arnold & Voigt, 2017; Kiel et al., 2017) and to limited reliability and stability of machine-to-machine communications (Sung, 2018).

The tenth perceived barrier is Organizational resistance linked to the degree of flexibility of human resources towards innovation (Automation Alley, 2017; Kiel et al., 2017; Vey et al., 2017; Von Leipzig et al., 2017; Bauer et al., 2015; Horváth & Szabó, 2019).

The eleventh barrier concerns the perception that The business sector to which the firm belongs does not need investment in Industry 4.0. This barrier is due to the high investments required by Industry 4.0 and the uncertain return on investment (Horváth & Szabó, 2019).

In addition to these barriers, many scholars (Lu, 2017; Piccarozzi, Aquilani, & Gatti, 2018) identify an additional barrier upstream of all the others: Lack of unambiguous definition of Industry 4.0. This barrier is also aggravated by: the presence of several Industry 4.0 synonyms – Industrial Internet, Advanced Manufacturing, Factories of the Future, Future of Manufacturing, Digital Factory, Digital Manufacturing, Smart Factory, Interconnected Factory, Integrated Industry, Production 4.0 and Human-Machine Cooperation (Büchi, Cugno, & Castagnoli, 2020) – used in a confused way; the number of enabling technologies involved – Chiarello et al., 2018 estimate that there are more than 1200 enabling technologies 4.0 – and their rapid obsolescence and high turnover.

These barriers are of different relevance depending on the size of the company and are generally higher in smaller companies (Stentoft et al., 2020).

3. Methodology

The paper follows a qualitative approach. In particular, the research is made by a focus group and a semi-structured in-depth interview.

First, the theoretical background has been implemented by focus group with practitioners with a solid experience in SMEs' Industry 4.0 adoption.

Second, a semi-structured in-depth interview with an expert on SME's Industry 4.0 adoption allows a structured data collection ensuring that new and unexpected information can be included (Yin, 2009; Cannel & Khan, 1968) such as the ones linked to managing complexity in Industry 4.0 based systems.

The qualitative approach is chosen because of the high degree of subjectivity of the phenomenon. This subjectivity is due to the fact that barriers are not only measurable barriers such as economic or infrastructural ones, but are also barriers related to knowledge of the revolution, of its opportunities and incentives and to innovative propensity of entrepreneurs, managers and employees. In addition, empirically grounded research on Industry 4.0 is still scares (Stentoft et al., 2020), which is why qualitative focus group and interview serve to explain the results from the literature review in five main empirical categories. Specifically, explanatory qualitative studies help to understand 'which', 'how' and 'why' certain relationships emerge (Yin 2009). Finally, the use of qualitative interviews is due to a gap in extant literature about the relevance and practice of Industry 4.0 technologies among SMEs (Barratt, Choi, and Li 2011).

3.1. Focus group

The focus group is addressed to experts in manufacturing SMEs technological adoption allowing to obtain the most complete, objective and broad spectrum view of the phenomenon under analysis. In order to ensure the desired intra-group heterogeneity, participants are selected among different experts with a broad background of collaboration with many SMEs in the manufacturing sector. The manufacturing industry represent a preferential one since Industry 4.0 – although it is a phenomenon transversal to all economic sectors – was born within manufacturing enterprises (Kagermann, 2013).

The focus group participants are leading figures of public-private partnerships in Industry 4.0, trade associations, centers and/or poles dealing with applied research, technology transfer and training active in accompanying companies in the 4.0 transition (Table 1).

Participants	Occupation	Region
A.C.	SMEs' association	Italy (Piedmont, Northern Italy)
P.D.	Technological pole	Italy (Piedmont, Northern Italy)
C.F.	Technological pole	Italy (Piedmont, Northern Italy)
V.I.	SMEs' association	Italy (Piedmont, Northern Italy)
N.M.	Local administration	Italy (Piedmont, Northern Italy)
L.M.	Foundation	Italy (Piedmont, Northern Italy)
R.T.	Technological pole	Italy (Abruzzo, Central Italy)
E.P.	Competence center	Italy (Piedmont, Northern Italy)
L.Mi.	Consulting	Italy (Piedmont, Northern Italy)

Tab. 1. Profile of focus group participants

An email is sent to the participants to describe the focus group procedure and to distribute an information sheet and a written waiver form. The information sheet includes basic information on qualitative research procedure, methodology (e.g. number of participants and inclusion criteria), organization and logistics (e.g. setting and duration) and content to be discussed.

In total 9 experienced Industry 4.0 professionals from 8 different institutions participate. The profession of the participants concerns the accompaniment – from an engineering-technological, economic-managerial and bureaucratic-administrative point of view – of Italian SMEs towards Industry 4.0.

All participants take part in a 180-minute guided session in a virtual classroom organized through the Zoom platform. The online solution is the only one possible during the Covid-19 emergency in Italy. However, respondents are extremely focused on the process and on the topic. The focus group is recorded and transcribed.

The whole process is deliberately unstructured to enhance spontaneous interventions. The role of the moderator is to facilitate every representation of the phenomenon and to increase the generation of ideas among the participants, favoring a process of social sharing of personal opinions, without interruptions, judgements or signs of approval in order to favor maximum fluidity. At the end of the session, the moderator devotes time to summarize and share the results obtained in order to allow participants to verify the information collected.

The information emerged during the focus group are recorded and transcribed. In order to explore and summarize the information provided by the participants, a content analysis is carried out. The content analysis is widely used in qualitative research to develop objective inferences on a specific topic of interest through the analysis of any type of communication, in this case the textual material resulting from the transcription of the focus group. Following Yin (2013) the analytical framework includes three phases: (1) analysis of the transcription of each participant's observations; (2) identification of common recurring themes; (3) analysis of shared themes. The analysis is performed by the authors independently through open coding. The first author performs the first phase of coding. The second phase is carried out by all authors. The recurrent concepts identified covering the same areas are condensed into key concepts. The selected key concepts are highlighted for similarities and differences and are then grouped to produce reference areas and sub-categories. Inter-observer consensus is ensured throughout the whole process. A sample of the generated material is checked by all authors for consistency and coding accuracy. Table 2 provides an example of how the coding is performed.

Number of barrier	Areas of barriers highlighted by participants	Dimensions identified in literature	Illustrative coding examples
1	-	Few information on the potential offered by technologies 4.0	-
2	Lack of managers/employees 4.0 within the company	Insufficient know-how within companies	"Once you buy a machine, you need someone to take care of it, an innovation explorer dedicated to Industry 4.0" (A.C.)
3	Generational polarization; lack of young entrepreneurs; generational turnover	Few skills on the labor market	"There is a lack of generational turnover in SMEs" (E.P.)
4	Insufficient financial resources	Insufficient financial resources within the company	"Small and micro enterprises do not have sufficient resources to invest alone in Industry 4.0" (L.M.)
5	Lack of ecosystem support and facilities in the early stages of development	Scarcity of external financing	"Piedmont does not assist companies in the first periods of innovation, unlike neighboring regions such as Lombardy or Emilia Romagna" (P.D.)
6	Digital retrofitting, revamping problems, digital infrastructure limits	Insufficient economic infrastructures	"One of the issues related to the adoption of Industry 4.0 is the revamping and digital retrofitting of machinery" (E.P.)
7	Bureaucratic complexity	Legal uncertainties	"The Italian National Plan for Industry 4.0 is highly complex with regard to the certification of investments made" (L.M.)
8	-	Difficulties in alliances with universities, polytechnics and research centers	-
9	-	Lack of unambiguous standards	-
10	Cultural problem, lack of approach 4.0, difficulty in innovative business models	Organizational resistance	"The most difficult change for traditional companies is to review their business model from a servitization perspective" (P.D.)
11	Perception of need, psychological aspects	The business sector to which the firm belongs does not need investment in Industry 4.0	"The automation process is more experienced by large companies. SMEs perceive this need less and do not know how to deal with it" (R.T.)
12	Shortage of information on public facilities to support investment in technologies 4.0.	-	"It is not true that SMEs have little information on Industry 4.0, they have confused information about it" (V.I.)

Tab. 2. Example of barriers coding

3.2 Semi-structured in-depth interview

The semi-structured in-depth interview is carry out with a practitioner working in a company that helps SMEs and enterprises in the transition to 4.0 in France. The in-depth interview is made in addition to the focus groups to compare the Italian and French reality, to investigate latent and unforeseen aspects and to start research on how SMEs manage complexity in Industry 4.0 based systems.

The interview take place online in July 2020 via Skype. The online solution is adopted as the only one possible during the Covid-19 emergence in Europe. However, the interviewee is really focused on the process and on the topic too. In-depth interview lasts 60 min and is recorded and transcribed. The authors carry out the interview administrating a semi-structured guide derived from the themes arising from the literature review. Typical questions included are:

Section 1 – Main advantages encountered by SMEs adopting Industry 4.0

Section 2 – Main barriers faced by SMEs adopting Industry 4.0

Section 3 – Approach used by SMEs adopting and implementing Industry 4.0

Section 4 – Modes and tools helping SMEs in managing complexity in Industry 4.0 based systems.

Section 5 – Further information to validate familiarity and reliability of the interviewee on the topic.

The study adopts an interpretive methodology to identify themes emerging from the analysis of the data. The interview transcript is compared to the results of the focus group. First, the experience of the interviewee is analyzed and the emerging themes are identified. Second, a categorical aggregation is carried out and emerging patterns are identified. Third, the data are revisited to search for relationships between the literature review results, the focus group results and the different concepts emerged in the in-depth interview.

4. Findings

4.1 Focus group findings

During the focus group, participants agree that the techniques used allows them to reflect profitably on their professional experience in Industry 4.0 and positively enriches the discussion.

The focus group with experts confirms the relevance of barriers emerged from the theoretical background, except for the first barrier - Few information on the potential offered by technologies 4.0 – the eighth barrier – Difficulties in relations with research centers – and the ninth barrier – Lack of univocal standards. These barriers are not mentioned by the focus group participants. One possible motivation lies in the fact that the participants in the focus group are professionals who belong to or collaborate with research centers, universities and technology poles. This may create a bias in the perception of these three barriers.

The theoretical background of the barriers is implemented by the twelfth barrier: Few information on public facilities to support investments in Industry 4.0. Moreover, it emerges that firms gives a different degree of importance to perceived barriers according to their nature related to (Table 3): cultural aspects; ecosystem characteristics; firms' characteristics; human resource management (HRM); business model innovation.

In particular, from the coding of the information obtained, 5 categories and 17 sub-categories emerge regarding the barriers that SMEs encounter adopting Industry 4.0.

Categories	Sub-categories
Cultural aspects	**Scarce attitude to innovation** **Inhomogeneity of the Industry 4.0 definition** **Complexity related to the certification of the use of incentives of the National Plan** **Lack of an approach 4.0** **Lack of cultural support from institutions** **Relevance of psychological aspects in the perception of the need for innovation**
Ecosystem characteristics	**Lack of networks between firms and institutions** **Lack of an integrated supply chain approach** **Little support from the institutions in the early stages of development** **Infrastructural limits** **Traditional dependence of the SMEs on large companies or groups**
Firms' characteristics	**SMEs' dimensional problems** **Problems of SMEs' location in poorly communicating geographical areas**
HRM	**Generational Polarization** **Absence of professionals dedicated to Industry 4.0 within companies**
Business model innovation	**Relative novelty of the servitization phenomenon**

Tab. 3. Main barriers to the adoption of Industry 4.0 in Italian SMEs

Each of the barriers listed in Table 3 is considered relevant by all participants with unanimous agreement without hesitation, doubt or perplexity. The work of the moderator is to reconstruct which of the barriers identified is most important according to the participants.

Cultural aspects

The participants - unlike the authors' expectations, focused on the strong relevance of economic and infrastructural barriers - place more emphasis on cultural issues in the adoption of Industry 4.0.

Cultural aspects are an upstream problem of the barriers to the implementation of Industry 4.0 and concern first of all a defining problem. The presence of different synonyms of Industry 4.0 – Fourth Industrial Revolution, Internet or Advanced Manufacturing (US), Factories of the Future (European Commission), Future of Manufacturing (UK), Digital Factory, Digital Manufacturing, Smart Factory, Interconnected Factory, Integrated Industry, Production 4.0, Human-Machine-Cooperation – does not facilitate the determination of the research domain boundaries. In addition, Industry 4.0 is often wrongly linked only to the adoption of enabling technologies without a long-term vision and without an approach 4.0 to redefine the working environment at 360 degrees. With reference to the defining issues, the authors highlight that the focus group participants themselves often use the term digitalization as a synonym for Industry 4.0 although the two terms are not synonymous, but rather the evolution of each other.

Further elements related to cultural problems are related to the propensity of entrepreneurs and employees to innovate, the lack of institutional support in this direction and the difficulty in taking advantage of tax benefits.

Characteristics of the reference ecosystem

Among the main barriers emerge the limits of the ecosystem in which Italian SMEs are located. In particular, the participants in the focus group insist on the lack of an integrated supply chain approach 4.0. "This approach should be based on the development of business networks through technologies 4.0". (A. C.), "It should consider a long supply

chain going beyond the traditional concept of an industrial supply chain and basing itself on collaboration between companies and organizational innovation that breaks up traditional supply chains" (C. F.).

However, the concept of collaboration also leads to differing opinions. In particular, it is stressed that "We should not only talk about collaborations, but about innovation chains, where the focal point is emulation and confrontation between entrepreneurs" (L.M.). From the terms used by the several participants regarding the concept of network or supply chain, it can be seen that the defining problem – far from being just a conceptual problem – remains not only among entrepreneurs but also among experts in the sector on some specific issues. It is therefore necessary to develop studies in this area to guide effective and efficient public policies and entrepreneurial strategies for the development of Industry 4.0.

Other concepts related to ecosystem concurs with the lack of support from institutions in the early stages of development, infrastructural limits for the proper functioning of technologies 4.0 and the traditional dependence of SMEs on large firms that have made smaller companies less innovative and more passive. In this last element, the theme of the supply chain emerges again as a determinant which should help SMEs to innovate following the model imposed by larger companies.

Firms' characteristics

Among the characteristics of firms, first of all, the dimensional problems of SMEs emerge, exacerbated by the discontinuous location in the territory which limits exchanges between firms. It should be noted that the concept of collaboration and supply chain previously emerged returns in this case as well.

Finally emerges a "Problem of rigidity of the organizational structures of SMEs, structured as if they were large firms, which slows down innovation processes and especially bottom-up initiatives that could be favored by the freedom of initiative of the new generations more accustomed to digital" (E. P.).

Human resource management aspects

A topic linked to the one emerged in the previous point of the organizational rigidity of SMEs, is the generational polarization. This element, together with the absence of professional figures dedicated to Industry 4.0 within the firms, or rather as external consultants of several companies, is seen as a serious lack by the participants in the focus group. The "Need for an Industry 4.0 manager or employee or an Innovation explorer helping the company and its employees to integrate machinery into production activities and maximize its benefits" (A. C.) is suggested almost unanimously. In addition, the focus group shows the need for employees to have T-shape knowledge in the company, i.e. having a main specialization on a subject but, at the same time, being able to have transversal knowledge so as to be able to collaborate as a team and to be a human resource more adaptable to the various tasks. For this reason, a re-skilling training activity is necessary.

Lack of business model innovation

The last point highlighted by the participants concerns the low capacity of business model innovation. In this regard, it emerges that the servitization business model is a phenomenon that is difficult to establish in Europe, unlike what happened in the United States. "Many companies, in fact, find difficulties to reconvert offering more services" (N. M.) because "Reviewing the business model is one of the activities that most profoundly modify a company and therefore lead to greater inertia" (C. F.).

4.2 Semi-structured in-depth interview findings

The in-depth interview is carried out with a dual purpose. The first is to compare the results of the focus group. The second is to extend the results of the focus group by bringing out information more specifically focused on how to manage complexity in Industry 4.0 based systems.

As far as the first aspect is concerned, the interview to an expert in SMEs' Industry 4.0 adoption in France confirms the primary role of the cultural factor highlighted by the focus group participants. In particular, the interviewee points out that the main problem of SMEs' reluctance to adopt Industry 4.0 is related to the low propensity of entrepreneurs to a high degree of technological and automation dependence and to a low knowledge and understanding of technologies 4.0. This reticence is also highlighted by the name of the French industrial plan for the development of Industry 4.0 (Ministère de l'Economie de l'Industrie et du Numérique, 2016). In fact, the interviewee pointed out how the term Industrie du Future was preferred to the expression 4.0 in order to avoid overemphasizing the technological aspect.

In addition, the interviewee agrees with the participants in the focus group concerning the problem of the geographical dispersion of enterprises. To this problem, the interviewee adds the problem of dispersed teams from which it emerges the need to encourage forms of collaboration and exchange of data within the same enterprise even before the supply chain level.

As far as the second aspect is concerned, the interviewee starts from the two main needs that SMEs have in managing the complexity in Industry 4.0 based systems that are currently unsatisfied in most SMEs: Need to use data in real time; Need for collaboration between employees.

In this regard, the interviewee points out that Industry 4.0 allows to obtain and store large amounts of data. However, the systems traditionally used by firms for the internal management – ESM or the more advanced ERPs – do not allow

the real-time use of these data due to system rigidities. This rigidity also hinders real-time communication and information exchange between employees.

The Need for collaboration among employees also emerges in the focus group. In particular, the need for employees in the company to possess T-shape knowledge, i.e. having a main specialization on a subject but, at the same time, being able to have transversal knowledge in order to work together as a team and be a human resource more adaptable to the various tasks.

In response to this need for collaboration, a re-skilling training activity is proposed in the focus group. The interviewee recommends to develop the re-skilling by enhancing the use of apps for the real-time exchange of information.

These two limitations of SMEs mean that the adoption of Industry 4.0 does not bring the expected benefits by limiting the propensity of companies to adopt it due to problems upstream of Industry 4.0 itself.

5. Discussion

The results identify 11 barriers through the literature review and an additional barrier through the qualitative analysis. Further, the results of focus group and interview to expert in Industry 4.0 adoption of manufacturing SMEs show five main categories of barriers and two main uncovered needs that hinder SMEs' readiness to adopt Industry 4.0.

These results could be analyzed in relationships with SMEs' readiness to Industry 4.0 adoption. In particular, the qualitative analysis shows a relatively low degree of Industry 4.0 readiness and concrete use among the sample of Italian and French SMEs. This is in line with an empirical analysis by Stentoft, Rajkumar, and Madsen (2017) showing that large companies have a significantly higher Industry 4.0 readiness than SMEs, which can be explained by larger companies having a relatively higher availability of resources to exploit the technologies.

However, the results show that this scarce readiness to Industry 4.0 adoption might be related to two different barriers leading to two opposite consequences.

From one side, the paper's results show that this scarce readiness in SMEs' Industry 4.0 adoption is highly dependent on the first category of barriers emerged from the analysis: Cultural aspects. SMEs, in fact, show some weakness related to: difficulties to define Industry 4.0; scarce innovative attitude; lack of approach 4.0 to transform firms into smart factories; psychological resistance to the perception of the needs for innovation. Hence the results show a clear lack of awareness of the technologies and of Industry 4.0 as an overall concept. These results support the findings by Issa, Hatiboglu, Bildstein, & Bauernhansl (2018) who found that SMEs in general struggle with such technologies.

From the other side, the results show that the current stage of Industry 4.0 application is highly linked to ecosystem conditions and to an integrated supply chain approach. This open-up the possibility that the current degree of Industry 4.0 adoption of SMEs might mature in the coming years as more practical applications developed by larger companies or innovative SMEs enable a wider application of such innovations in SMEs. This is in line with Stentoft et al. (2020).

Despite these qualitative results show a positive relationship between barriers in Industry 4.0 adoption, needs in complexity management and Industry 4.0 readiness, the literature demonstrates that, in some cases, barriers seemingly do not make the SMEs less Industry 4.0 ready. In fact, some studies (Büchi, Cugno, & Castagnoli, forthcoming) empirically verify that certain categories of barriers do not appear to influence the adoption of the technologies. One explanation may be that companies that engage in Industry 4.0 initiatives and report of high barriers are simply more aware of such barriers compared to companies with less focus on Industry 4.0 (Stentoft et al., 2020). For these reason, it should be suggested that firms and policymakers focus on the drivers instead of on the barriers in order to improve Industry 4.0 readiness and effective implementation looking at the opportunities rather than focusing on the constraints (Stentoft et al., 2020).

6. Conclusion

The paper analyzes, through a qualitative approach, the Italian and French manufacturing SMEs' readiness to adopt and implement Industry 4.0 and to manage complexity in Industry 4.0 based systems. Industry 4.0, in fact, was born in manufacturing firms – even if it reached a rapid expansion in all the industries – and Italy and France are the European countries that reached the higher manufacturing turnover following Germany (Eurostat, 2017), the country where Industry 4.0 concept was born (Kagermann et al., 2013).

The research is carried out through a focus group and a semi-structured in-depth interview with practitioners belonging to public-private partnerships in the field of Industry 4.0, trade associations, centers and/or clusters involved in applied research, technology transfer and training active in accompanying enterprises in the transition 4.0.

In particular, the research focuses on SMEs knowledge, adoption and implementation approach of Industry 4.0, main barriers faced by SMEs during these processes, awareness and usage of models and tools to manage complex systems in Industry 4.0.

The main results are that from one side SMEs face five main barriers – related to cultural aspects, ecosystem role, firms' characteristics, HRM and business model innovation – where the most intense barrier is the cultural one. From the other side SMEs has two main unsatisfied needs – the need to use real-time data and the need for real-time communication – which hinder the achievement of the potential benefits of Industry 4.0.

6.1 Theoretical contribution and managerial implications

The results presented have several research contributions and provide implications for policy and management.

The research contributes to the literature with an interdisciplinary approach in two main fields integrating Industry 4.0 management literature with engineering tools to manage system complexity. The key contributions of the paper are as follows. First, it identifies the barriers to implement Industry 4.0 in the manufacturing industry in the context of developed economies. Second, it classifies the 11 types of barriers into 5 main categories. This classification allows to identify the degree of influence of each barrier and provides better decoding of uncertainty and vagueness in the responses of experts. Second, the paper explores the solution used by firms in managing Industry 4.0 based system complexity identifying two main uncovered needs that may prevent firms from fully benefiting from the Industry 4.0 revolution.

The results might suggest relevant managerial implications concerning how to solve the goal 8 of the UN Sustainable Development Goals on decent work and economic growth through a better understanding of how to reach performance and efficiency in Industry 4.0 based systems. In particular, the results help firms to formulate appropriate strategies to achieve a higher degree of success in implementation of Industry 4.0. The results reveal that managers and policy makers should consider to: enhance culture of managers and employees in favor of innovation; improve ecosystems in support of technological adoption; support SMEs which generally have less resources than big companies; develop HRM encouraging generational exchange; stimulate business model innovation.

6.2 Limitations and future research lines

The research is still in an early phase. For this reason, findings are proposed as suggestions for future research lines to expand and quantitatively verify it and to guide effective and efficient public policies and business strategies for Industry 4.0 development.

In particular, some limitations and concerns arise from this study. First, the analysis is based on a limited number of experts (10) and on a limited number of countries (2). For a generalization of the research findings, more responses from multiple industries should be collected and analyzed. Second, some additional quantitative techniques should be applied to enable a comparison within the results. Furthermore, some additional barriers remain uncovered in the current studies. For example, quoting verbatim from a speech by the proponent of the Italian Institute for Artificial Intelligence (I3A): "One of the biggest challenges of Industry 4.0 is the ethical issue of the role, the scope and the impact of these technologies that are not neutral nor uncontrollable by human being". Hence, the research should be enriched widening the sample of expert and broadening the professional background of the interviewees in order to have a more complete and detailed view of barriers and solutions to Industry 4.0. Finally, the paper investigated barriers to Industry 4.0 implementation and solutions in complexity management. To help overcome these barriers and to improve these solutions, future research could analyze different enabling factors and drivers for Industry 4.0 implementation.

References

1. Alley, A. (2017). Technology in Industry Report.
2. Barratt, M., Choi, T. Y., & Li, M. (2011). Qualitative case studies in operations management: Trends, research outcomes, and future research implications. Journal of Operations Management, 29(4), 329-342.
3. Basl, J. (2017). Pilot study of readiness of Czech companies to implement the principles of Industry 4.0. Management and Production Engineering Review, 8.
4. Bauer, W., Hämmerle, M., Schlund, S., & Vocke, C. (2015). Transforming to a hyper-connected society and economy–towards an "Industry 4.0". Procedia Manufacturing, 3, 417-424.
5. Barz, C., Jalba, C. K., Erdei, Z., & Hahn, S. M. L. (2019). Approaches for the planning and implementation of Industry 4.0. Periodicals of Engineering and Natural Sciences, 7(1), 375-380.

6. Baygin, M., Yetis, H., Karakose, M., & Akin, E. (2016). An effect analysis of industry 4.0 to higher education. In 2016 15th international conference on information technology based higher education and training (ITHET) (pp. 1-4). IEEE.
7. Benešová, A., & Tupa, J. (2017). Requirements for education and qualification of people in Industry 4.0. Procedia Manufacturing, 11, 2195-2202.
8. Büchi, G., Cugno, M., & Castagnoli, R. (Forthcoming). Openness to Industry 4.0 and performance: The impact of barriers and incentives. Technological Forecasting and Social Change.
9. Büchi, G., Cugno, M., & Castagnoli, R. (2020). Smart factory performance and Industry 4.0. Technological Forecasting and Social Change, 150, 119790.
10. Büchi, G., Cugno, M., & Castagnoli, R. (2018). Economies of scale and network economies in Industry 4.0. Symphonya. Emerging Issues in Management, (2), 66-76.
11. Cannel CF and Khan RL. Interviewing, in G Lindzey and E Aroson (eds). The hand book of social psychology. Research methods. Addison Wesely 1968;2: cited in Cohen, L., & Manion, L. (1994). Research methods in education. (4th ed.) London: Routledge.Pp271.
12. Chiarello, F., Trivelli, L., Bonaccorsi, A., & Fantoni, G. (2018). Extracting and mapping industry 4.0 technologies using wikipedia. Computers in Industry, 100, 244-257.
13. Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. International Journal of Production Economics, 204, 383-394.
14. Eurostat (2017). Manufacturing statistics - NACE Rev. 2. Retrieved from http://ec.europa. eu/eurostat/statistics-explained/index.php/Manufacturing_statistics_-_NACE_Rev._2.
15. Horváth, D., & Szabó, R. Z. (2019). Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?. Technological Forecasting and Social Change, 146, 119-132.
16. Issa, A., Hatiboglu, B., Bildstein, A., & Bauernhansl, T. (2018). Industrie 4.0 roadmap: Framework for digital transformation based on the concepts of capability maturity and alignment. Procedia CIRP, 72, 973-978.
17. Kagermann, W.W.H., Helbig, J., & Wahlster, W. (2013) Recommendations for Implementing The Strategic Initiative Industrie 4.0. Final report of the Industrie 4.0 Working Group. Forschungsunion, pp. 1-84.
18. Karre, H., Hammer, M., Kleindienst, M., & Ramsauer, C. (2017). Transition towards an Industry 4.0 state of the LeanLab at Graz University of Technology. Procedia manufacturing, 9, 206-213.
19. Kiel, D., Müller, J. M., Arnold, C., & Voigt, K. I. (2017). Sustainable industrial value creation: Benefits and challenges of industry 4.0. International Journal of Innovation Management, 21(08), 1740015.
20. Kiel, D., Arnold, C., & Voigt, K. I. (2017). The influence of the Industrial Internet of Things on business models of established manufacturing companies–A business level perspective. Technovation, 68, 4-19.
21. Kinzel, H. (2017). Industry 4.0–Where does this leave the Human Factor?. Journal of Urban Culture Research, 15, 70-83.
22. Liboni, L. B., Cezarino, L. O., Jabbour, C. J. C., Oliveira, B. G., & Stefanelli, N. O. (2019). Smart industry and the pathways to HRM 4.0: implications for SCM. Supply Chain Management: An International Journal.
23. Lu, Y. (2017). Industry 4.0: A survey on technologies, applications and open research issues. Journal of industrial information integration, 6, 1-10.
24. Machado, C. G., Winroth, M. P., & Ribeiro da Silva, E. H. D. (2020). Sustainable manufacturing in Industry 4.0: an emerging research agenda. International Journal of Production Research, 58(5), 1462-1484.
25. Ministère de l'Economie, de l'Industrie et du Numérique, (2016). Nouvelle France Industrielle. Construire l'industrie française du futur.
26. MISE, (2016), Piano nazionale Industria 4.0, Ministero dello Sviluppo Economico, Roma.
27. MISE, (2017), Piano nazionale Impresa 4.0, Ministero dello Sviluppo Economico, Roma.
28. MISE, (2020), Piano nazionale Transizione 4.0, Ministero dello Sviluppo Economico, Roma.
29. Núñez-Merino, M., Maqueira-Marín, J. M., Moyano-Fuentes, J., & Martínez-Jurado, P. J. (2020). Information and digital technologies of Industry 4.0 and Lean supply chain management: a systematic literature review. International Journal of Production Research, 1-28.
30. Mittal, S., Khan, M. A., Romero, D., & Wuest, T. (2018). A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs). Journal of manufacturing systems, 49, 194-214.
31. Moeuf, A., Lamouri, S., Pellerin, R., Tamayo-Giraldo, S., Tobon-Valencia, E., & Eburdy, R. (2020). Identification of critical success factors, risks and opportunities of Industry 4.0 in SMEs. International Journal of Production Research, 58(5), 1384-1400.
32. Motyl, B., Baronio, G., Uberti, S., Speranza, D., & Filippi, S. (2017). How will change the future engineers' skills in the Industry 4.0 framework? A questionnaire survey. Procedia Manufacturing, 11, 1501-1509.
33. Müller, J. M., Buliga, O., & Voigt, K. I. (2018). Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. Technological Forecasting and Social Change, 132, 2-17.
34. Piccarozzi, M., Aquilani, B., & Gatti, C. (2018). Industry 4.0 in management studies: A systematic literature review. Sustainability, 10(10), 3821.
35. Raj, A., Dwivedi, G., Sharma, A., de Sousa Jabbour, A. B. L., & Rajak, S. (2020). Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective. International Journal of Production

Economics, 224, 107546.Rosin, F., Forget, P., Lamouri, S., & Pellerin, R. (2020). Impacts of Industry 4.0 technologies on Lean principles. International Journal of Production Research, 58(6), 1644-1661.
36. Saucedo-Martínez, J. A., Pérez-Lara, M., Marmolejo-Saucedo, J. A., Salais-Fierro, T. E., & Vasant, P. (2018). Industry 4.0 framework for management and operations: a review. Journal of ambient intelligence and humanized computing, 9(3), 789-801.
37. Schneider, P. (2018). Managerial challenges of Industry 4.0: an empirically backed research agenda for a nascent field. Review of Managerial Science, 12(3), 803-848.
38. Schwab, K. (Ed.). (2016). The global competitiveness report 2016-2017: insight report. World Economic Forum.
39. Stentoft, J., Adsbøll Wickstrøm, K., Philipsen, K., & Haug, A. (2020). Drivers and barriers for Industry 4.0 readiness and practice: empirical evidence from small and medium-sized manufacturers. Production Planning & Control, 1-18.
40. Stentoft, J., Rajkumar, C., & Madsen, E. S. (2017). Industry 4.0 in Danish Industry. Department of Entrepreneurship and Relationship Management, University of Southern Denmark.
41. Sung, T. K. (2018). Industry 4.0: a Korea perspective. Technological forecasting and social change, 132, 40-45.
42. Vey, K., Fandel-Meyer, T., Zipp, J.S., Schneider, C., 2017. Learning & development in times of digital transformation: facilitating a culture of change and innovation. International Journal of Advanced Corporate Learning, 10.
43. Vogel-Heuser, B., & Hess, D. (2016). Guest editorial industry 4.0–prerequisites and visions. IEEE Transactions on Automation Science and Engineering, 13(2), 411-413.
44. Von Leipzig, T., Gamp, M., Manz, D., Schöttle, K., Ohlhausen, P., Oosthuizen, G., ... & von Leipzig, K. (2017). Initialising customer-orientated digital transformation in enterprises. Procedia Manufacturing, 8, 517-524.
45. Wei, Z., Song, X., & Wang, D. (2017). Manufacturing flexibility, business model design, and firm performance. International Journal of Production Economics, 193, 87-97.
46. Xu, L. D., Xu, E. L., & Li, L. (2018). Industry 4.0: state of the art and future trends. International Journal of Production Research, 56(8), 2941-2962.
47. Yin, R. K. (2013). Validity and generalization in future case study evaluations. Evaluation, 19(3), 321-332.
48. Yin, R. K. (2009). Case study research: Design and methods 4th edition. In United States: Library of Congress Cataloguing-in-Publication Data.