Progressing and advancement of Industry 4.0 in the Italian manufacturing context: a dynamic state-of-the-art

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Abstract: Manufacturing companies are required to provide more value-added products in a faster and more reliable way in today's competitive market. Meantime, the rapid evolving of digital technologies is leading the fourth industrial revolution, also named as Industry 4.0 (I4.0). Although some contributions have been made in the literature to describe the state-of-the-art of I4.0 from national level perspective, it seems that there is still missing a dynamic evaluation over time concerning the evolution of the I4.0 paradigm, especially for the Italian manufacturing sector. This paper tries to fill this gap, by conducting a survey in 2019 with a sample of 102 companies and comparing the results with a first survey carried out in 2017.The results show that more companies are implementing I4.0 technologies compared to the 2017 survey, with an increase of 12%. It is also revealed that the large companies, characterized by a high level of informatization, still tend to behave better than small and medium ones. Companies consider lead time reduction and delivery of high-quality product/service as biggest benefits perceived from implementing I4.0 paradigm. As a conclusion, based on the results of the survey, authors show and describe the main levers to be adopted by practitioners in order to accelerate the 4.0 transformation.

Keywords: Industry 4.0, Disruptive technologies, Digital transformation, Survey, Manufacturing, State-of-the-art

1. Introduction

The process of globalization, mass customization and competitive business environment are driving "traditional" companies to face new business challenges in today's turbulent economy (Simmert et al., 2019). To adapt the novel competitive environment, companies are seeking digital approaches to moderate business processes and update technological solutions, which is normally known as Industry 4.0 (I4.0) transformation. According to Schumacher et al., (2016), I4.0 is enabled by the recent technological advances where the Internet of Things (IoT) serve as the backbone to integrate physical objects, human actors, intelligent machines, product lines, and processes across organizational boundaries. Meantime, other digital technologies also emerge as enablers of this new paradigm. Indeed, the effects of Big data & Analytics (BDA) for improving system scalability, security and efficiency is investigated by (Xu and Duan, 2019). Patel et al., (2018) explored the use of Artificial Intelligence (AI) for realizing autonomous resources scheduling. Turner et al., (2016) study the scenario testing and decision-making process enabled by Virtual Reality (VR) and Discrete event simulation (DES). Besides, Chen, (2017) identified Collaborative Robotics as one of the emerging technology trends for integrated and intelligent manufacturing (i2M). Furthermore, Chen and Lin, (2017) investigate on profit maximization of 3D printing within smart manufacturing system focusing on technical and managerial challenges to be overcome. In recent years, the manufacturing context has been tentative on investigation of specific technology application, while it seems that a global perspective is missing, especially from a national point of view. More concretely, the literature lacks an empirical study which focus on mapping the state-of-the-art of how I4.0 is adopted and implemented in manufacturing enterprises, as well as comparing two state-of-the-art at different time slot considering the evolving perspectives. This paper is thus trying to fill this gap by investigating the knowledge and adoption level of Industry 4.0 paradigm, the main factors that impact the I4.0 technologies application, the benefits and obstacles perceived by companies, as well as the dynamic comparison of the survey results at 2017 and 2019. Indeed, selecting Italian manufacturing companies as research target also derives from the fact that Italy is the second most important country in European Union (EU) with respect to the sold production value (EC, 2020). The rest of paper is structured as follows: Section 2 presents the literature review. Section 3 describes methodology, Section 4 show the survey results, and Section 5 draws conclusions and future directions.

2. Literature review and research gaps

2.1 I4.0 enabling technologies and their impacts

The spread of awareness on I4.0 has caused a huge hype on both scholars and practitioners. In particular, the technological stream constitutes an important research field concerning this new paradigm, which make possible both vertical and horizontal integration (Almada-Lobo, 2016). In this paper, the authors consider a list of 6

technologies, resulting from a critical revision of the ones mentioned in acknowledged researches in the literature (Ghobakhloo, 2018; Oztemel and Gursev, 2018), namely: Industrial Internet of Things (IIoT), Big data & Analytics (BDA), Artificial Intelligence & Machine Learning (AI & ML), Virtual & Augmented Reality (VR & AR), Collaborative Robotics and, finally, Additive Manufacturing (AM). The investigated technologies are also aligned with the survey conducted by authors in 2017 (Zheng et al., 2019).

2.2 I4.0 empirical study

Literatures have shown mainly two streams of empirical studies for I4.0, which are I4.0 maturity model and survey of I4.0 paradigm at national level.

Regarding I4.0 maturity models, several studies have been conducted, measuring the I4.0 maturity levels from different perspectivs. Schuh et al., (2015) proposes I4.0 maturity matrix based on German companies, taking into account corporate structure, process and development as measurable dimensions. Lichtblau et al., (2015) concern strategy and organization, employees, smart factory, smart operations, smart products and data-driven services as dimensions. These two models are proposed by two associations in Germany, which are Acatech and VDMA. Moreover, from scientific communites, Schumacher et al., (2016) pose the I4.0 maturity model targeting for manufacturing firms, considering 9 dimensions. Pirola et al., (2019) measured digital readiness level of Italian SMEs from Strategy, people, process and technologie integration perspectives. Santos and Martinho, (2019) on the other side, take into account the dimension of smart factories and smart products and services.

From empirical survey side, Choi and Choi, (2018) studied how Korean SMEs are satisfied concerning their smart factory implementation and the main challenges in advancing to the next maturity level. Jäger et al., (2016) try to understand how much the enterprises from Rhine-Neckar region in Germany are familiar with I4.0 principles. Basl, (2017) and Veza et al., (2016) investigate the readiness for implementing the main features of I4.0 in manufacturing companies in Czech Republic and Croatia respectively. Luthra and Mangla, (2018) evaluate how to exploit I4.0 as lever to achieve supply chain sustainability in Indian manufacturing industry. Morover, Tortorella and Fettermann, (2018) focus on the Brazilian manufacturing context examining the relationship between lean production practices and the implementation of I4.0. The operational performance impact by I4.0 enabled lean practices is also investigated by Tortorella et al., (2019). Besides, Beier et al., (2017) compare China and Germany with a focus on the expected changes brought by I4.0. Tortorella, Rossini, et al., (2019) consider Italy and Brazilian companies as targets for the comparison of I4.0 and lean practices implementation.

2.3 Research gaps and questions

The extant literatures show that some survey-type investigation have been carried out to study the I4.0 paradigm from national level as well as from international comparison level. Based on the study conducted by authors in 2017, which has provided a state-of-the-art of how Italian manufacturing companies are involved in I4.0 transformation (Zheng et al., 2019), the authors take another step forward, eager to understand how companies are advanced from 2017 to 2019. In order to fill this gap, the following research questions are put forward:

RQ1: How the Italian manufacturing companies are approaching and involved in the implementation of the I4.0 paradigm? RQ2: What are the critical factors that impact the knowledge and implementation of I4.0 enabling technologies?

RQ3: What are the main benefits achieved by the companies that are "on the move" and what are the obstacles they are facing?

RQ4: What are the differences between state-of-the-art in 2019 with respect to that in 2017?

3. Methodology

3.1 Survey design

Scholars often distinguish between exploratory, descriptive and confirmatory (theory-testing) survey research (Pinsonneault and Kraemer, 1993). The approach adopted in this study is the descriptive survey, since it is aimed at understanding the relevance of a phenomenon and describing its incidence in a population, more concretely, to understand the impacts of I4.0 paradigm in Italian manufacturing sector, through describing the knowledge level, utilization level of I4.0 enabling technologies, the perceived benefits and challenges, as well as the involvement of organization's business area in the I4.0 transformation. The data collection window is opened in the first six months in 2019, which is as the same survey conduction period adopted in 2017 (Zheng et al., 2019). Concerning the survey sample, the unit of analysis in this survey refers to the Italian manufacturing companies and Italian sites of multinational corporations, with no limits of size and industry sector, and the sample group is controlled as the same with that in 2017. Moreover, web survey technique has been adopted for the survey data collection. The questionnaire is composed by 3 main sections, which cover the I4.0 strategy, organizational informatization level and competencies level, as well as I4.0 enabling technologies.

3.2 Sample description and variables

Overall, a sufficient heterogeneous classification has been achieved of the survey sample in 2019, around 54% of the sample is represented by SMEs, 29.4% are large companies and 16.7% are very large ones separately. Such data is pretty align with the data collected in 2017, where 56.3% belong to SMEs, 28.2% are large companies and 15.5% are very large ones Moreover, different manufacturing sectors have been included. Indeed, the front five sectors of the sample composition remains almost the same comparing 2019 and 2017, which counts for around 82% of the total sample. More concretely, manufacture of machinery equipment ranks in the first place both in 2017 (35.0%) and 2019 (32.4%). From

second to fifth place are manufacturer of metal products, electrical equipment, basic metals and motor vehicles. Slightly difference is that in 2017, the manufacturer of metal products stands for 16.5%, while such proportion in 2019 is 18.6%. Furthermore, regarding to the role of respondent, Directors such as CIO, CTO, R&D director and Production and operations managers, as well as top management constitute the main respondent group. However, a smooth difference is that in 2019, the proportion of top management for filling the questionnaire increased from 14% to 18%.

Table1 demonstrate an overview of the variables adopted for the analysis and their characteristics. The variable 'Company size' follows the classification already depicted in Table 1.

The variable 'Current informatization systems coverage level' evaluates the company informatization level and is built on the basis of the number of different IT systems implemented, namely: Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), Manufacturing Execution System (MES), Advanced Production Scheduling (APS), Product Lifecycle Management (PLM), Warehouse Management System (WMS), Business Intelligence (BI) and Computer-Aided Design/Manufacturing (CAD/CAM), corresponding evaluation level is ranged from low to high.

For 'I4.0 technology knowledge level', 'Null' means that the enterprise is not aware of the technology in question; 'Superficial' means that the company only investigated the general application field of the technology; 'Medium' means that the company has examined the state-of-the-art and understood the potential benefits of technology without investigating any specific application. 'Profound' means that the enterprise holds a deep knowledge of technology and has already evaluated all its benefits and costs. Concerning 'I4.0 technology utilization level', since we totally investigated 6 technologies, companies adopting no technologies is levelled "null", companies adopting up to 2 technologies are considered to have 'low' utilization level, 3 or 4 technologies 'medium', and 5 or 6 technologies 'high'.

'Business function involvement' variable evaluates the involvement of each company business function in the adoption of the single I4.0 enabling technology. Since each technology investigated 4 levels of involvement (from 0-null to 3-high) of each business function, authors also introduced an involvement index that is the mean value of the numbers obtained by each business function for all the technologies adopted by the company.

For 'Benefits', authors investigated 4 types of benefits, which are named: cost reduction, time reduction, quality improvement and flexibility improvement. For 'Obstacles', 4 types of obstacles are studied, namely: immature technology, high investment, missing of competency and absence of technology provider. For both benefits and obstacles, four-level scale is used ranging from null to high, thus an 'index variable' is introduced to facilitate the analysis, which is the mean of the values of the six technologies.

Table 1: Definition and criterions of variables

Variable	Type	Nr. of levels	Levels
Company size	Categoric	3	SME; Large; Very large
Current informatization systems coverage level	Ordinal	3	Low; Medium; High
I4.0 technology knowledge level	Ordinal	4	Null; Superficial; Medium; Profound
I4.0 technology utilization level	Ordinal	4	Null; Low; Medium; High
Business function involvement	Ordinal	4	Null; Low; Medium; High
Benefits	Ordinal	4	Null; Low; Medium; High
Obstacles	Ordinal	4	Null; Low; Medium; High

4. Results

4.1 How the Italian manufacturing companies are approaching and involved in the implementation of the I4.0 paradigm

To answer RQ1, the authors depicted the distribution of I4.0 enabling technology knowledge and utilization, as well as the involvement of organization's business functions. As shown in Figure 1, companies are found to have limited knowledge in general. Among the investigated six technologies, IIoT and BDA seem to be better known by companies, for which more than 40% of the companies have superficial knowledge and above. On the contrary, AI & ML seems to be the least familiar technology. The reason why companies are more aware of IIoT is aligned with the fact that IIoT is the pillar technology of I4.0.

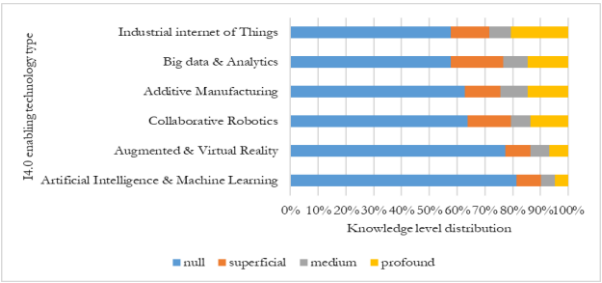

Figure 1: I4.0 enabling technologies knowledge distribution

In Figure 2, we find out that for all technologies, there is a proportion of companies who did not take any actions although they state to have at least superficial knowledge of the technology. Besides, we noticed that more than 30% of the surveyed companies have already implemented IIoT, and more than 20% for BDA. Similar implementation proportion can be found also for AM which is slightly lower than 20%. Regarding AR & VR and AI & ML, the result of utilization rate is coherent with the knowledge distribution. However, we detected that for AM, Collaborative Robotics and AR & VR, there are companies state to have used the technologies and then abandoned.

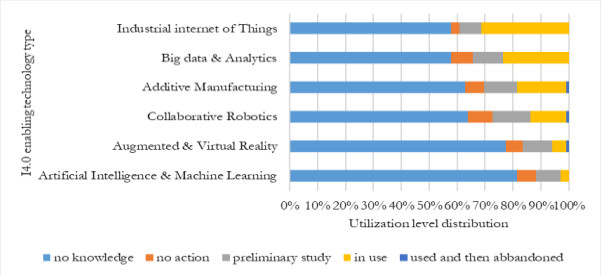

Figure 2: I4.0 enabling technologies utilization distribution

Figure 3 maps the relationship between technology utilization level and business function involvement. It shows that R&D, IT, Direction and Production are the highest impacted business areas by I4.0 technologies. Moreover, with the increase of technology utilization level, expands in the meanwhile the business area involvement, except for HR, Production and Quality, which all show to be slightly lower involved when comparing companies who implement no technologies and those who have implemented one or two technologies.

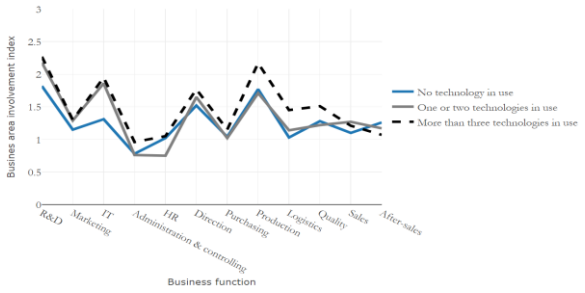

Figure 3: Relationship between I4.0 technology utilization level and business function involvement

4.2 What are the critical factors that impact the knowledge and implementation of I4.0 enabling technologies?

The first factor that impacts company's knowledge and utilization level is company size. Figure 4 and Figure 5 show the plots to demonstrate such relationships. We observed from Figure 4 that the bigger the company size, the higher the I4.0 technology knowledge level. Indeed, the proportion of companies who have at least superficial knowledge is higher in Large and Very large companies with respect to SMEs. Although there is not obvious difference between Large and Large ones, the gap between SMEs and Large companies is still found to be significant.

Figure 5 also confirms the difference between SMEs and Large companies regarding the utilization level. Although there are some cases where I4.0 implementation have been carried out in SMEs, they are still shown to have activated few I4.0 technology related projects, while for Large and Very large companies, it seems that more than half of them have adopted at one I4.0 enabling technologies. However, there is almost no difference between Large and Very large companies regarding the I4.0 implementation level.

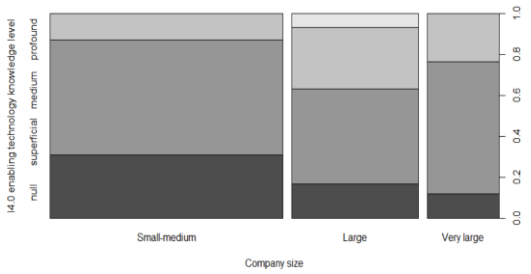

Figure 4: Relationship between Company size and I4.0 technology knowledge level

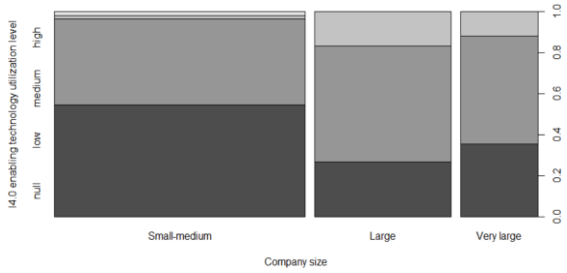

Figure 5: Relationship between Company size and I4.0 technology utilization level

The second impact factor is company's current informatization level. Figure 6 and Figure 7 show the evidences. Looking at Figure 6, a significant increase of I4.0 technology knowledge is observed between low informatization level and medium level. Meanwhile, the knowledge level seems to be equal between medium informatization level and high informatization level companies, but the percentage of above-medium knowledge level is higher for high informatization level group. In general, a positive impact of current informatization level on I4.0 enabling technology knowledge level is shown.

Figure 7 put the focus on the utilization level, it indicates that with the increase of informatization level, it tends to implement more technologies. For companies with low informatization level, no technology has been applied, for medium informatization and high informatization level companies, the average value lies the same between them, but the high informatization level companies are illustrated to implement more technologies than medium informatization level.

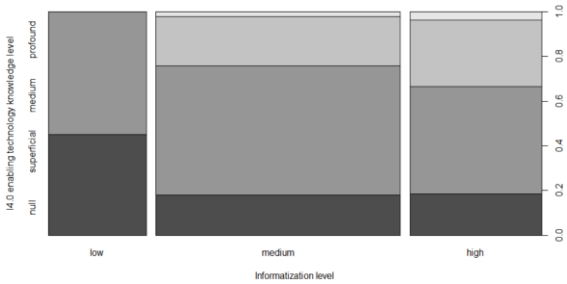

Figure 6: Relationship between Informatization level and I4.0 technology knowledge level

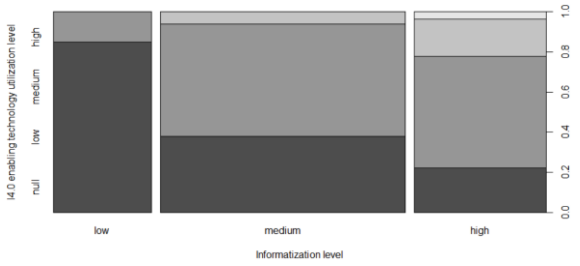

Figure 7: Relationship between Informatization level and I4.0 technology utilization level

4.3 What are the main benefits achieved by the companies that are "on the move" and what are the obstacles they are facing?

Figure 8 and Figure 9 depict the benefits from implementing I4.0 enabling technologies and obstacles in using them respectively. Figure 8 illustrates that the higher the number of technologies implemented, the higher the perceived benefits in overall, except for Flexibility improvement, where the companies who adopted one or two technologies are shown to perceive slightly higher benefits than those who implement more than three technologies. Indeed, companies who have adopted at least one technology are shown to perceive more benefits than the ones who have not yet adopted any technology. Another finding is that Time reduction and Quality/service improvement are considered to be the biggest benefits, implying that companies are utilizing digitalized solutions as levers to reduce time-to-market and deliver high quality product/service.

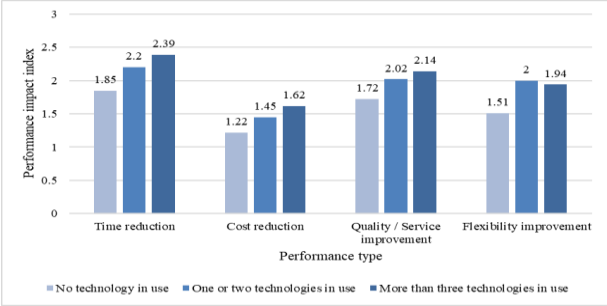

Figure 8: I4.0 enabling technologies utilization benefits

Figure 9 shows the results of obstacles faced by companies when implementing I4.0 enabling technologies. We notice that companies who adopted more than three technologies perceive less obstacles compare to those who adopted less technologies and those who adopted no technologies, the exception is High investment, where companies with higher adoption level shows to require more investment in technology implementation with respect to the ones who lower adoption level. In addition, High investment on technologies and Missing of competencies are considered as the biggest barriers for companies. Indeed, we observed that for companies who have implemented at least one technology, they perceived that there is lack of competencies for the management and utilization of technological solutions.

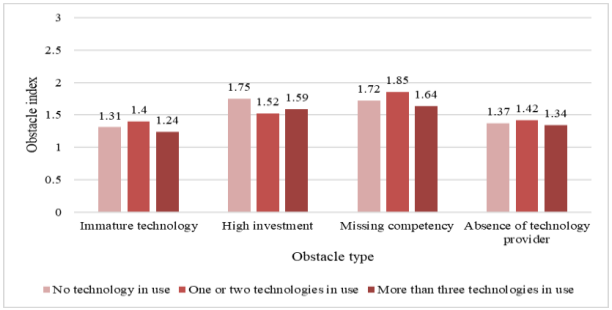

Figure 9: Obstacles in implementing I4.0 enabling technologies

4.4 What are the differences between state-of-the-art in 2019 with respect to that in 2017?

In this section, we compare the I4.0 paradigm state-of-the-art in 2019 to that of 2017 from the perspectives of I4.0 knowledge distribution, implementation distribution, performance impacts and obstacles. As shown in Figure 10, the percentage of companies which have no knowledge and superficial knowledge have been both increased with 2% and 12% separately in 2019. Meanwhile, the percentage of companies who have medium and high knowledge have decreased in 2019. Overall, the proportion of companies who have at least superficial knowledge remains almost the same in 2019 compared to in 2017.

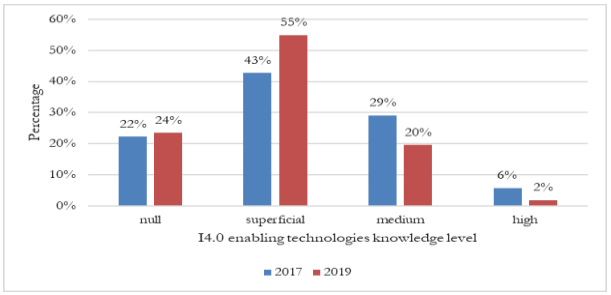

Figure 10: I4.0 enabling technologies knowledge distribution comparison

From Figure 11, we find out that there is an increase trend of technology utilization in 2019, companies who implement more than three technologies has reached almost 10% of the total sample in 2019, meantime, companies who have no technology implementation has decreased by 12%. Moreover, the proportion of companies who have adopted at least one technology has surpassed half of the sample in 2019, while in 2017 this ratio is only 45%. If we look at the utilization distribution together with knowledge distribution, we may notice that although the company's knowledge level in 2019 are smoothly lower than that in 2017, the utilization level is alternatively higher. A reasonable explanation could be that in 2017, even if the companies have higher knowledge level, they were also facing high investment on technology and immature technology as barriers for further implementation, and indeed, these two factors are perceived higher in 2017 than those in 2019 as shown in Figure 13. Therefore, companies in 2017 take more actions on economical and feasibility analysis of I4.0 solutions instead of putting into practices.

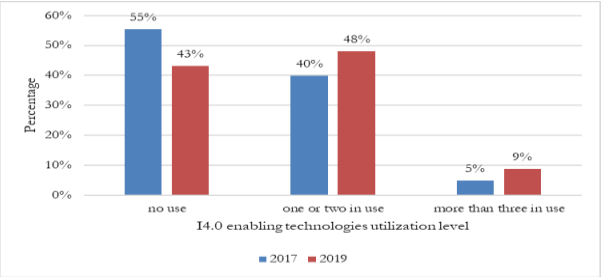

Figure 11: I4.0 enabling technologies utilization distribution comparison

The comparison of benefits and obstacles from implementing I4.0 enabling technologies are separately shown in Figure 12 and Figure 13. Several changes have been detected comparing 2017 and 2019. Regarding benefits, we observed that there is a relevant alteration for Cost reduction, where companies in 2017 perceived it as one of the biggest benefits by I4.0, instead in 2019, it falls to the last place. Flexibility improvement is also demonstrated to be lightly fall in 2019. On the contrary, Time reduction increases its position in 2019. The explanation of the above changes could be that since in 2019, the utilization level of technologies are generally increased compared to 2017, so even though the cost reduction brought by I4.0 implementation is reflected on process efficiency improvement etc, companies have still perceived the investment pressure on corresponded technologies.

Figure 12: Comparison of I4.0 enabling technologies on performance impacts

Comparing obstacles faced by companies in 2017 and 2019. We noticed from Figure 13 that apparent reverse happens for High investment, Missing competency and Immature technology. High investment and Immature technology are considered as smaller obstacles by companies in 2019 than in 2017, while Missing competency is perceived as the biggest barrier in 2019. Such transpose is predictable, since the more companies involved in implementing I4.0 technological solutions, companies require more technical and managerial competencies to manage such transformation. Moreover, as it has passed two years, companies are more familiar with the I4.0 national initiatives launched by Italian government, and they may take the advantage of investment reimbursement, thus less investment barrier is perceived.

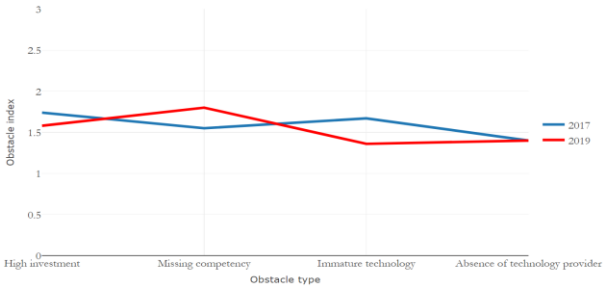

Figure 13: Comparison of I4.0 enabling technologies on obstacles

5. Discussion and conclusion

In this paper, the authors try to take the Italian manufacturing companies as research target, to map the I4.0 state-of-the-art through descriptive survey, and compare the result with that in 2017, which makes a first attempt of making longitudinal empirical study for I4.0 impact (Kamble et al., 2018; Tortorella, Giglio, et al., 2019). Our investigation shows that the Italian manufacturing companies have limited knowledge of the I4.0 enabling technologies, and they have diverse approaches when facing I4.0 paradigm transformation. Indeed, larger and more informatized companies are much more aware of the potential of I4.0 and they show a higher level of both knowledge and adoption of I4.0 enabling technologies. Such results are aligned with previous findings, for example, Gomes and Kruglianskas (2009) argue that company size might affect the access to technologies, while Chen and Fu (2001) show that company size can be an important indicator for the IT adoption pattern in manufacturing firms. Indeed, as SMEs may have not the same financial capacity as larger companies, and there is a pre-existing digitalization gap, SME may not benefit from I4.0 transformation. Thus, they require a more comprehensive assessment of their current resources and economical & technical evaluation of I4.0 solution, in order to guide their progresses in I4.0 implementation. Moreover, the comparison between 2019 and 2017 demonstrate that companies are putting more practically in I4.0 solutions adoption, meantime, they perceive more benefits regarding reduction in lead times and quality improvement, which implies that in the first stage of I4.0 practice, companies are capitalizing more on process improvement, while with the more maturity of process, they seek for creating new business model, which require for higher quality and service improvement. Finally, the survey results show that they face more difficulties in finding adequate competencies in managing digital transformation. In fact, higher skilled managerial and technological workforce are required in the novel manufacturing environment (Grzybowska and Łupicka, 2017). Companies should evaluate their workforce, plan proper qualification and update technical and managerial competencies of their workforce, in order to adapt flexibly in the changing context.

Considering that this paper presents the results of a preliminary study, there is still extensive room for improvement. In our future work, the definition of

constructs and their relationships will be tested statistically, and regression analysis will also be conducted to figure out the impact patterns of each variable. Moreover, we will put more focus on SME, to understand the success roadmap for them in I4.0 transformation.

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