Digital readiness assessment of Italian SMEs: a case-study research[1]

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Purpose: Given the challenges posed by Industry 4.0, this paper proposes a comprehensive assessment model suitable for evaluating SMEs digital readiness level. Then, the results of an assessment of 20 manufacturing SMEs using the proposed model are discussed, and the main priorities to successfully undertake the journey towards Industry 4.0 are highlighted.

Methodology: Given the nature of research, a multiple case studies empirical approach has been adopted. Starting from a literature review about maturity and readiness assessments models for Industry 4.0, the model has been built and validated with two pilot case studies. The final model has been used in an extensive case studies research with 20 enterprises.

Findings: On average, the SMEs analyzed present an intermediate readiness level with respect to Industry 4.0: they are aware of the phenomenon, but the management is still moving the first steps to identify the most appropriate strategy towards this fourth industrial revolution. Companies still need support to contextualize Industry 4.0 in their reality, and to identify the investments required for a successful transition.

Originality/value: Since the industry landscape is mainly composed by SMEs and they are the ones needing more support to understand their path toward Industry 4.0, the proposed model specifically focuses on SMEs, given its modularity, easiness to be understood, and fit to SMEs organizational structure. Furthermore, insights from 20 Italian SMEs are discussed and a list of priorities are highlighted.

Keywords: Digitization, Industry 4.0, Small and Medium Sized Enterprises, Case studies

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1. Introduction

Globalisation and technological innovation engendered enormous challenges to industrial companies such as aggressive competition, shortened product lifecycles, and high demand volatility. Many manufacturing enterprises have moved from a mass-oriented to a customized production to cope with an unstable and increasingly complex business environment, and with the changing customer requirements (Brettel et al., 2014). In this context, the disruptive concepts linked to the Industry 4.0 (and synonyms like Smart Manufacturing) pose additional challenges which require organisational capabilities for managing the whole value-chain in an agile and responsive way to maintain global leadership (Schumacher, 2015). This implies an increasing complexity on multiple firm levels, that in turn generates uncertainty about the necessary organizational and technological capabilities, as well as about the suitable strategies to develop them (Schumacher et al., 2016). Indeed, the transition towards Industry 4.0 requires suitable strategies and organizational models potentially leading to radical changes involving the whole organization in terms of physical infrastructure, manufacturing operations and technologies, human resources, and process management (Gilchrist, 2016). This transformation journey is potentially fraught with concerns and ambiguity related to the financial resources needed for acquiring the enabling technologies, to the overall impact on the business model, and to the impact on the companies' specific business strategy (Schumacher et al., 2016). As a first response to overcome the current stream of mainly conceptual and anecdotal outcomes of Industry 4.0 presented by both academics and practitioners, firms have started pilot projects implementing one or more enabling technologies in their current processes, even though only few have fully and completely exploited their potential and implemented new business models (Roland Berger, 2016). Organizations need to develop their own strategic roadmap defining the development directions to understand and facilitate their transition toward Industry 4.0. To this end, the assessment of the current level of development with regard to the Industry 4.0 vision represents the first relevant step allowing for a strategic management of the transition (Ghobakhloo, 2018). This is particularly relevant for Small and Medium Enterprises (SMEs), which encounter difficulties in developing their own strategy regarding Industry 4.0 due to the lack of time, resources, and flexibility (Löfving et al., 2014; Schröder, 2016). However, as suggested by Sommer (2015), the Industry 4.0 successful implementation could take place only involving SMEs, which play an important role in many countries' industrial value creation. Hence, the necessity for new methods and tools to support SMEs in assessing their current position, identifying fields of action, roadmaps, and projects. In particular, maturity and readiness assessment models for Industry 4.0 aims at highlighting enabling technologies and new operational and organizational factors that companies have to manage while transforming into smart manufacturing systems (Jung et al., 2016).

The aim of this paper is twofold. First, it focuses on the definition of a comprehensive assessment model, named Digital Readiness Level 4.0 (DRL 4.0), specifically suitable for SMEs to assess their current digital readiness level, that is their current position with respect to the digital transformation process. The proposed DRL 4.0 model aims at overcoming the general limitations of other existing models, providing a tool for SMEs desiring to assess their readiness before undertaking the transformation towards Smart Manufacturing. Since Industry 4.0 is a broad concept entailing several aspects, this model focuses on both technology implementation and strategical and operational levels. Second, insights drawn from the assessment of the digital readiness of 20 manufacturing SMEs through the DRL 4.0 are discussed, highlighting the main priorities to successfully undertake the journey towards Industry 4.0. In doing so, we aim at accelerating the rate of adoption of the innovations required for the digitization of the industry by providing a robust knowledge of the current context and of the potentialities implied.

Due to the exploratory intent of the study, we based our work on a multiple case studies empirical research (Sousa and Voss, 2001), aiming at answering the following research questions:

1. How is it possible to measure the readiness of SMEs regarding Industry 4.0 implementation?
2. What is the current level of Industry 4.0 maturity in SMEs, and how is it possible to accelerate the transformation towards it?

In order to achieve these two objectives, the paper is structured as follow. Section 2 deals with a literature review of extant readiness assessment and maturity models highlighting the main gaps and laying the foundation for the definition of the digital readiness model. Then, Section 3 reports the research methodology while Section 4 presents the construction and validation of the model. In Section 5, the results of the implementation of the model in an extensive case study research are discussed. Starting from them, we suggest a prioritized set of actions for the acceleration of the transformation towards Industry 4.0 in Section 6. Section 7 concludes the paper with limitations and further developments.

2. Literature Review

Readiness assessment and maturity models

Industry 4.0 is nowadays one of the major opportunities for companies. However, to successfully implement Industry 4.0, companies need to define a specific vision and a transformation path in relation to their business strategy and objectives (Crnjac et al., 2017). Erol et al. (2016), for example, propose a three-stage process to plan such a transformation. In the first stage, the company needs to "envision" the potentials of Industry 4.0 tailoring the general ideas according to the peculiarities of the industry and company's environment. In the second stage, referred to as "enable", a deeper analysis of the current strengths and weaknesses of the company is performed to build a roadmap for implementation strategies. Finally, the last stage, named "enact" has the goal of transforming strategies into concrete projects. In such a model, the "enable" stage requires an evaluation of the current status of the company to outline properly the future steps. To this end, *readiness assessment models* and *maturity models* represent two useful tools (Bücker et al., 2016).

Besides the differences in their definitions, *readiness* and *maturity* are generally used indifferently in literature to represent the same set of concepts. The concept of *readiness* refers to "the state of being both psychologically and behaviourally prepared to take action (i.e., willing and able)" (Weiner, 2009). More pragmatically, the systemic analysis of an organisation's ability to cope with and undertake a transformational process or change is defined as *measuring* or *assessing readiness*. A readiness assessment aims at identify the risks, the opportunities, and the potential challenges that might arise when change processes (concerning new processes, procedures, organization, etc.) are implemented within an actual organisational context. In addition, a readiness assessment creates the opportunity to address the gaps in the existing organisation either before or as part of the change implementation plan (Holt et al., 2007). The purpose of a readiness assessment is also to find potential barriers to success, thus allowing the organisation to address them before beginning the change project.

Maturity can be defined as "the state of being complete, perfect or ready" (Soanes and Stevenson, 2006). To reach a state of maturity, a progressive evolution in demonstrating a specific ability or in achieving a target, from an initial to a desired end stage, is required (Mettler, 2011). Some argue that maturity relates to "the degree of formality and optimisation of processes, from ad-hoc practices, to formally defined steps, to managed result metrics, to active optimisation of the processes" (Singh et al., 2015). Therefore, also maturity models, similarly to readiness assessment models, are helpful in addressing the objective and impartial evaluation of a company's position, and in answering questions such as what needs to be measured and how to assign a specific stage or degree of maturity (Becker et al., 2009). For this reason, in our research, we considered both readiness and maturity models.

Maturity and readiness assessment tools provide systematic frameworks enabling benchmark and performance improvement. Generally, they include a series of descriptions of business performance for discrete corporate elements. The descriptions are ordered into levels of capability from “not able to do it” through “continuously improving”. Most of the tools encompass five levels, although it is possible to find models with a number of levels between three and nine (Vivares et al., 2018). The structure of each level contains a set of goals that must be addressed to achieve maturity at that specific level, supporting sub goals which define the scope, limits, and needed actions for a particular level, and activities and tasks that should be performed in order to achieve the goals at each level (Singh et al., 2015). To move from one level to another, a company (or a business unit within it) has to undertake improvement actions.

By assessing its current level, an organisation can derive various benefits. First of all, a situational analysis of its capabilities, the setting of a starting place and a structure that prioritises actions. Then, the assessed readiness or maturity can be used as a benchmark for comparison, as an aid to understand and to enable continuous improvement, by understanding the needs of an organisation.

Generally, maturity and readiness models are limited to measure a particular aspect of a domain; even though multiple models can be aligned to facilitate assessments at a broader level, the multiple models can create challenges when different dimensions and levels exist (O’Donovan et al., 2016). In fact, in literature, different groups of maturity models and readiness assessment have been presented. In particular we recognize assessments focused on people, such as organizational readiness assessments (Shea et al., 2014) and change readiness assessments (Lehman et al., 2002), or focused on assets and resources, such as technology readiness assessment (Tran and Daim, 2008). In the next paragraph, we review some of the existing readiness and maturity models for Industry 4.0 that have emerged in recent years.

Industry 4.0 readiness and maturity assessment models

The maturity of an industrial company with respect to the Industry 4.0 model can be defined as “the state of advancement of internal and external conditions that support Industry 4.0’s basic concepts, such as the vertical and horizontal integration of manufacturing systems and enterprises as well as the digital integration of engineering across the entire value chain” (Schumacher et al., 2016). Similarly, a firms’ readiness towards Smart Manufacturing is “the willingness and capacity of companies to implement the ideas behind Industrie 4.0” (Lichtblau et al., 2015). Several models have been proposed in literature (Table 1) to address the need for guided support in developing a company specific Smart Manufacturing vision and a specific project planning (Ganzarain and Errasti, 2016).

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Table 1 – Industry 4.0 readiness assessment and maturity models

The existing models target a wide spectrum of enterprises along several dimensions. The Industry 4.0 Maturity Model (I40MM) addresses manufacturing companies regardless of their geographical location, kind of products, position along the value chain or size, whereas the Croatian HR-ISE model focuses on manufacturing enterprises in Croatia, producing a variety of product categories with no specific reference to the companies’ size. The Forrester’s Digital Maturity Model 4.0 (FDMM 4.0), PwC online self-assessment (PwC SA), IMP^{3}rove Digital Innovation Quotient, Acatech Industrie 4.0 Maturity Index, instead, do not address a specific business, assessing the digital maturity of firms from financial and insurance services to manufacturing and retail, without geographical or size limitations. On the other hand, the System Integration Maturity Model Industry 4.0 (SIMMI 4.0) is more specific, as it focuses on companies' IT landscape and design to make a company move towards Industry 4.0. The Test Industria 4.0 (TI40) addresses manufacturing firms, without focusing on a specific size. Also in Industry 4.0-MM from Gökalp et al. (2017) and in Industry 4.0 Maturity Model from Akdil et al. (2018) a specific reference about the target of the involved enterprises is not presented. Finally, only the IMPULS, the Three Stage Maturity Model in SME's (3SMM) and the SM^{3}E models are designed to raise awareness and promoting Industry 4.0 implementation in SMEs. With respect to the output, the majority of the models in Table 1 provide an aggregate index built from the evaluations of the considered dimensions. Radar charts are often used to show the results. It is worth noticing the heterogeneity between the considered models regarding the dimensions adopted to evaluate companies (Table 2).

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Table 2 – Considered dimensions among existing maturity models

The most relevant dimensions addressed are Technology, Operations, Organization, People/Culture, Strategy and Products. In the choice of the dimensions for our model, we considered a subset of all the dimensions in Table 2, aggregating some topics under the same name.

Finally, some of the models feature a modular structure, enabling a tailored analysis of each examined organisation's context. Modularity in maturity models is crucial to provide flexibility and adaptability to the needs of the organization that is assessed (Garcia et al., 2007). In modular maturity models, individual components of assessment can be chosen, allowing flexibility in the evaluation (Wiegers and Sturzenberger, 2000). For these reasons, we considered modularity as a key feature of our model. Only two of the models in Table 1 have a modular structure. In particular, IMPULS model allows for adapting the questions to the company's context; for instance, by choosing Mechanical Engineering as the industry in which the analysed firm operates, an additional question about VDMA (Verband Deutscher Maschinen- und Anlagenbau, Mechanical Engineering Industry Association representing more than 3200, mostly medium-sized, companies) membership is added to the common survey. PwC SA allows each analysed firm to set at the beginning of the assessment which of the six dimension better fit their situation and context, giving the possibility to exclude the last three sections (IT architecture, Compliance, risk, security, tax and Organisation and culture) that will be not evaluated in the final result.

Limitations of existing models and contribution of the research

The comparison of the different models available in literature allowed for the identification of some limitations. Due to the relative infancy of the Industry 4.0 topic and the vast array of features that can be considered, it is difficult to be in any sense exhaustive. Therefore, for the purpose of this study, we aim to propose an incremental improvement over the existing models. To this end, the effort has been mainly focused on overcoming two major limitations commonly found in readiness and maturity models: 1) the lack of focus on SMEs, and 2) the rigidity of the models.

The first limitation concerns the fact that most of the models are not tailored to the specific requirements that SMEs may have, neither directly nor indirectly. Moeuf et al. (2018) show how Industry 4.0

implementation is complex in SMEs, which under-exploit or ignore some of the available innovative technologies and practices. In particular, SMEs need help in identifying how to transform the visionary idea of Industry 4.0 in increased productivity in the shop floor (Ganzarain and Errasti, 2016). For these reasons, maturity and readiness assessments for SMEs require a deeper investigation about the company's strategic vision, and technological and human aspects. Moreover, the most of the abovementioned readiness and maturity models are conceived to examine different departments of the enterprise or specific ICT tools. However, SMEs often do not have a well-defined structure both at operational and management level.

The second limitation concerns the fact that the available models usually lack in modularity. The monolithic structure of existing tools forces the respondents to answer all the questions, even those that do not apply to their specific context; this in turn generates the risk that questions not relevant for the specific enterprise's context negatively influence the final index obtained. For instance, the innovative technologies and processes that can be implemented into companies are strictly connected to the industry, the business model, and the products offered by the enterprise. For these reasons, taking into account the applicability of the Industry 4.0 features on a specific company context allows to perform a better evaluation of the readiness and to provide a roadmap that is tailored to the specific expected benefits that the enterprise wants to achieve.

To overcome the abovementioned limitations, the readiness assessment model presented in the next sections has been created with the aim at targeting SMEs and allowing for modularity.

3. Methodology

Given the nature of the research, we adopted a multiple case studies empirical approach (Sousa and Voss, 2001). A case study is defined *"an empirical inquiry that investigates a contemporary phenomenon within its real-life context, when the boundaries between the phenomenon and the context are not clearly evident, and in which multiple sources of evidence are used"* (Yin, 2009). Thus, the case study approach allows to observe the actual practices of companies related to a specific topic (Meredith, 1998; Voss et al., 2002) and allows to answer the questions "why", "what" and "how" with a relatively full understanding of the nature and complexity of the complete phenomenon. Case study is recommended when dealing with complex adaptive systems, such as the digitalization of companies' processes. In these cases, researchers should consider "insider" and "participatory" approaches to research (Ottosson and Björk, 2004), to capture depth, nuance, and complex data during the interviews (Mason, 2002). In addition, case study research is particularly appropriate in the development and validation of an assessment methodology, because the case study's purpose may be strictly to describe a situation but, more often, it is to understand how or why events occur (Yin, 2009). Within a case study, the researcher assesses the conditions surrounding the phenomenon to build a plausible explanation or discover a causal relationship that links the antecedents to the results (Benbasat et al., 1987; McCutcheon and Meredith, 1993). Moreover, case study methodology has been used successfully applied to SMEs, allowing theoretical and literal replication, enabling the identification of similarities and differences within the group of cases (Chetty, 1996). Finally, field-based research methods, like case studies, are suitable especially to cope with growing frequency and magnitude of changes in technology and managerial method (Lewis, 1998), as it is for Industry 4.0 adoption.

To ensure an effective multi-case research, the research protocol depicted in Figure 1 has been devised (McCutcheon and Meredith, 1993).

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Figure 1 – Research protocol

First, a literature review about maturity and readiness assessments models for Industry 4.0 has been performed to identify the limitations of existing models, outline the research objectives, and position the contribution of this study (see Section 2). Then, a first draft of the model has been built, and a validation phase has been carried out to gain feedback from two pilot case studies. The validation phase ended after few cycles with a final release of the Digital Readiness Level 4.0 (DRL 4.0) validated model that incorporated some refinements in the original concept. The released model answers the RQ1. The DRL 4.0 was then used in an extensive case studies research with 20 enterprises. Finally, the collected data have been analysed to provide significant results, thus answering the RQ2.

A critical phase during case study research is the sampling choice (Miles et al., 1994). The overall research involved 22 small and medium enterprises localized in Lombardy, Northern Italy, where more than 99% of companies are SMEs (ISTAT, 2017). The sample for the extensive case study has been built adopting a judgmental sampling approach (Eisenhardt, 1989; Hameri and Nihtilä, 1998). Differently from the random sampling, where a population is identified and the sample is randomly selected from it (Voss et al., 2002), judgmental sampling is considered appropriate in exploratory research and in case of limited resources (Henry, 1990). Moreover, sampling randomly could produce biased samples, while choosing the most appropriate cases for a specific research strategy is more successful (Seawright and Gerring, 2008).

Thus, the company's selection has been based mainly on available data from the local industrial association. In particular, the two companies of the in-depth case studies have been selected taking into account the main features of the companies and their propensity towards innovation: company A produces machines with a high technological content mainly through a manual assembly process; company B is more focused on increasing efficiency in its manufacturing process. The other 20 companies have been selected covering the main industries in the Lombardy area (Table 3).

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Table 3 – Company demographics

4. The Digital Readiness Level (DRL) 4.0 model

DRL 4.0 model building and validation

According to the research protocol (Figure 1), we designed a first proposal of the Digital Readiness Level 4.0 and submitted it to the companies A and B for suggestions. The initial model was composed of 35 questions with the purpose of gathering information about the company and investigating specific investments and technological and operational changes related to the Industry 4.0 along five dimensions: Strategy, People, Processes, Technology, and Integration (Table 4).

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Table 4 – Description of the five dimensions of the DRL 4.0

The validation phase in the companies A and B has been carried out by two experienced researchers through in-depth interviews (Johnson, 2001) with the innovation managers, who have been in charge of Industry 4.0 pilot projects inside their companies in the last three years. In particular, they provided valuable feedbacks about the structure and the contents of the DRL 4.0, highlighting the strength and weaknesses of the proposed model. They had a positive judgement about the dimensions chosen, and proposed some additional questions to enlarge the scope of the model. Based on these insights, the DRL 4.0 has been amended adding some more specific questions about the human factor and the competences required in Industry 4.0. Further, the introductive section about the general overview of the enterprise has been extended to include more details about the company. These parts, in fact, has been considered crucial to the correct evaluation and scoring of the answers given by the companies, in order to provide a real modular model.

The final DRL 4.0 model is composed of 46 questions (available upon request to the authors). To facilitate the respondents, the questionnaire has been released in Italian. The model is structured in three main sections. In the first section, 12 close-ended questions concerning the vital statistics of the firm aim at identifying the size of the enterprise in terms of employment and turnover, the industry, and the general features of the production process. The second section includes 24, 5-point Likert scale questions concerning the Industry 4.0 technological implementation in the enterprise, encompassing five different dimensions (described in Table 4). These questions are the core contribution to the DRL assessment. Finally, the third section includes 10 single-choice questions concerning the investments that the examined firm is undertaking or intends to evaluate in the short period. These questions can influence the final scoring: in fact, if an enterprise is undertaking an investment into a technology, an increment is assigned to the score assigned for the current implementation of that technology.

Considering the questions in the second section of the DRL 4.0, referring to technologies and features, the respondents should provide an answer $a_j \in \{1, \dots, 5\}$ (5-point Likert scale) to each of them; then, a score $S_i \in [1, 5]$ is defined for each dimension i as follows:

$$S_i = \frac{\sum_{j \in Q_i} b_j}{m_i} \tag{1}$$

where Q_i is the subset of questions referring to the dimension i, b_j is a parameter calculated as follows:

- $b_j = 0$ if the technology/feature j is deemed not applicable,
- $b_j = a_j$ if the technology/feature is applicable and the company is not planning any investment on it (or the investment has already been carried out and completed in the past),
- $b_j = \min(a_j + 1; 5)$ if the technology/feature is applicable and the company is currently investing on it.

and m_i is defined as:

$$m_i = card\big(\{j: j \in Q_i \wedge b_j > 0\}\big) \tag{2}$$

From these scores, a single index I is calculated:

$$I = \frac{\sum_{i=1}^{n} S_i}{n} \tag{3}$$

where $n = 5$ is the total number of dimensions.

The final score I defines the Digital Readiness Levels (DRL) of the company according to the rules presented in Table 5, which also provides the definition of the DRLs.

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Table 5 – DRL Clusters rules and definitions

The DRL 4.0 model focuses mainly on SMEs, often not led by professional managers and with great capacity for improvisation. In this respect, the questions are structured in such a way that fit the SMEs organizational structure, easy to be understood, and do not require particular a-priori knowledge (Wiesner et al., 2018). The most important feature of the DRL 4.0 with respect to the majority of other models is its modularity concerning the context, the vital statistics, and the situation in which each analysed firm finds itself. The DRL 4.0 model aims at fitting the company situation in the best possible way, overcoming the rigidity of the state-of-the-art tools, which force the examined firm to answer even those questions that do not concern the company's context, both in terms of identity data (production process, manufactured products, etc.) and technologies suitable for that business.

To achieve modularity, the scores assigned to the answers have not been fixed *a priori*. On the contrary, the answers to specific questions could be dependent on previously given answers. For instance, if a technology is not considered as relevant for the firm's business strategy or process, the fact that it is not adopted do not affect the final DRL of the enterprise. In the case of Company B, for example, robotics systems were not identified as a suitable technology, because the company operates in Engineer to Order fashion with low production volumes requiring many human interventions in the production process. Therefore, although in a question the respondent stated that no robotic systems are present in the shop floor, the score of the question did not negatively affected the DRL.

DRL 4.0-based assessment

In order to answer the second research questions, 20 case studies have been developed using semi-structured interview and direct observation. All the collected data have been stored in a structured database, to facilitate the analysis. Each interview lasted about three hours on average, involving two to three people with different business roles: overall, 60% were CEO/entrepreneurs, 20% CIO, 10% production managers and 10% operations managers. In addition, direct observations of the company production systems provided valuable insights on the status of the company, especially referring to the adopted technologies. After the interview, two directions of analysis have been followed: first, data within case have been analyzed in order to become intimately familiar with each case as a standalone entity, and to allow the unique patterns of each case to emerge before seeking to generalize across cases (Eisenhardt, 1989). This analysis allowed to define the maturity level of each company along the five dimensions, to identify the main strengths and weaknesses, and to develop a personalized roadmap towards Industry 4.0. Secondly, a cross-case analysis has been carried out to compare the different cases: by looking at the data in many divergent ways, it was possible to draw out general insights related to the current state of the art of Italian companies to accelerate Industry 4.0 implementation.

The results of the interviews have been reported to each company during dedicated meeting where results and suggestions specific to each company have been discussed with the people that participated in the interview, along with other relevant decision making roles. In the next section, the results from the multiple case studies are discussed.

5. Case-studies results

In this section, we summarize the main results emerging from the adoption of the DRL 4.0 model in 20 Italian SMEs (refer to section 3 for the discussion of the sample). Considering the whole sample, we observe an average index $\bar{I} = 2.8$, thus defining an average DRL equal to 3. Figure 2 shows the distribution of the DRL levels in the sample.

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Figure 2 - DRL distribution

This means that companies are currently approaching the path towards Industry 4.0 and the digitalization of their processes, but there is still room of improvement. More insights can be drawn looking at the different dimensions, shown in Figure 3.

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Figure 3 – Average scores S_i of the total sample

Processes

The analysis of the five categories shows that "Processes" is the most mature dimension in the interviewed companies. As reported by Khan and Turowski (2016), one of the key point of Industry 4.0 is the availability of a huge amount of data retrieved from the different areas that allows to effectively monitor processes and to make more informed decisions. Thus, this area analyses, first, how data are gathered, shared and managed inside the company and, second, how the main internal processes are managed.

Regarding the first point, almost all the analyzed companies gather some kinds of data from the production system. In particular, 47% of the sample gathers data only at the end of the working shift, while 47% has implemented tools to continuously retrieve data from their machines. Among this second group, 50% of the sample is able to remotely monitor in real time the main performance of the production machines. Only 6% of the sample does not gather any kind of data from their production system.

The main data gathered are those related to warehouse and to wastes and defects generated during the production process. A smaller portion of the sample monitors data related to the machine performance, processing time, machine availability, and functioning parameters. These data are mainly used to monitor the performance of the production system and quality, while application of forecasting, optimization and predictive maintenance are still missing. However, 50% of companies in the sample are currently investing in this field in order to increase the amount of data recorded from the production processes, and to improve the way these data are managed. These results can be justified considering the National Industry 4.0 plan promoted by the Italian Government, which provides fiscal incentives for investments in new tangible assets, devices and technologies enabling companies' transformation to "Industria 4.0".

Regarding commercial data, they are generally analyzed with a fixed frequency to assess the commercial process, even if only 35% of companies has a Customer Relationship Management (CRM) tool. However, 40%

of the sample is evaluating its introduction to improve the management of actual and potential customers as well as all the management of data related to the relationship.

The second aspect analyzed in this dimension is the management of internal processes, considering the digitalization level and the integration with other processes. The main processes, starting from the strategy definition and product design to production management, delivery and after sales, have been deeply investigated. As shown in Figure 4, for each process, the supporting system class has been identified, distinguishing among Enterprise Resource Planning (ERP), ERP-integrated applications, and stand-alone applications. The results show that the operative processes are mainly supported by the ERP or ERP-integrated applications (such as logistics processes, order management and warehouse management). Stand-alone applications are still used in the after-sales services and in the managerial processes, such as budget definition and reporting. Thus, it is possible to conclude that the use of integrated information system is quite spread among the companies especially for routinary tasks. On the other side, advanced data analysis applications and/or decision support systems are still rarely implemented, as companies generally leverage on people expertise and personal market and product know-how for decision making. From this point of view, there is room for improvement in the management of these processes in order to provide information useful from a strategical point of view.

The “Process” dimension also encompasses after-sales services. Only six companies in the sample provide after-sales services to their customers; among them, only three leverage on connected products (usually machines) offering remote maintenance and remote monitoring. Only one company offers Condition Based Maintenance (CBM), which presumes the remote monitoring or product parameters and the intervention when one or more parameters are under or above their critical thresholds, signaling that a potential failure is imminent. The remaining 14 companies do not offer any after-sales services, because either the product is not suitable to services or the company is still product-oriented without a focus on service. However, the service processes are not well integrated in the companies, and it is usually managed without the support of an information system. Consequently, data, information and feedbacks from the service department are not well managed inside the companies.

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Figure 4 – Supporting systems for the enterprise processes

Strategy

The second dimension with the highest value is “Strategy”. This dimension involves the investment in Research & Development, the strategy definition towards Industry 4.0 and the related roadmap, and top management commitment. The average investment in R&D is between 1% and 5% of the revenue, aligned with the Regional level but below the European average (Rapporto Assolombarda, 2017). About 50% of companies have an Industry 4.0 strategy in place even if not all these companies have already defined a roadmap and a path toward the implementation of Industry 4.0 principles. These data are confirmed by the fact that about 50% of companies in the sample are investing in product and technologies related to Industry 4.0. Furthermore, 65% of companies declared that the top management commitment is high, representing a positive signal for the success of the implementation (De Sousa Jabbour et al., 2018). However, analyzing the main barriers to implement Industry 4.0 strategy, almost 50% of companies declared that the main barrier is the lack of an action plan (Figure 5). This can be related to the fact that the companies are currently approaching their path towards Industry 4.0 and they are still defining the strategy.

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Figure 5 – Barriers to Industry 4.0 implementation

People

One of the main key factor in defining and implementing successfully strategy is the competence level of people involved in the decision and implementation process (Prifti et al., 2017). Figure 6 reports the average competence level related to smart technologies within a range from 1 (no competence) to 5 (high competence). Companies are lacking knowledge on the main Industry 4.0 technologies, especially robotics, automation, big data, IoT and Cyber-physical systems (CPS). For this reason, they should establish upskilling and reskilling actions to allow the employees to exploit the potentials of new technologies. In particular, lifelong learning and training are required (Zinn and Tenberg, 2015).

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Figure 6 – Competence level about smart technologies

Integration

The fourth dimension analyzed is integration, both vertical and horizontal. Vertical integration describes the intelligent cross-linking and digitalization within the different aggregation and hierarchical levels of a value creation module from manufacturing stations via manufacturing cells, lines and factories, also integrating the associated value chain activities such as marketing and sales or technology development (Stock and Seliger, 2016). In our case, it has been evaluated considering the information systems currently implemented inside a company and their level of integration. Thus, considering the ERP as the core of the company, we assume that vertical integration is achieved when all the information systems are integrated with it, meaning that they exchange data in a bidirectional way.

To this purpose, we analyzed which information systems are used in the company and if they are integrated with the ERP. Figure 7 shows the results. Considering only the integration of information system in a scale from 1 to 5, the average value is 2.9 demonstrating that the different departments are still acting as separate silos and there is room of improvement to achieve a more efficient internal data sharing and integration. Analyzing the results in more detail, CAD, CAM, document management and CRM are the most popular applications, even if they are not always integrated with the ERP. Furthermore, data show that MES systems are rarely used in the companies (only the 50% has it implemented, and only in the 30% of cases it is integrated with the ERP). This means that the shop floor is still managed based on people expertise, and its performance are difficult to keep monitored continuously and in real time. Among companies that do not currently have a MES, only the 30% is evaluating its introduction. E-commerce and PLM systems are quite difficult to find in SMEs, maybe because they mainly rely on traditional selling, and PLM are usually not affordable for small and medium enterprises.

========================== INSERT FIGURE 7 ABOUT HERE ===================================

Figure 7 – IT tools integration

Horizontal integration aims at forming efficient ecosystem through a fluent flow of information, finance, and material among companies (Wang, Wan, et al., 2016). To this purpose, integration with customers and suppliers has been investigated in terms of communication and information sharing. The results show that currently, horizontal integration is very limited (the average value is 2 out of 5): only five companies out of 20 have an Electronic Data Interchange (EDI) system in place with the main customers and suppliers replacing ordinary e-mail and fax.

Technology

The lack of knowledge about main technologies (Figure 6) is strictly related to the level of adoption of these technologies. The companies interviewed still leverage traditional manufacturing systems, characterized by high level of automation but generally adopting traditional human-machine interfaces, provided by the machines' suppliers, in order to read machine information (PLC with the related consolle to read the main working parameters, alarms, and so on). Only two companies are introducing wearables to monitor machines and receive alarms. Regarding robotics, usually companies use traditional robotics to move products and components inside their machine tools or the production lines, while collaborative robotics is still considered not applicable to their production processes. The same for additive manufacturing technologies, where only 30% of companies declared to use 3D printing mainly for the production of samples and prototypes.

Almost all companies are adopting some traceability systems to identify products and component during the production process and/or after the sale of the product. In particular, 50% of companies use barcode to trace lots of finished products and components whereas only 20% of the sample uses RFid. However, single product traceability inside the production process is still limited.

The last technology considered is the cloud. In general, companies prefer to keep data stored on in-house servers rather than on the cloud. The few companies that trust cloud services mainly exploit it for storage services or use some software-as-a-service. None of the companies interviewed exploit cloud analytical services, namely that a user sends data to a provider, and the provider's hardware performs necessary actions to the data (i.e. data analytics) and then sends back the results.

========================== INSERT FIGURE 8 ABOUT HERE ==================================

Figure 8 – Technology adoption

6. Discussion

According to the outcomes discussed in the previous section, the sample presents on average an intermediate readiness level with respect to Industry 4.0. The involved SMEs are aware of the phenomenon, but the management is still moving the first steps to identify the most appropriate strategy towards this fourth industrial revolution. Companies still need support to contextualize Industry 4.0 in their reality, and to identify the investments required for a successful transition.

Independently from the field, the highest priority step and the starting point to undertake a successful improvement project in any organization is the top management commitment and the definition of company's objectives at strategical level (Erol et al., 2016; Fassoula, 2006; Ghobakhloo, 2018). This holds true also in the definition of a roadmap towards Industry 4.0. In fact, the companies in the sample with the highest score in the strategy dimension are also the ones with the highest DRL. Furthermore, the lack of a digital strategy, vision, and action plan were the most mentioned barriers. Top management must endorse initiatives in the Industry 4.0 areas, providing the necessary resources and support along all the implementation phases. Indeed, only the highest levels of management have budget responsibility, and are able to dedicate resources to specific activities and realign the incentives to develop cross-functional capabilities. A lack of top management support makes any integrative efforts superficial and ineffective. At the same time, also lower-level managers and workers across the organization should be involved and committed to the project (Fawcett et al., 2006).

The Industry 4.0 strategy should encompass a (re)definition of the company's offering and its relationship with customers. The results showed in the previous session demonstrates that companies are still mainly product-oriented, and only a small percentage of the sample offers after-sales services through connected products. This trend would probably change in the next years, and companies would need a structured approach to integrate the product and service components since the early stage of the design phase (Pezzotta et al., 2018). Indeed, as more software and embedded intelligence are integrated in the products, a growing amount of data related to all the phases of the lifecycle are becoming available, fostering companies to develop new businesses. Predictive technologies along with intelligent algorithms will allow to predict product performance degradation, and autonomously manage and optimize product and service needs (Lee et al., 2014). This would lead manufacturing company to move towards service transformation and, in particular, towards the offering of services enabled by digital technologies and connectivity, such as remote monitoring and predictive maintenance (Ardolino et al., 2018), moving the paradigm of manufacturing from product to usage (Roland Berger, 2016).

Companies need to identify and recruit the competence and the skills needed to implement the Industry 4.0 strategy and their business model. In this context, competence related to problem solving, optimization, analytical skills, big data, and cognitive abilities are becoming increasingly relevant (Benešová and Tupa, 2017; Pinzone et al., 2017; Prifti et al., 2017). Even if the companies analyzed seem aware of this necessity – and are trying to fulfill their gap, especially in terms of data analytics – skills gaps still exist, mainly related to the technological field (e.g. IoT, robotics). Further, as Industry 4.0 will lead to a more interdisciplinary, international and flexible work environments, competencies such as working in interdisciplinary environments, flexibility, adaptability, critical thinking, customer orientation, and change management are becoming required skills (Prifti et al., 2017). Thus, exhaustive training programs devoted to the different facets of Industry 4.0 are required.

Once the management has defined the objectives of the company, and allocated the appropriate resources, investments can take place. The case studies showed that the "Process" dimension is the most mature area, even if the automatic collection of data regards only some production data and it is used to a limited extent, while "Integration" is one of the less mature dimensions. Thus, investment should aim at connecting the different departments of companies, improving the information sharing and enabling a data-enabled decision-making processes. Indeed, personal expertise is so far the main support for managerial processes, and decision support systems are not widespread among SMEs. As pointed by Lasi et al. (2014), Industry 4.0 drives manufacturing in two directions: *application-pull* (changes are induced by new exogenous conditions, i.e. short development period, individualization of demand, flexibility, decentralization and resource efficiency), and *technology-push*, with an increase of digitalization, automation, mechanization and miniaturization. Thus, at the organization level, the success factor is the ability to implement a smart factory, where components are able to communicate with one another at the field level, in real-time, and with an intelligent functionality that collects data, interprets them, and offers meaningful insights to the management (Gilchrist, 2016). On the one side, this requires the integration of CPS in the production floor to manage the interconnection between physical assets and computational capabilities (Lee et al., 2015). On the other side, it requires an ubiquitous processes integration among companies to allow real time and effective data and information sharing at the different levels of the organization, enabling prompt reactions in case of internal and/or external problems. Developing a CPS application requires the acquisition of accurate and reliable data from machines and their components, through sensors (Lee et al., 2015). These data, along with traceability information, allow a real-time management of the production flows, and help decision makers understanding how plant floors can be optimized and production outputs improved. To this purpose, technologies for the single piece traceability (e.g. RFid) and the implementation of Manufacturing Execution System (MES) integrated with the ERP would facilitate the information transparency and connectivity to business data in real-time (Wang, Gunasekaran, et al., 2016). Furthermore, data and information sharing among the other areas of companies (e.g. design, marketing, …) and with other actors of the value chain (i.e. suppliers and customers) can be reached through the implementation and integration of other information systems, such as PLM, PDM, WMS, and so on.

The results from case studies along with these Industry 4.0 principles and technology trends, such as horizontal and vertical integration, indicate that IT has a relevant weight in the digital transformation. Thus, an initial detailed analysis of the actual IT infrastructure and an accurate cost-benefit analysis of possible investment should be the starting point of any projects, which must be characterized by precise definition of needs, objectives, to-be situation, and activities planning.

Lastly, Industry 4.0 is also about automation technologies (such as robotics, additive manufacturing, and so on) which make the production processes more efficient. Our research suggests that the main problems for SMEs are mainly related to the data and information management inside and outside the company boundaries, which is one of the main key point of Industry 4.0. Then, the integration of data and processes, mainly between the production floor and the other areas of the company, represents a higher priority in the journey towards the implementation of Industry 4.0.

7. Conclusions

The assessment of the current capabilities of an organization with respect to the endeavor required by the structural changes advocated by the Industry 4.0 model is a mandatory step to outline the projects and the investment to undertake. In this respect, the primary aim of this research was to design an assessment tool addressing the readiness of SMEs with respect to Industry 4.0. The DRL 4.0 tool was designed to overcome some limitations of existing maturity models, whose monolithic structure does not always fit SMEs organization. The analysis of the maturity of 20 companies based on the DRL 4.0 allowed us to identify some priorities in the transition towards Industry 4.0. These priorities involve the strategy and business model, the technology basis of the company, the skills and competence required, the processes' digitalization, thus requiring a careful and overarching planning and execution.

Future work should aim at extending the capabilities assessment with the definition of specific road maps and action steps to drive the transition from the current maturity level to the desired one, taking into account the, often limited, amount of resources available to SMEs.

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Name	Source	Target	Output	Analysed dimensions
Industry 4.0 Maturity Model - (I40MM)	(Schumacher et al., 2016)	Manufacturing Firms	Spider diagram of nine analysed dimensions	Strategy, Leadership, Customers, Products, Operations, Culture, People, Governance, Technology
Croatian model of Innovative Smart Enterprise – (HR-ISE model)	(Veza et al., 2015)	Croatian Manufacturing Firms	Index based on the average of the positioning of each dimension in the 1st-4th Industrial Revolution	Product Development, Technology, Production Management, Production Monitoring, Materials Inventory Management, Management of Stocks of Finished Products, Quality Assurance, Product Lifecycle Management, Toyota Production System
Forrester Digital Maturity Model 4.0 - (FDMM40)	(Gill and VanBoskirk, 2016)	Firms	Index to assign to maturity segments (Differentiators, Collaborators, Adopters, Skeptics)	Culture, Technology, Organisation, Insights
System Integration Maturity Model Industry 4.0 - (SIMMI 4.0)	(Leyh et al., 2016)	Firms	Positioning of four dimensions in five maturity Levels	Horizontal, Vertical integration, Digital Product Development, Cross-sectional Technology Criteria
Industry 4.0 Readiness Online Self-Check for Businesses - (IMPULS)	(Lichtblau et al., 2015)	SMEs	Positioning in six readiness levels	Strategy&Organisation, Smart Factory, Smart Operations, Smart Products, Data-driven Services, Employees
Test Industria 4.0 – (TI40)	(Politecnico di Milano, 2017)	Manufacturing Firms	General maturity index to assign to five digital maturity levels - Report with Opportunities	Analysis Dimensions (Execution, Monitoring&Control, Technologies, Organisation)
PwC - Online Self-Assessment (PwC SA)	(PwC, 2014)	Firms	Radar chart based on six dimensions, positioning in one of four levels	Business Models, Product&Service portfolio; Market&Customer Access; Value chains, process & systems; IT Architecture; Compliance, risk, security, tax; Organisation and Culture
IMP^{3}rove Digital Innovation Quotient	(IMP^{3}rove Academy, 2007)	Firms	Radar chart of dimensions, report with benchmark, roadmap for Innovation	Innovation Strategy, Business models, Processes, Ecosystem and Culture, Enabling Factors (Financial resources, IT, risks and compliance)
The Acatech Industrie 4.0 Maturity Index	(Schuh et al., 2017)	Firms	Positioning of the four dimensions in six levels	Resources, Information Systems, Organizational structure, Culture
Three Stage Maturity Model in SME's (3SMM)	(Ganzarain and Errasti, 2016)	SMEs	Positioning in five maturity levels	Not considered

SM³E	(Mittal et al., 2018)	SMEs	Positioning of five dimensions in four maturity levels	Finance, People, Strategy, Product, Process
Industry 4.0-MM	(Gökalp et al., 2017)	Firms	Positioning in six maturity levels	Asset Management, Data Governance, Application Management, Process Transformation, Organizational Alignment
Industry 4.0 Maturity Model	(Akdil et al., 2018)	Firms	Positioning of three dimensions in four maturity levels	Smart products and services, Smart business processes, Strategy and Organization

Table 6 – Industry 4.0 maturity and readiness assessment models

	PRODUCTS	**CUSTOMERS**	**SERVICES**	**TECHNOLOGY**	**OPERATIONS**	**STRATEGY**	**ORGANISATION**	**PEOPLE/CULTURE**	**INTEGRATION**	**INNOVATION**	**RISK**
I40MM	X	X		X	X	X	X	X			
HR-ISE	X			X	X						
FDMM 4.0				X		X	X	X			
SIMMI 4.0	X			X					X		
IMPULS	X		X		X	X	X	X			
TI40		X		X	X		X	X			
PwC SA	X	X	X	X	X	X	X	X			X
IMP³rove				X	X	X		X		X	
Acatech	X			X			X	X			
3SMM						X					
SM³E	X			X		X		X			
Industry 4.0-MM				X	X	X		X			
Industry 4.0 Maturity Model	X		X	X	X	X	X				

Table 7 – Considered dimensions among existing maturity models

Industry	% of SMEs in the industry	Number of case studies
Manufacture of fabricated metal products, except machinery and equipment	26%	3
Manufacture of machinery and equipment n.e.c.	17%	4
Manufacture of rubber and plastic products	11%	2
Manufacture of textiles	6%	2
Manufacture of electrical equipment	5%	5
Manufacture of wearing apparel	5%	1
Manufacture of chemicals and chemical products	4%	1
Manufacture of food products	4%	
Manufacture of other non-metallic mineral products	4%	
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	3%	
Manufacture of basic metals	3%	
Manufacture of computer, electronic and optical products	3%	1
Printing and reproduction of recorded media	2%	
Manufacture of paper and paper products	2%	
Manufacture of motor vehicles, trailers and semi-trailers	1%	
Manufacture of other transport equipment	1%	
Manufacture of beverages	1%	
Manufacture of basic pharmaceutical products and pharmaceutical preparations	1%	1
Other manufacturing	3%	

Table 3 – Case studies distribution among industries

Dimension	Description	Considered literature dimensions
Strategy	Analyses the strategy of the company with respect to digitalization and the adoption of Industry 4.0 principles.	Strategy, Organisation, Innovation, Risk
People	Analyses people skills and how the know-how is managed inside the company.	People/Culture
Processes	Analyses how internal processes are managed from a digitalization point of view and how data are collected, shared and managed inside the company.	Products, Customers, Services, Operations
Technology	Analyses the current adoption of the Industry 4.0 enabling technologies.	Technology
Integration	Analyses the digitalization level and the integration with other actors of the value chain.	Integration

Table 4 – Description of the DRL 4.0's five dimensions

DRL	Rule	Definition
DRL 1	1 < *I* ≤ 1,8	Identifies a company not involved in Industry 4.0 pilot initiatives. Information Technology (IT) systems support only few processes (processes are partially digitised or not digitised at all), and the current infrastructure do not allow process integration. Collection of data from field is not done. The skills needed to expand Industry 4.0 are found only in few areas of the company. Horizontal integration and internal information sharing are limited while no integration is foreseen with other actors of the value chain. The business does not pursue service-oriented and cloud-based approaches.
DRL 2	1,8 < *I* ≤ 2,6	Identifies an intermediate-level company that includes Industry 4.0 into its strategic orientation. The company is planning some pilot initiatives. Information Technology (IT) systems support routinary activities (processes are quite digitised), and the current infrastructure allows some process integration. Automatic and real time collection of data regards only some production data and it is used to a limited extent. Horizontal integration and internal information sharing is limited to some areas and the first steps are being taken to integrate data with value chain members. Employees own the necessary skills with respect to Industry 4.0 only in some areas.
DRL 3	2,6 < *I* ≤ 3,4	Identifies a company that has formulated an Industry 4.0 strategy and is investing to promote the introduction of Smart Manufacturing. Information Technology (IT) systems support most of the processes, and the current infrastructure allows process integration. Data are automatically collected in real time in key areas of production. Information sharing, both internal and with external actors, is partially integrated into the system. At this level, the company manufactures products equipped with IT-based functionalities, enabling the provision of first data-driven services, which still account for a small share of revenues. Efforts to expand employee skills are in place.
DRL 4	3,4 < *I* ≤ 4,2	Identifies a company which is already implementing an Industry 4.0 strategy, monitoring its development with suitable indicators. The company is horizontally and vertically integrated, and Industry 4.0 requirements have been implemented within the company, automating information flows. Investments concern nearly all relevant areas, and an interdepartmental innovation management supports the process. Data about production processes are collected and used for optimization. Information sharing is largely integrated into the system, both internally and with value chain partners. The products feature IT-based functionalities, allowing data collection during the usage phase, enabling and supporting data-driven services. Services are available ubiquitously within the company, and can be accessed anywhere, allowing employees to retrieve information through mobile devices. The company has the necessary skills in most of the relevant areas.
DRL 5	4,2 < *I* ≤ 5	Identifies a company that has already implemented its Industry 4.0 strategy and continuously monitors its implementation. The company is fully digitized, both inside and beyond corporate borders, and integrated with the value chain. Investments are made throughout the company. Large amount of data about production processes are collected and used for process optimization. Some areas of production currently use autonomously guided work lines and processes able to react autonomously. The data collected in during the product usage phase are used considerably for functions such as product development and remote maintenance. Data-driven services for consumers account for a significant share of revenues, and the producer is fully integrated with the customer. The company has the internal human skills it needs in all critical areas.

Table 5 – DRL cluster rules and definitions

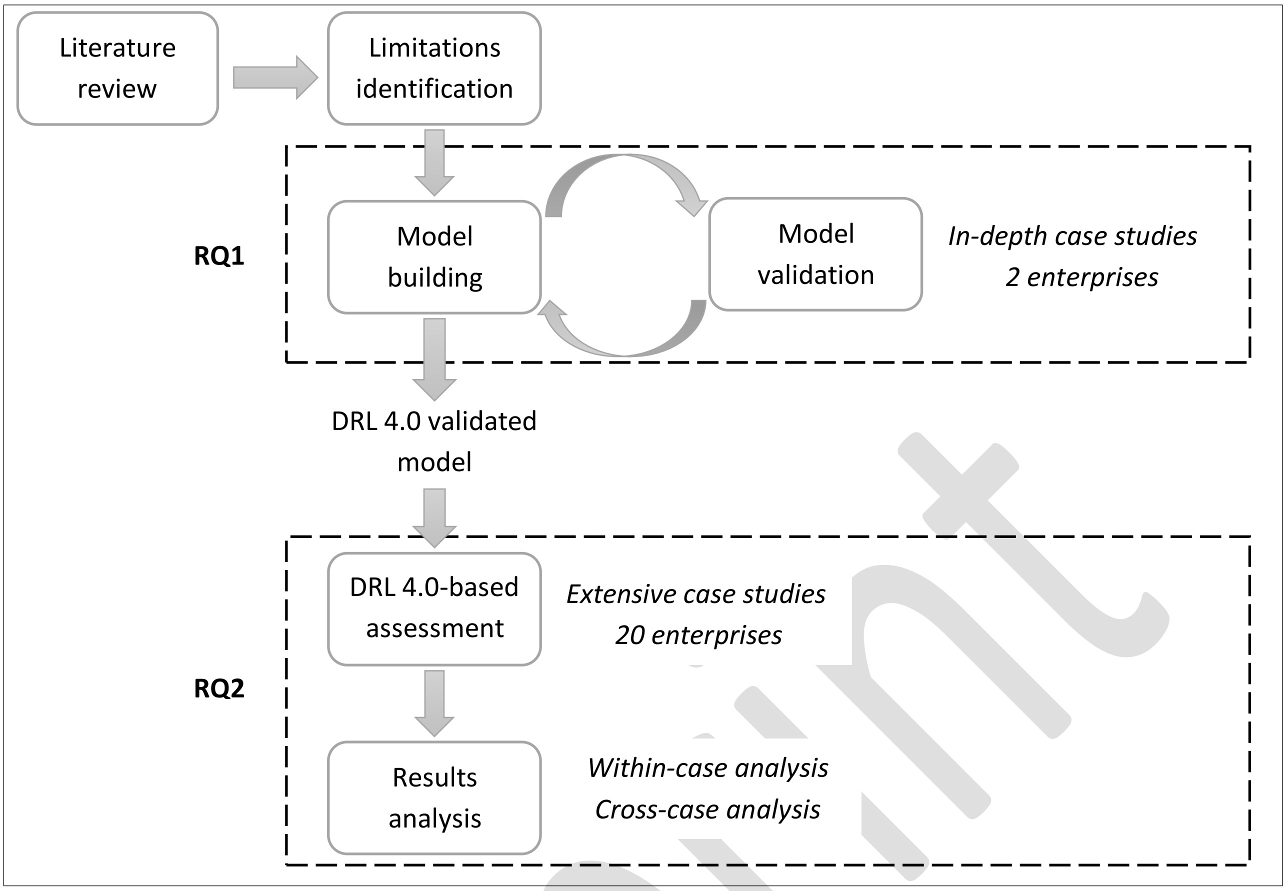

Figure 9 – Research protocol

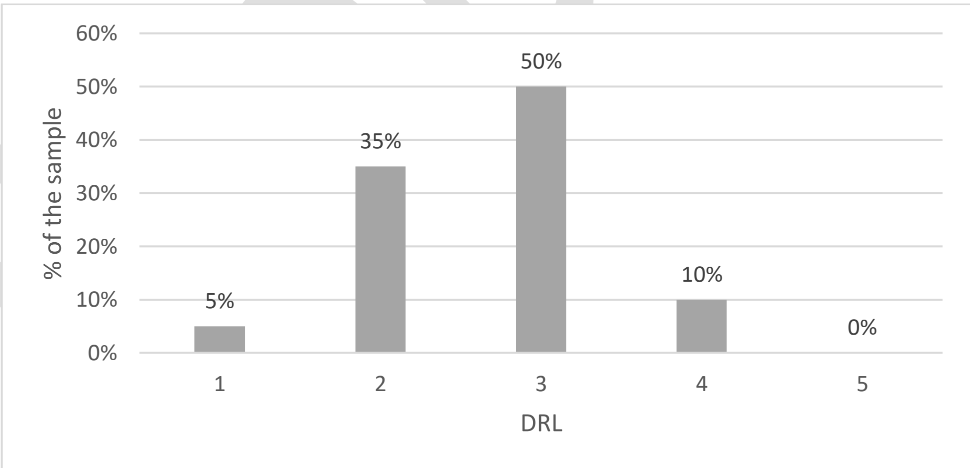

Figure 10 - DRL distribution

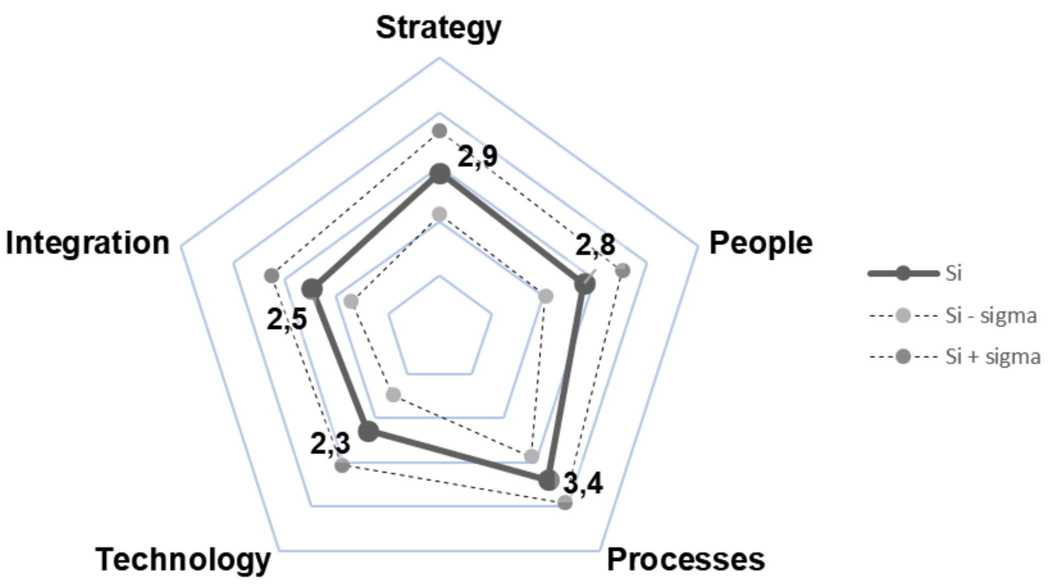

Figure 11 – Average scores S_i and standard deviations of the total sample

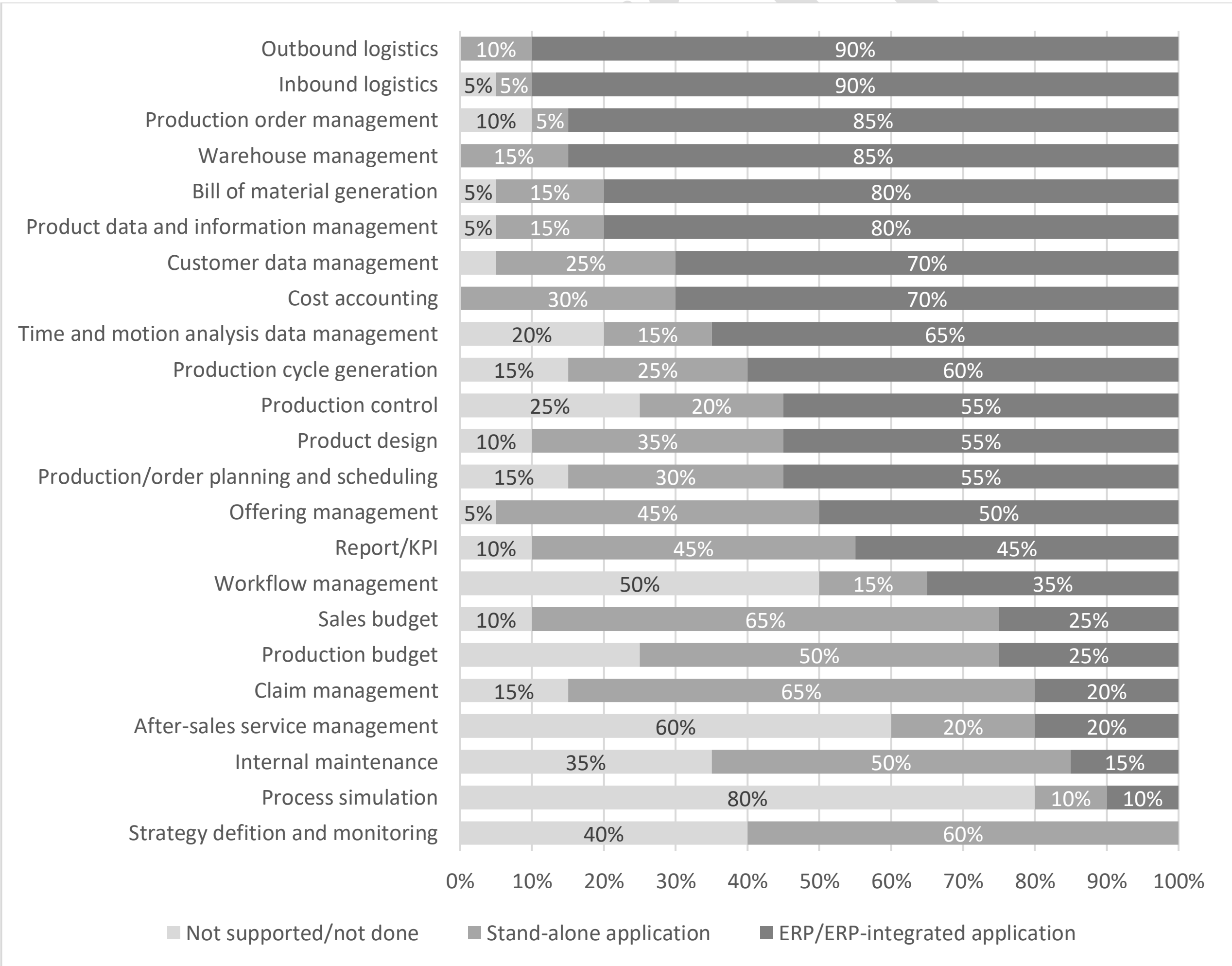

Figure 12 – Supporting systems for the enterprise processes

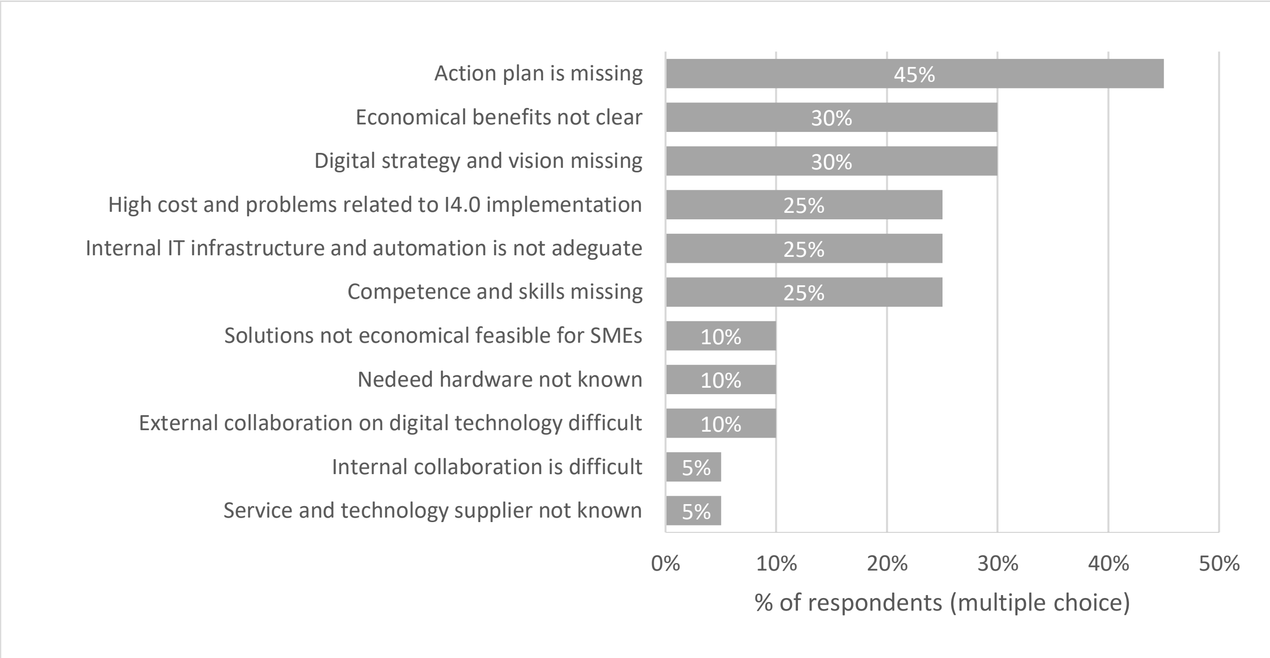

Figure 13 – Barriers to Industry 4.0 implementation

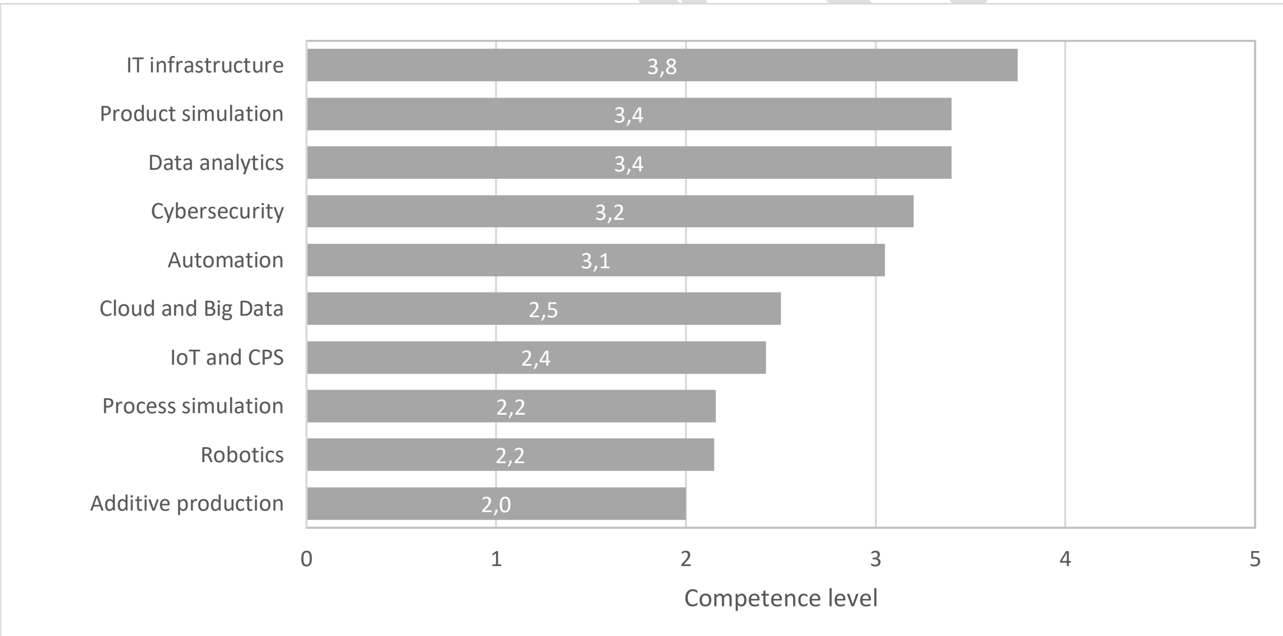

Figure 14 – Competence levels about smart technologies

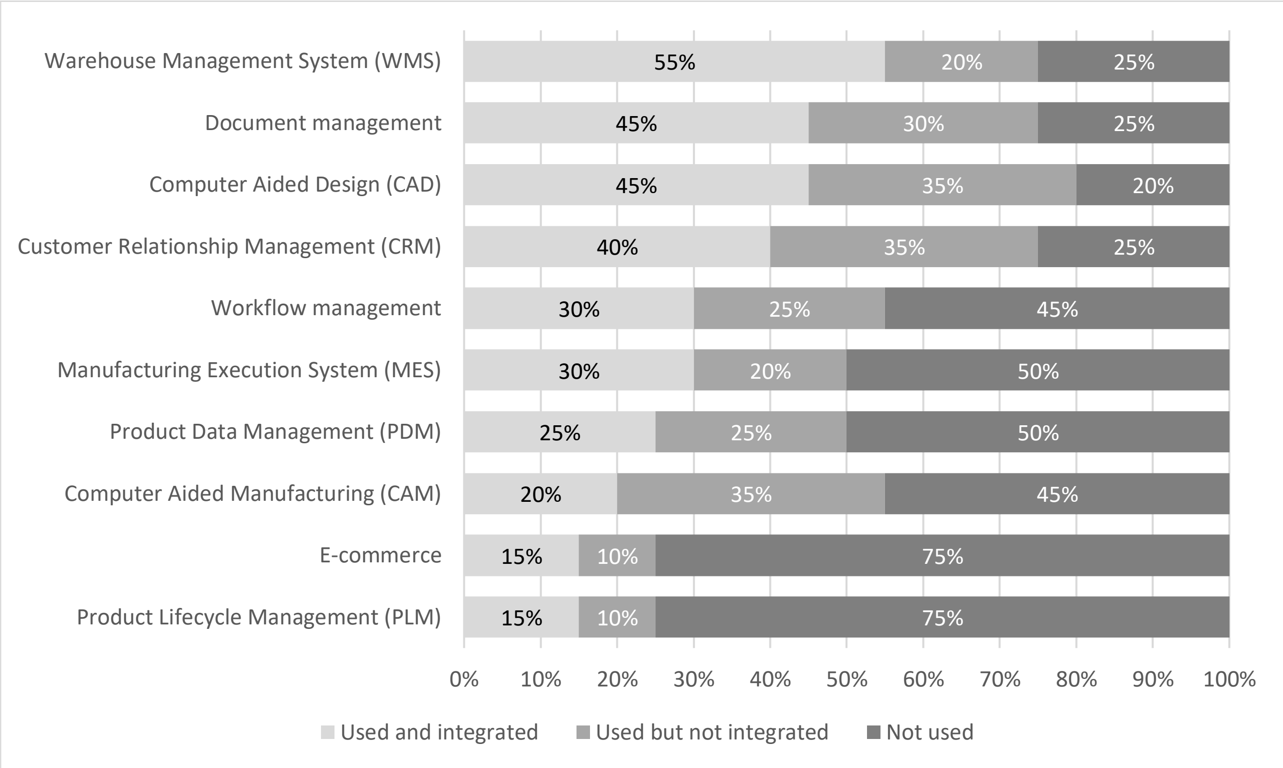

Figure 15 – IT tools integration

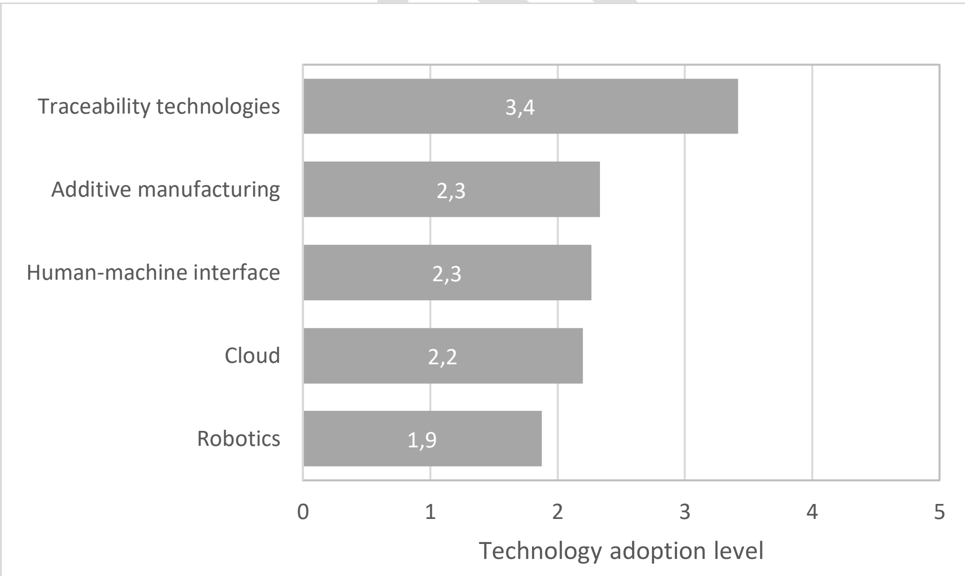

Figure 16 – Technology adoption