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Key Readiness Indicators To Assess The Digital Level of Manufacturing SMEs

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Abstract

The assessment of the digital level is considered pivotal, for manufacturing companies including Small- and Medium-Sized Enterprises (SME), at the outset of implementing Industry 4.0 solutions in their digital strategies. Several self-assessment tools exist measuring the digital readiness and maturity, returning the overall digital level of the companies. On the one hand, the application of such tools proved to be effective, as it enables companies to systematically reflect about their digital level, strengths and weaknesses as well as opportunities and challenges to consider prior to the implementation of Industry 4.0. On the other hand, particularly for SME facing higher challenges compared to large companies in the management of digital transformation, relying exclusively on the knowledge of their overall digital level may offer limited elements to strategically orient decision-making process in this field. The present study presents the methodology used to develop, within the framework of a self-assessment tailored to the requirements of SME, a set of Key Readiness Indicators (KRI), deepening the interpretation of the overall digital level of the companies in specific areas of interventions. The KRI focus on the digital readiness of companies in terms of strategy, technological requirements, awareness about digital trends, and competences of employees, to offer complementary information to ease the definition of strategies for technological implementation in SME. Besides the methodological approach employed, the study shows the distribution of KRI within a sample of manufacturing companies located in the Marche region (Italy) taking part to the proposed self-assessment. The emerging dynamics of the distribution of KRI according to varying company characteristics such as size, turnover and overall digital level will be presented and discussed, together with the main implications related to the use of KRI for strategic planning of Industry 4.0 in manufacturing companies.

Keywords: Industry 4.0; Assessment; Digital Level; SME; Key Readiness Indicators; Field Study;

1. Introduction

Manufacturing companies in general, and SMEs in specific, face the challenge of adapting existing strategies, towards more flexible production processes, following the introduction of Cyber-Physical Systems (CPS). Encompassing a wide range of hardware and software systems, CPS contribute to the intelligent digitalization of processes and production systems, allowing a continuous exchange of information from the physical world to the digital world [1]. This will enable companies to progressively increase product complexity, without compromising system efficiency, enabling the transition from the mass production model to a flexible and highly customized production model (Mass Customization). The achievement of this ambitious goal also requires SMEs to adopt Key Enabling Technologies for Industry 4.0, while rethinking their business models, production, and organizational processes, to ensure their integration in increasingly digitalized and global supply chains. In recent years, an increasing amount of scientific research in this field agrees about the potential of Industry 4.0 for SMEs [2] and the higher number of challenges to overcome, compared to larger companies, in the implementation of relating concepts and technologies [3]. Besides financial and knowledge constraints [4], the lack of a company specific digital transformation

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strategy are the main challenges [5], limiting the transition of Industry 4.0 in SMEs to a mere theoretical level.

To support SMEs in the technological and organizational planning of Industry 4.0, the assessment of the digital level of the company is found to be the starting point for an effective strategic development [6]. Consulting companies, universities and applied research centers have developed various readiness and maturity models, aiming at positioning the companies in the context of Industry 4.0 and enabling the definition of action plans tailored to their specific requirements. Notably, [7,8,9,10,11,12], offered systematic recent reviews of the main exiting tools readiness and maturity models, usually proposed as self-assessment surveys. These models, although not all exclusively targeting SMEs, share the similar main structures, namely dimensions of analysis to be assessed, such as among others, "Strategy", "Processes", "Products", "Cyber Security", rating systems, metrics for the assessment of the questions and the resulting maturity level. The latter represents the most critical information for SMEs, as it conveys the digital starting situation of the company to consider toward the adoption of Industry 4.0 solutions. Against this background, [8] argue that incomplete definition of maturity level might confuse SMEs in the proper interpretation of results.

To offer additional information, easing the interpretation of results, relating to the digital readiness, the present paper developed metrics defining ready-to-use Key Readiness Indicators (KRI). This concept was formulated, considering the diffuse and effective utilisation of Key Performance Indicators (KPI) in several management issues, enabling the timely identification of action plans improving the performance of the companies [13]. In this regard, attempts made to transfer such tools in the field of strategic planning for Industry 4.0 are summarised in the present work. The set-up of KRI should convey information enabling, particularly SMEs with less dedicated resources available to manage innovation processes, to promptly recognize specific areas of intervention, prior to the implementation of Industry 4.0 solutions. The KRI face the challenging objective of briefly deepening the reflection about specific aspects related to the overall digital readiness level. Companies self-assessing their digital level following such an approach, besides displaying the results in a relatively innovative format, encounter with higher likelihood room for improvements, regardless of their overall digital level achieved. To this respect, the results show that both the highest and lowest overall digital level achieved, is rarely combined with the attainment of the highest and lowest level of KRI, respectively.

This paper is structured as follows. After this introduction, the methodology used to derive the KRI will be described. Then, the distribution of KRI, resulting from a sample of manufacturing companies will be outlined. Finally, conclusions about the main implications of the findings, limitations and outlook for future research will be drawn.

2. Methods

The methodological framework employed to derive the KRI is based on a self-assessment tool named "Digital Check", developed, among others, by the authors of the present work [14]. The survey comprising 26 questions (Q-n), enables companies evaluating their digital readiness level across the following dimensions, namely (D1) Strategy, (D2) processes, (D3) Industry 4.0, (D4) employees, (D5) Information Technology (IT) and data security. The resulting readiness level was calculated taking the overall-average of selected five-points Likert scale questions, ranging from 1 (low implementation level) to 5 (high implementation level), in each considered dimension. The outcome of the assessment results in a three-level readiness model, classifying companies as (i) "Digital Newcomers" (low digital level), (ii) "Companies in Transition" (Medium digital level) and (iii) "Top Performers" (high digital level). Furthermore, based on the concept of Key Performance Indicators (KPI) [15] a set of Key Readiness Indicators (KRI) were derived considering additional metrics from the survey, measuring the preparation of companies toward industry 4.0 with a focus on strategy, technological requirements, awareness about digital trends, and competences of employees. The KRI convey additional information useful to deepen the interpretation of the overall digital readiness level of individual companies. They have been chosen among these specific fields, to obtain further parameters for the evaluation in relation to the main challenges that SMEs face toward digital transformation, such as lack of strategy [5] ("KRI-Strategy), limited awareness of relevant technological trends and the implementation of Industry 4.0 concepts [16] ("KRI Awareness" and "KRI Technological Requirements"), limited knowledge and skills of employees [4] ("KRI Competences"). Such indicators are generated automatically according to specific combinations of responses provided by the company during the compilation of the Digital Check, also referring to pair of questions relating to different dimensions, as outlined in Table 1.

Table 1. Combination of questions for Key Readiness Indicators (KRI).

KRI	Target questions	Dimension
Strategy	Q-1 Degree of definition of a strategy towards Industry 4.0?	D1
	Q-2 Have you planned intervention of Industry 4.0 over the next two years?	D1
Technological requirements	Q-5 Expected adoption of Key Enabling Technologies for Industry 4.0 in the next two years.	D2
	Q-10 Knowledge about Industry 4.0.	D3
Awareness	Q-10 Knowledge about Industry 4.0.	D3
	Q-11 Need to increase knowledge about Industry 4.0 over the next two years.	D3
Competences	Q-18 Adequacy of digital skills of collaborators.	D4
	Q-19 Need to increase digital competences of collaborators over the next two years.	D4

The pairs of questions were combined considering their relevance to the content of the KRI, regardless of their dimensions, in terms of scope of detecting potential misalignment SMEs should consider for implementing Industry

4.0, additionally to the notion of their overall digital level. Following this approach, it resulted that the majority of KRI consists of pair of questions deriving from the same dimension, in which misalignments may emerge from inconsistent evaluations of the digital level, within the current (today) and expected (within two years) time perspective. The "KRI-Technological requirements" involves instead pairs of questions from different dimensions, in which additional information are conveyed, assessing the alignment of what the respondents consider as Key Enabling Technology and their perceived knowledge about Industry 4.0. The KRI is expressed in three-levels (L1) low, (L2) medium, (L3) high, according to the specific combination of responses referring to the target questions. To this respect, the classification into levels considers the Likert-Points rating assigned by the respondents to the pair of target questions constituting the specific KRI. Following this indication, a relatively high rating to both questions (e.g. 4-5; 5-5) will imply a high KRI. Conversely, joint average or low rating will result in medium or low KRI, respectively. The systematic evaluation of the joint rating can either be in line with the overall digital level of the company or detect potential misalignment across the responses. Table 2 provides an example of the combination of rating used, for the derivation of the "KRI-Strategy", measuring the presence of a coherent strategy. This relates to the areas of intervention the company intends to address, as stated during the self-assessment survey. In such a case, the lack of an adequate strategy in relation to the degree of complexity of specific intervention that the company is willing to undertake may signal the presence of inconsistences, resulting in a low KRI. For this reason, while the willingness to intervene in several areas of the company may contribute increasing the overall digital readiness level, a relatively lower KRI provides warnings with respect to the consideration of the corporate strategy toward Industry 4.0.

Table 2. Exemplary derivation of "KRI-Strategy".

Level	Rating (Q1-Q2)	Description
L1	1-1; 1-2; 2-1; 2-2; (…)	Not adequate preparation. Defining a strategy planning interventions and areas of application of Industry 4.0 technologies and concepts is essential for the future development of the company.
L2	3-3; 4-3; (…)	Moderate preparation as the company is in the process of initiating - or has already defined - an action plan for the digital transformation. The strategy seems limited to certain business areas.
L3	5-4; 5-5; (…)	Adequate preparation as there is a strategy in progress and it seems to be aligned with the scale of interventions the company intends to implement in the medium and long run.

The derivation of the other KRI previously mentioned refers to similar considerations defining the three resulting levels of attainment, while measuring different aspects as follows:

- adequacy of knowledge related to industry 4.0 in relation to the technologies to be adopted in the short and immediate term ("KRI-Technological requirements")
- to what extent the company is aware of the relevance of industry 4.0 in relation to the level of knowledge perceived by respondents ("KRI-Awareness")
- Alignment of digital skills of employees to the scale of planned investments in Industry 4.0 ("KRI-Competences").

The next section presents the results of the case-study, in which a sample of manufacturing companies compiled "Digital Check" self-assessment, returning both the digital readiness level and the four described KRI as complementary information. For the sake of this paper, the analysis of digital performances relating to the Key Readiness Indicators will focus on the "KRI-Strategy", "KRI-Awareness", "KRI-Competences". The selection of the statistical tests performed in the next sections, was operated considering the analysis of categorical variables, following to the work of [17]

3. Case-study in the manufacturing sector

The results presented in this section refer to a sample of manufacturing companies located in Central Italy Marche. A total of 65 companies from the manufacturing sector, mainly covering the machine construction (65%), chemical (13%) and footwear industry (7%), took part to the "Digital Check" self-assessment survey. Most companies account as SMEs, namely employing less than 250 collaborators and having less than 50 million Euro of yearly turnover, as defined by the European Commission [18]. Approximately one-fifth of companies achieved the highest digital readiness level of top-performer. Overall, the results indicate that most companies exhibit an average digital readiness level (companies in transition), while a limited number of companies assessed a low digital readiness level (4.6%). The latter group of companies are solely composed by SMEs. Nevertheless, the Pearson Chi-squared test, indicated the existence of no significant association between the two categorical variables employed, namely company size and digital readiness level ($N=65$, $Chi=6.890$, $p<0.142$). Table 3 summarizes these results in the percentage of responses with respect to the entire sample (%-ALL), as well as in absolute figures for the entire sample (N-ALL) and considering the participating SME (N-SME), respectively.

Table 3. Digital readiness level.

Readiness level	N-ALL	N-SME	%-ALL
Digital Newcomers (low)	3	3	4.6%
Companies in transition (medium)	49	35	75.3%
Top Performer (high)	13	8	20.1%

The distribution of the KRI (Fig. 1) indicate that a large proportion of companies, regardless of their overall digital readiness level, achieved relatively high levels of the indicators. Notably, 49 companies, accounting for approximately the 75% of the sample, achieved the highest value of the "KRI-Awareness". Relatively, high values were achieved by companies in the remaining KRI, such as "KRI-Strategy" (56.9%) and "KRI-Competences" (66.2%).

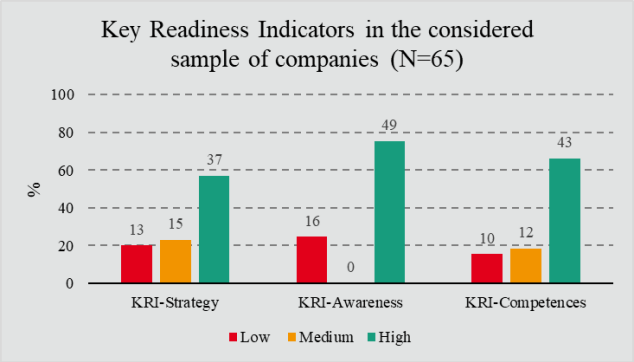

Fig. 1. Key Readiness Indicators in the considered sample of companies

Stratified by size in terms of number of employees, turnover and digital level the characteristics of the sample are outlined in Table 4. The total amount of companies, considering the turnover are lower (60) compared to the other categories, since five participating companies did not give their consent to provide their range of yearly turnover compiling the "Digital Check" survey. In the following paragraphs, such varying characteristics will be used to test potential association to the KRI. The statistical software SPSS v.19 was employed for the data analysis.

Table 4. Digital readiness level.

Characteristics	Small/Low	Medium	Large/High	Total
Size	23	23	19	65
Turnover	14	13	12	60
Digital readiness level	3	49	13	65

3.1. Company size as variable for different association in the performances of the KRI

The percentage of small companies characterized by a high level of the "KRI-Strategy" is marginal (18.9%) if compared to 68. 4% of large enterprises. A strong association (Chi=15.594, p-value<0.006) is detected between the size of the company and the indicator capturing the strategy readiness toward Industry 4.0. Overall large companies tend to consider themselves having successfully embedded a strategic vision toward digital transformation. A similar result is obtained considering the association of the size of the company with the "KRI-Competences". The Chi-Squared statistics (Chi= 20.216, $p < 0.000$) also signals the existence of a significant association between such variables. Larger companies perceive a higher adequacy of collaborators in terms of digital skills (89.5%) compared to 43.5% observed in companies with less than 50 employees. Conversely, the Chi-Squared statistics indicate the existence of no significant association (Chi= 2.181, $p < 0.336$) between the size and the "KRI-Awareness". Table 5 summarizes the distribution of the KRI varying the size of the company expressed in terms of number of employees.

Table 5. Size of the company (rows) against levels of Key Readiness Indicators (columns).

		KRI-Strategy		
	% (N)	*Low*	*Medium*	*High*
Size	Small (23)	43.5 (10)	26.1 (6)	18.9 (7)
	Medium (23)	4.3 (1)	21.7 (5)	73.9 (17)
	Large (19)	10.5 (2)	21.1 (4)	68.4(13)
		KRI-Awareness		
Size	Small (23)	34.8 (8)	0.0 (0)	65.2 (15)
	Medium (23)	21.7 (5)	0.0 (0)	78.3 (18)
	Large (23)	15.8 (3)	0.0 (0)	84.2 (16)
		KRI-Competences		
Size	Small (23)	39.1 (9)	17.4 (4)	43.5 (10)
	Medium (19)	0.0 (0)	30.4 (7)	69.9 (16)
	Large (19)	5.3 (1)	5.3 (1)	89.5 (17)

3.2. Turnover as variable for different association in the performances of the KRI

Tailoring such an approach, differences in the KRI were tested considering varying turnover of companies (Table 6). As reference to classify companies according to their size (small, medium, and large), considering yearly turnover (EUR) the definition of the EC applies [18]. The Chi-Squared statistics indicate the existence of a significant association between the variable returning the yearly turnover of the company and the "KRI-Competences" (Chi = 17.979, $p < 0.001$). No or very limited association exists regardless of the level of yearly turnover and the "KRI-Strategy" (Chi = 11.539; $p < 0.021$) and "KRI-Awareness" (Chi = 2.533, $p < 0.282$), respectively.

Table 6. Turnover of the company (rows) against levels of Key Readiness Indicators (columns).

		KRI-Strategy		
	% (N)	*Low*	*Medium*	*High*
Turnover	Small (22)	40.9 (9)	13.6 (3)	45.5 (10)
	Medium (19)	10.5 (2)	31.6 (6)	57.9 (11)
	Large (19)	5.3 (1)	15.8 (3)	78.9 (15)
		KRI-Awareness		
Turnover	Small (22)	36.4 (8)	0.0 (0)	63.6 (14)
	Medium (19)	15.8 (3)	0.0 (0)	84.2 (16)
	Large (19)	21.1 (4)	0.0 (0)	78.9 (15)
		KRI-Competences		
Turnover	Small (22)	36.4 (8)	13.6 (3)	50.0 (11)
	Medium (19)	5.3 (1)	31.6 (6)	63.2 (12)
	Large (19)	0.0 (0)	5.3 (1)	94.7 (18)

3.3. Digital readiness level as variable for different association in the performances of the KRI

A final set of potential associations was tested considering as variables the digital readiness level of companies and the resulting Key Readiness Indicators (Table 7). For the statistically significant variables, the association between the digital level and the "KRI-Awareness" has the lowest p-value (Chi = 13.529, $p < 0.001$), suggesting a strong association between the digital level of companies and the awareness about technologies and concepts of Industry 4.0. To this respect, the entire samples (100%) of small and large companies face opposite scenarios, showing the latter group a higher awareness, compared to companies with less than 50 employees. The association between the digital level and the remining considered KRI remains low, for both the "KRI-Strategy" (Chi = 12.376, $p < 0.015$) and the "KRI-Competences" (Chi = 11.824, $p < 0.019$).

Table 7. Digital level of the company (rows) against levels of Key Readiness Indicators (columns).

		KRI-Strategy		
	% (N)	*Low*	*Medium*	*High*
Readiness level	Low (3)	67.7 (2)	0.00 (0)	33.3 (1)
	Medium (49)	22.4 (11)	28.6 (14)	49.0 (24)
	High (13)	0.0 (0)	7.7 (1)	92.3 (12)
		KRI-Awareness		
Readiness level	Low (3)	100 (3)	0.0 (0)	0.0 (0)
	Medium (49)	26.5 (13)	0.0 (0)	73.5 (36)
	High (13)	0.0 (0)	0.0 (0)	100 (13)
		KRI-Competences		
Readiness level	Low (3)	66.7 (2)	33.3 (1)	0.0 (0)
	Medium (49)	16.3 (8)	20.4 (10)	63.3 (31)
	High (13)	0.0 (0)	7.7 (1)	92.3 (12)

4. Discussion

The present research work described the approach used to derive Key Readiness Indicators (KRI), providing additional information for companies self-assessing their digital readiness level toward Industry 4.0. The paper focused on the KRI referring to the areas of strategy, awareness of technological trends, and digital competences of collaborators. Besides the methodological note, the present article showed the distribution of the KRI in a real case-study, involving a sample of manufacturing companies operating in the Marche Region (Italy), comprising small, medium, and large enterprises. Considering the overall digital readiness level achieved, the results do not outline significant differences, with the size of the company in terms of employees varying. Conversely, several authors acknowledge SMEs having a relatively lower digital starting level and facing higher challenges toward digital transformation [19]. Against this background, the KRI support the latter evidence, indicating larger companies, counting more than 250 employees, strategically better prepared and disposing the required digital competencies of collaborators to support the transition toward the Industry 4.0 paradigm. This finding confirms the validity of the main challenges toward Industry 4.0 identified in the literature, depicting SMEs facing more challenges due to the lack of a strategic vision [5] and limited knowledge and skills [4] [19] to drive digital transformation. The analysis of KRI also shows that companies with a higher yearly turnover perceive the know-how of their collaborator as adequate. Finally, one of the main finding relates a higher awareness about technological and conceptual developments of Industry 4.0 to those company self-assessing a higher digital level. Such additional information, complementing the interpretation of the results about the digital readiness, provide companies and supporting institutions, such as among others Digital Innovation Hubs, with relevant information, to steer their digital innovation projects and strategies, to specific requirements and characteristics. To this respect, KRI proved particularly effective in providing counterintuitive evidence at times, signaling specific areas of intervention, which might have been overseen by companies. This is witnessed by the evidence, emerging from the analysis of the sample, indicating the levels of the three considered KRI being aligned to the overall digital level, approximately only in the 20% of the cases. A more accurate interpretation of the overall digital level, employing the notion of KRI, may hence implicate for companies, a better interpretation of results of self-assessment, potentially leading to an improved decision making and monitoring of interventions toward Industry 4.0, complementary to the information deriving from the overall digital readiness level.

5. Conclusion

This research presented the approach to enrich the effectiveness of self-assessment survey measuring the digital readiness of companies, which can be considered a fundamental step prior to any implementation of Industry 4.0 technology or concept. We showed the attempts made to develop a set of Key Readiness Indicators (KRI), providing complementary information to the overall digital readiness level of companies, as main outcome resulting from most existing self-assessment tools. The evidence collected, in the framework of a broader study involving a sample of 65 manufacturing companies, depicts such tools as effective, as they can provide counterintuitive elements, diverging from the level of the overall digital readiness. Against this background, the KRI may convey implications for decision making for companies regardless of their achieved digital level, enabling the prompt identification of specific fields of intervention. The use of KRI may be particularly relevant in the context of SMEs, in which the dynamics of each individual KRI show a higher variation in relation to the overall digital level achieved. Furthermore, the immediate information conveyed by the KRI, suites the limited resources in terms of staff for R&D and time to devote to a careful interpretation of results. The familiarity across manufacturing companies to the concept of Key

Performance Indicator, from which the KRI is conceptually rooted, ease the application of such tools also among SMEs.

For a continuous methodological improvement of such tools certain limitation should be considered. To this respect, more efforts should be done to extend the set of KRI, to provide ready-to-use information for the strategic planning of Industry 4.0 in additional fields. The KRI described in the present study relates to the main challenges SMEs face toward SMEs deriving from the current literature on the topic and should not be considered as exhaustive of the complex dynamics potentially emerging from the conduction of self-assessment tools. In this regard, the development of KRI should also be extended to other realms of increasing relevance for companies, for instance, relating Industry 4.0 applications to economic, social, and environmental sustainability [20]. Among other topics, the present research could contribute stimulating the transfer of the notion of KRI to facilitate the measurement of readiness, among SMEs, with respect to Flexible Mass Customization and the emerging implications for sustainable manufacturing.

Future applied research activities should aim at extending the geographical coverage and number of companies involved in the sample conducting the self-assessment survey. This will positively contribute to the level of inference, which can be drawn from the collected data. From the analytical point of view, besides the detection of association, the establishment of causality between variables could deserve more attention, to further increase the quality of results.

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