Managing the Fourth Industrial Revolution: A Competence Framework for Smart Factory

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Abstract Several industrial initiatives around the globe usher in the Fourth Industrial Revolution that points at the deployment of a Smart Factory. A Smart Factory builds on several advanced digital technologies to integrate the production process within and across organizations. The literature asserts that Smart Factory increased efficiency and production outcome. While the technical aspects of the Smart Factory are quite extensively studied, few pieces of research paid attention to the competencies that organizations need to manage a Smart Factory. Therefore, we develop a competence framework for handling Smart Factory from a systematic literature review of Smart Factory empirical cases. We contribute to the literature proposing a framework with six competences areas.

Keywords Fourth industrial revolution · Smart factory · Competence · Industry 4.0 · Systematic literature review · Skill

1 Introduction

To preserve the competitiveness of the manufacturing industry, the German government and manufacturing associations of U.S. launched industrial initiatives ushering in the Fourth Industrial Revolution which aims at developing the Smart Factory [1, 2]. Within a Smart Factory, several leading-edge technologies—Big data analytics, Robotics, Cloud Manufacturing, Additive Manufacturing—are interconnected with human resources along the assembly line to increase efficiency, flexibility, and automation of the production process [1, 3]. The two industrial initiatives share the same principle of interconnection within the organization and along the supply chain [1, 4], while they differ on the leading technology. Industrial Internet, the U.S. initiative, builds a Smart Factory on Internet of Things infrastructure which integrates all the technology and people. The German initiative Industrie 4.0, on the

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other hand, aims at developing a programmable cyber-physical system which aims at increasing the interconnection in the Smart Factory integrating the physical and virtual worlds [5]. Also, cyber-physical systems is that allows to address mechanical problems on the assembly line without human interaction but through autonomous machines that take on the job from the workforce [6].

The two initiatives are considered by most the most critical industrial initiatives for the Fourth Industrial Revolution and their blueprints have inspired other industrial plans around the world. As a matter of fact, several European countries launched their industrial initiative to develop the cyber-physical system with the label Industry 4.0 which also became a synonym of the Fourth Industrial Revolution.

Since the Fourth Industrial Revolution is mainly a technological wave, most of the studies so far concentrated on the development of Smart Factory technologies [3, 6] and the value creation of Smart Factory [7, 8]. Smart Factory adoption leads to enhanced organizational productivity and flexibility which places particular emphasis on sustainability practices [9].

While few pieces of evidence pay attention to how the organization manages the transition of Smart Factory. The technologies of Smart Factory creates a new level of socio-technical interaction between all the actors and resources involved in manufacturing [1]. Therefore, Smart Factory technologies transform work practices turning the organization into a more knowledge-intensive oriented and need the support of a high-specialized workforce [1, 8, 10].

To address the gap, we aim at identifying the specific requirement for organizations to take advantage of this transition through the study of competences [11, 12]. We consider competence as a set of knowledge, skill and personal traits that an organization should have for a significant performance [13]. We build over and systematize existing studies on competences for Smart Factory, which though surveys and non-systematic literature reviews, led to conflicting frameworks with competence different lists varying from study to study [11, 14–16].

We aim at defining in a systematic and rigorous way a comprehensive framework of competencies needed by organizations to handle Smart Factory. We perform a systematic literature review of Smart factory pioneering empirical case studies and seminal articles inspiring the Smart Factory. We identify the competencies for Smart Factory [17] through open coding using as a sensitive device the concept of competences and adopting validity principles of qualitative inquiry [18]. We answer the following research question: "*What competencies are needed for organizations to manage Smart Factory?*".

2 Theoretical Background

In this section, we present the Fourth Industrial Revolution, the concept of competences, and the existing competence framework for Smart Factory.

2.1 The Fourth Industrial Revolution

Similar to the previous industrial revolution which brought innovation in the way of production, the Fourth Industrial Revolution refers to the development of the Smart Factory (SF) [1, 3]. Due to the complexity of the innovation, several governments and manufacturing associations around the world launched industrial initiatives to promote the SF development.

The main industrial plans for SF are Industrial Internet by manufacturing associations in the U.S. and Industrie 4.0 by the German government. These initiatives are then followed by European countries that launched similar industrial initiatives with the label Industry 4.0 (I40) and Asian initiatives such as “Made in China 2025” in China and “Smart Manufacturing” in Korea [3]. Since most of the industrial plans employ the label Industry 4.0 (I40), this term is used as a synonym of the fourth industrial Initiative and SF.

The initiatives share the same principles which are the horizontal and vertical integration of production processes driven by share real-time data interchange and flexible manufacturing to enable SF [4, 19]. Vertical integration means that several organizational departments are integrated, while horizontal integration refers to the inclusion of several organizations composing the supply chain and the customer [1, 20].

The initiatives build on several leading technologies, including Big Data analytics, Additive manufacturing, Cloud manufacturing, and Robots to develop a SF [3, 8]. The primary technology of Industrial Internet initiative is the Internet of Things, which is an IT infrastructure enabling the collection and transmission of data between devices, resulting in identification, localization, tracking, and monitoring of objects [4]. While the primary technology paradigm of Industrie 4.0 is the cyber-physical system. Cyber-Physical system control pieces of machinery automatically in assembly lines. The way with which organizations use SF technologies allows them to address problems on the assembly line without human interaction but through autonomous machines that take on the job from the workforce [6].

The effective deployment of SF promises to deliver benefits in an economic, environmental and social contexts [20, 21]. SF allows to increase the efficiency and flexibility of the production process. SF allows to increase the production outcome and to produce small lots of customized products in order to fulfill different customer needs [1, 20]. The SF production process reduces natural resource usage with increasing data granularity and more sophisticated technologies [1, 8]. SF allows a more ergonomic workplace and oriented towards workforce needs [8, 22].

2.2 The Concept of Competences

The concept of competence is a traditional organizational topic in literature since the 90 s, and it is considered a critical organizational component to gain a competitive advantage [23]. In the literature, the concept competence appeared for the first time in 1973 [24], which refers to a set of knowledge, skills, traits, attitudes, self-concepts, values, or motives directly related to job performance leading to superior performance. Afterward, scholars from different disciplines sharpened the definition in different directions. In the IS context, competence studies dealt with the competence assessment to anticipate changes in the IS professions [25, 26].

There is not a collective agreement for the classification of competences. Scholars classify them based on the logic, theory, and purpose of the analysis [27]. However, there is a consensus that competence is composed of three main elements [23]:

- Knowledge: theory, concepts, and tacit knowledge which workers gain through experience.
- Skills: requirement for a given occupational area that the workforce affords to do.
- Attitude or personal traits: workforce characteristics for effective performance in a job.

Within the organization, the competencies are systematically managed to identify the current and future competencies required for the work and to assess available competences of the workforce [28]. According to Sandberg [17], competencies can be identified by the job analysis through three different methodological approaches [17]:

- Worker-Oriented Approach: It employs predefined categories to capture competencies from the workforce. This approach produces a too generic and abstract list of competencies, and therefore limited value as a basis for competence development.
- Work-Oriented Approach: It identifies activities that are central to accomplishing specific work and then transform those activities competences. This approach produces more concrete and specific competence. Here, the limitation regards the work activity list, which might sufficiently indicate the attributes required to accomplish those activities.
- Multimethod-Approach: It employs together the previous two approaches to identify more specific and comprehensive competences minimizing their weak points.

Finally, through competence (or skill) assessment, organizations can evaluate competence levels and identify competence gaps. Thus, organizations can fill the competence gap through vocational courses or hiring personnel [29]. Accordingly, this process allows the organization to maintain a high level of distinctive competencies which lead to competitive advantages [12].

2.3 Existing Competence Framework for Smart Factory

In literature, there are four attempts to develop a SF competence framework. Indeed, the two World Economic Forum competence frameworks have captured competences through surveys that have administered to Chief Human Resources and Chief Strategy Officers of leading global employers portraying their expectations regarding competencies for future jobs [11, 14]. Each report provided a framework of ten competencies, which include core competencies like complex problem solving, critical thinking, creativity and emotional intelligence. However, we find these frameworks challenging to follow for organizations since several competences varied from report to report, and this variance does not help organizations to create a path for acquiring all these competecnies. Also, these two frameworks are focus on competences related to the job of the future and therefore they are not center to SF. Table 1 depicts the last competence framework by World Economic Forum, which forecasts the most important competencies for 2020.

Hecklau et al. [15] proposed an SF competence framework presenting either the methodology for detecting competences by a literature review and how to manage the competencies gap by a radar chart. In this study, the authors employed a worker-oriented approach exploiting the PESTEL-Framework to detect competences based on a literature review of SF. They provided a competence framework including four primary categories, namely technical competences, methodological competences, social competences and personal competences. Each group contains a narrow list of competencies. The study emphasized on core competencies like problem-solving, coding skills, analytical skills as well as generic competencies like language skills and attitude to work under pressure. However, the focus is more on the methodological implications rather than on providing a competence framework since the SF literature review resulted non-systematic and limited to 7 studies.

Analogously, Erol et al. [16] present a learning approach to prepare future managers and workers for the fourth industrial revolution. The authors developed this approach for Austrian SF pilot projects. This approach highlights the importance of personal competencies, social competencies, action related competencies, and domain-related competences. Authors argued that these competencies are required for the workforce to deal with SF context characterized by an uncertain environment.

3 Research Method

Our investigation aims at developing a theoretical framework containing competences for SF. Figure 1 presents our data analysis. First of all, we performed a systematic literature review in February 2019, applying the protocol by Webster & Watson [30]. Table 2 shows the details of the literature search we performed over the SCOPUS database of indexed scientific publications to review literature discussing

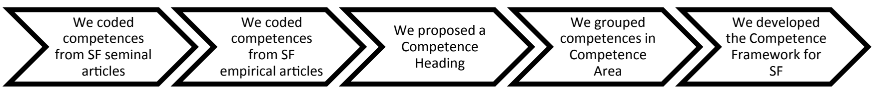

Fig. 1 Data analysis

the empirical SF case studies. The query contains "Smart Factory" and keywords that researchers often used as a synonym of SF like Industry 4.0, internet of things, and cyber-physical systems [9] as well as Industrial Internet [2]. Moreover, we used a set of secondary keywords, namely implementation, application, and adoption, since they point to empirical adoptions of the SF.

We included in the database only papers containing industrial empirical case studies that deployed SF. Instead, we excluded all theoretical and survey articles as well as 19 "false positive" papers that have the title in English but text in a different language. As can be noticed, there has been a large drop between the initial hits (386) to the first exclusion step (25). Still, we dropped several I40 applications in the first step since discussing applications of different sectors like smart building, agriculture and e-health. Indeed, the authors employed the I40 referring to the interconnection feature of the initiative making the query wider. Afterward, to include papers regarding the single technology of SF, we picked in the "title and abstract" step its literature review paper (e.g. a RFID literature review [31]) exploring the citations in the "backward and forward" search. The final query produced 18 entries that have used as a database to identify the SF competences. Lastly, to enlarge the number of potential competencies, we added in the database the two seminal papers of SF initiative [1, 2]. Secondly, adopting a work-oriented approach to define competencies, we identified SF competences from activities presented in the publications [17]. To maintain a qualitative rigor we follow the principles of qualitative inquiry [18] performing open coding on the literature sources, categorizing them in first and second level codes, and eventually identifying competences areas, labeling and describing competences.

We used the following definition of competence as a sensitive device: a set of knowledge, skills and attitude or personal traits that an organization should have for superior performance. Along the process, one researcher acted as a primary coder and performed open coding (first and second level coding) proposing competences. Whereas a second researcher questioned and verified the developed framework. We accomplished the final framework after three iteration rounds adopting a two-fold saturation criterion: (i) all the data sources could be coded with the set coding structure, and (ii) the research team agreed on the result of the coding.

We proposed a first-level coding from which we detected the competence and a second-level coding representing the competence heading. Thereafter we grouped competence into competence areas following aggregation criteria based on common sense and easily observable classes. Thirdly, we developed the competence framework following the criteria by Stuart [32]. Indeed, the competence framework should be *generalizable* across different organizations adopting SF. The competences and the competence area should be *simple* and *accurate* in order to be comprehensive and usable from various organizations. Accordingly, we present in Table 3 our competence framework for SF. From each competence, we propose a heading, a competence area and a description that is deduced by the literature review.

Table 1 Competence Framework 2020 for jobs of the future by World Economic Forum

Competence	Description
Complex problem solving	Identifying complex problems and reviewing related information to develop and evaluate options and implement solutions
Critical thinking	Employing reasoning to identify the strengths and weaknesses of alternative solutions, conclusions or approaches to problems
Creativity	Workers on this job try out their own ideas
People management	Motivating, developing, and directing people as they work, identifying the best people for the job
Coordination with others	Adjusting actions in relation to others' actions
Emotional intelligence	Ability to understand and manage your own emotions, and those of the people around you
Judgment and decision making	Considering the relative costs and benefits of potential actions to choose the most appropriate one
Service orientation	Actively looking for ways to help people
Negotiation	Bringing others together and trying to reconcile differences
Cognitive flexibility	Mental ability to switch between thinking about two different concepts

Table 2 Literature search for empirical smart factory case studies

Item	Description
Source	SCOPUS database
Query	TOPIC: "smart factor*" OR "industrial internet" OR "internet of thin*" OR "industry 4.0" OR "cyber physical system*" AND "implementation*" OR "application*" OR "adoption*" Refined by: LANGUAGES: (ENGLISH), Subject Area: Business, Management and Accounting, Source Type: Journals
Hits	386
Papers retained after: • Title and abstract selection • Full-text selection • Backward and forward search	 25 10 18

4 Findings

We propose a competence framework for SF (in Table 3) based on a systematic literature review of empirical case studies.

The SF competence framework distinguishes six competence areas. The *inter-functional competence* area embraces technical and behavioral competencies at the individual level demanding a cross-functional approach to the management of increasing complexity of work practice and innovation practice. Competences such as

Table 3 Competence framework for the smart factory

Competence area	Competence heading	Description	Refs.
Inter functional	Risk-tolerance attitude	SF requires a workforce with risk tolerance attitude stretching firms beyond their comfort zone	[1, 2, 8, 33–37]
	Leadership and cross-discipline guidance	SF requires leadership roles that are explicitly cross-discipline for taking advantage of the initiative	
	Proficient IT use skills	SF requires the management of IT software and solutions to generate value from the initiative	
	Complex problem solving	SF requires workforce managing complex problem-solving owing to the increasing complexity of processes	
	Flexible work attitude	In SF, workforce with a flexible work attitude enables greater compatibility between work and personal needs	
	Self-development	SF requires a highly skilled and highly-motivated workforce to generate value	
	Interdisciplinary team orientation	SF requires workforce capable of working in an interdisciplinary team that draws on the expertise to generate value	
	Innovation attitude	SF requires workforce with an innovation attitude, capable of developing research projects	
Organizational management	Data management	SF requires the management of exploiting data sources of different types of machinery to enable self-decision making	[1, 8, 38–42]
	Business logistics skills	SF requires the workforce which manages novelty inventory management to handle the storage and the fruition of productions	

(continued)

Table 3 (continued)

Competence area	Competence heading	Description	Refs.
	Knowledge management	SF requires the management of the formalization of the knowledge foundations that data talent will need	
Business model innovation	Network creation	In a SF context, a key challenge will be to use the technology to create novel value networks	[1, 8, 38–42]
	Service and product orientation	SF generates value through the development and the realization of new services and products	
	Quality Focus	SF emphasizes quality assurance since the workforce performs routine tasks with more autonomy	
	Technology leadership	Within SF, managing investment plays a key role in leveraging hardware and software innovations	
	Sustainability	SF requires workforce capable of embracing sustainability practices within the organization's business model	
IS Design	Integration Skills	SF requires workforce capable of managing digital integration among advanced technologies	[37, 43–47]
	Interface design skills	SF requires workforce capable of managing new platforms that enable firms to build specific applications easy to use	
	Cybersecurity skills	SF requires workforce capable of managing the impact of new technologies on sensitive corporate data	
Organizational design	User-oriented Workplace Design	SF allows creating a safer and more attractive workplace oriented towards workforce interests	[1, 8, 41, 48]

(continued)

Table 3 (continued)

Competence area	Competence heading	Description	Refs.
	Workforce continuous improvement	SF operative issues enable companies to engage in constant learning to maintain a higher process quality	
Legal	Intellectual property management	SF requires workforce capable of facing intellectual property issues when innovations are developed in partnership	[1, 2]
	Legal liability	SF requires workforce capable of facing liability issues when the innovation is adopted in an organizational network	

problem-solving, self-development and risk tolerance attitude result essential in this initial stage of SF adoption. Likewise, proficient IT use skills are required to interact with advanced technologies. The *organization management* includes competences at the organizational level for managing recurring SF technology issues. Indeed, there is a constant need for data management capabilities to inform the choice of data for undertaking predictive analysis. The areas of *IS Design, Organizational Design* and *Legal Competences* classify competences to establish SF organizations. The IS foci is predominant since SF benefits derive from the interconnection and integration of advanced technologies as well as their effective employment through intuitive interface design.

Further commitment lies in the cybersecurity skills for protecting data which also implies a legal analysis regarding the connected intellectual property and the legal liability. Lastly, designers should pay particular attention to workplace design which is safer and engaging for workforce. The *business model innovation* area encompasses competences at the organizational level allowing to generate value through network creation and the development of new service & product [49]. In particular, these models have enriched whether organization leverages on advanced technology investment and sustainability mindset.

5 Discussion

Most of the literature regarding SF concentrates on the technical dimension of the initiative underpinning the idea that SF technologies deliver value mainly through the integration and automation of technologies [50, 51]. Our study debates this perspective showing how human competencies play a crucial role in a SF. Despite the competence frameworks show a lack of manual skills for the workforce, the primary skill for manufacturing organizations, we noted that there is an increasing request for competencies a higher level of knowledge. SF workforce operates in a more complex environment that requires problem-solving skills, a strong attitude towards innovation and attitude to work in an interdisciplinary team. This implies that the effective deployment of SF is challenging, and the role of the workforce is increasingly important to achieve it.

The competence framework of SF confirms the literature that SF should base its competitive advantage on technology leadership [1, 3]. Also, the framework shows that human resources with a sustainability mindset may develop an SF production process that contributes to the sustainable development of our society.

The framework also clarifies the fuzzy role of "data scientist" which is considered by most the most relevant job for the fourth industrial revolution [2]. Our competence framework for SF pinpoints proficient IT use and data management as his distinctive competences.

The framework also portrayed a socio-technical nature since there is a demand for competencies to improve work conditions through a safer workplace and workstations. Furthermore, SF technologies can also support a knowledge management system and undertaking a continuous learning approach for the workforce.

Moreover, according to the literature, SF integrates supply chain along with different organizations through the horizontal integration of advanced technologies [52]. This feature opens to several legal issues from intellectual property issues to legal liability. These concerns should be managed in advance for an effective implementation of SF within organizations.

Finally, we debate our work against the previous competence framework. Our work contributes to validating the World Economic Forum competence frameworks for the future of jobs, highlighting that problem-solving skills, people management, and integration skills are also proper skills for SF. Moreover, our study shows the importance of integration of technology skills and legal competencies, which are missed to the competence framework by Hecklau et al. [15]. While our study validates the competence categories of the framework by Erol et al. [16] since our competence areas, although with a different name, purports similar competencies.

6 Conclusion

The study aims at proposing a competence framework for handling SF based on a systematic literature review of SF empirical case studies. The competence framework for SF distinguishes six areas of competences that underlie a socio-technical perspective.

The study suggests implications both for practitioners and for research. Regarding the implications for practitioners, the SF competence framework provides guidance for organizations aiming at undertaking SF transition. Indeed, it is notably useful for the Human Resource department during the implementation stage, where it can be used as a required competence to seek in the labor market. It is also valuable for maintaining a high competence level in mature SF organizations preventing competence lack through the competence gap analysis [15]. Hence, the competence catalog can serve as a reference to develop tailor-made courses. The study is also useful for technical institutes and universities that may build a tailor-made study plan to develop SF workforce. The study highlights that organizations require several types of competencies to manage the transition towards SF. Therefore, we recommended that schools and universities create multidisciplinary paths for students to develop SF competences.

Regarding the implication for researchers, the SF competence framework sheds light on the nature of SF initiative. Several researchers claimed the determinist nature of the initiative conducting empirical studies where SF can emulate workforce tasks or decision making [3]. Nevertheless, these advanced technologies cannot automatically manage analysis on data. Therefore the SF requires a highly specialized workforce for handling them. Therefore, we confirm that human resources and these technologies are part of a sizeable socio-technical system within the SF where the conjoint optimization of the two systems leads to the effective implementation of the initiative.

Finally, we claim for further studies on SF initiative since SF allows to extend our IS focus on information encompassing those from the assembly line. Indeed, even though IS studies paid attention to the management of administrative information through ERP [53], our knowledge regarding information from the assembly line is limited. Further studies should cover this gap investigating how to manage that information as well as how to generate value employing both information sources.

To conclude, our study lays the foundation for our complete research project, which aims at investigating SF competences empirically and exploring pattern associations among them. Indeed, the next stage will concern administering a survey based on SF competence framework to organizations that adopted SF in order to validate it, proposing thus descriptive statistics regarding SF competences. Therefore, we encourage researchers to perform Fs/QCA [7, 54] otherwise, different quantitative methods to test our SF competence framework on a large sample.

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