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How to Sustainably Implement a Smart Factory through a Socio-Technical perspective: an evolutionary framework

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Abstract. In recent years Industry 4.0, in particular through Smart Factory, promises a revolution in manufacturing due to the digitization, automation and virtualization of all organization processes. However, the requirements for a sustainable implementation of Smart Factory go beyond technological and processual issues. The orientation of technology management strategy with the organizational goals, infrastructure, culture, processes and people should be judiciously carried out. Adopting a socio-technical perspective based on six-dimensional model, this study aims at developing a framework that describes the evolutionary path to design a sustainable architecture for implementation of a Smart Factory. We argue that the implementation of Smart Factory is, and should be, an incremental process. In particular, we identify three evolutionary steps for implementation of the Smart Factory, namely Aspiration, Awareness and Maturity. Finally, the framework is tested through an exploratory case study.

Keywords: Smart Factory, socio-technical approach, sustainable implementation, evolutionary framework, integration.

1 Introduction

In recent years Industry 4.0 promises a new wave of revolution in manufacturing due to the digitization, automation and virtualization. Industry 4.0 integrates the cyber world with the physical systems by using embedded systems, IoT, semantic machine-to-machine communication and Cyber-Physical Systems. One part of the concept of Industry 4.0 relies on Smart Factory. Smart Factory is characterized by a perfect flow of information, a high level of data safety, an ability to adjust to the customers' requirements. Smart systems in a Smart Factory keep track of and are capable of using acquired real-time data in order to develop a model of virtual reality. According to this concept, Smart Factory is equipped with a decentralized system able to make decisions on its own, respond to current and accurate information and notify expert employees if necessary.

Most of the studies on Industry 4.0 have focused on the technical aspect of the design of the architecture for integration for implementing Industry 4.0 (e.g. [1]; for a

systematic literature review see Sony and Naik [2]). However, technology (in particular, artificial intelligence and robotics) and process reengineering through digitalization are strictly related to social relations and therefore there could be many inefficiencies if technical and social aspects are not given equal importance [2; 3].

Socio-technical systems theory advocates when designing a new system it is critical to focus on and optimize both technical and social factors [4]. The system is considered holistically since changes to one part will require subsequent changes to other parts [5]. One of the most widely used framework to consider the changes according to the socio-technical perspective is proposed by Leavitt [6], which was based on 4 dimensions: people, task, structure and technologies. Subsequently, the framework was modified into a six-dimensional hexagon interrelated structure: people, processes and procedures, goals, culture, technology, and buildings and infrastructure [7]. According to Sony and Naik [2], we apply the socio-technical approach based on six dimensions for sustainable implementation of Industry 4.0. A sustainability-oriented firm takes purposeful action to improve its social and ecological performance, giving consideration to different stakeholder groups according to socio-technical issues [8]. We believe the concept of sustainability must be applied also in the transition process to become a Smart Factory: the implementation of a Smart Factory must take into account firm's responsibilities towards different stakeholder groups through their involvement in the transition process.

In the managerial literature there is an abundance of studies concerning the definition of Industry 4.0 and its requirements. Based on these studies, it is easy to describe the features of a Smart Factory [2]. Regrettably, there is a lack of clarity concerning the implementation of the concept and the practical aspects of its development [9]. Managerial literature focuses on the implementation process and priorities needed to undertake a successful journey towards Industry 4.0 [e.g. 10]. This paper is part of this research stream. Adopting a socio-technical perspective, this study aims at developing a framework that describes the evolutionary path to design a sustainable architecture for integration in a Smart Factory. We argue that the implementation of Smart Factory is, and should be, an incremental and sustainable process. The incremental approach better support the needs of different stakeholder groups (employees, partners, suppliers, customers, etc.) and the continuous fit between the social and the technical areas. We argue that the human factor requires a slow transition process since it allows people to better manage change. In particular, we identify three evolution steps, namely Aspiration, Awareness and Maturity. For each step we describe the evolution of each component of the socio-technical model. Finally, the framework is tested through an exploratory case study. The case study, developed through a qualitative analysis, is a good example since the firm, already highly digitalized in the production process, is now approaching a transformation process to implement a Smart Factory.

2 Theoretical background: Industry 4.0 integration with socio-technical systems theory

Industry 4.0, of which Smart Factories are a part, is going to provide integration of production processes and supply chains and make them more efficient and flexible [11]. It is based on structures of production capable of dealing with the complexity of the production process, by being agile and flexible, smart, self-regulating and self-configuring [12]. The integration of the cyber and physical systems is commonly known as the Smart Factory creating an environment where the production systems such as machinery and equipment are interconnected digitally through automation, self-optimization and self-regulation [13]. However, the concept goes beyond just the physical production of goods and services, since the management functions such as planning, organization, controlling, delegating, coordinating, forecasting etc. are also automated. Moreover, the concept of Smart Factory, goes beyond the firm's boundaries: automation technologies impact also supply chain. A Smart Factory is defined 'as a smart, independent factory equipped with sensors and orientated towards support for people and machines in carrying out their tasks' [9: 259]. A Smart Factory is also defined as a collection of systems which are fully integrated and interoperable and are able to work in real time in response to varying demand, circumstances in the supply chain and customer requirements [14].

The purposes of Industry 4.0 are [9]:

- Enabling the communication and cooperation of people and machines with the systems of ICT in real time.
- Production of non-standard items, manufactured in small production batches, based on high automation and efficiency [15].
- Enabling production process to occur in a flexible, efficient and sustainable way in compliance with high quality and low cost [16].
- Attaining a global network of setting value [17], influencing business models and corporate structure.
- Introducing devices to production process, enabling system management in a flexible and dynamic way, considering the importance of a customer [18].

In order to reach these purposes, Industry 4.0 is based on three kinds of integration [16].

Horizontal integration is the integration of value networks to enable collaboration between organizations in the value chain [19]. Value chain partners collaborate through the integration of their ICT systems, processes and data flows. This integration sheds light on how cyber-physical space should be used to sustainably implement and support the company's business strategies, value networks, and business models. Through digitization, a new efficient, self-regulating, self-optimizing, digitized and self-evolving ecosystem is created [13].

End-to-end digital integration of engineering across the entire value chain describes the cross-linking and digitization of the entire product lifecycle. The product is tracked from its raw material status, manufacturing, use and disposal. The end-to-end

engineering integration results in integration which enables the creation of customized products and services across the value chain [20]. Technologies can be integrated to create customized, automated, self-organized product and services according to the customer requirements [21].

Vertical integration is the integration of various hierarchical sub-systems within the organization to create a flexible, agile, efficient and reconfigurable manufacturing system within the organization. Vertical integration connects different internal sections of the manufacturing company such as ICT systems and processes. Data flow in all organizational areas (from product development to fabrication, logistics, administration, and marketing) creating a smart and flexible manufacturing environment.

In order to reach full integration, many authors focused mainly on technology and processes. However, a Smart Factory is more than new technologies and process redesign. To be effective, the implementation of a Smart Factory must focus on people, in particular on employees and customer satisfaction, and on organizational culture. Moreover, to become sustainable different stakeholder groups should be involved the implementation process [22]. Adopting a socio-technical perspective and according to Sony and Naik [2], in this work we focus on 6 dimensions.

People

A major concern in Industry 4.0 is about a change in the labour market. The fourth industrial revolution presents huge challenges, such as how to face reduction of employment by automation rendering human work force uncompetitive with machines [23]. However, the previous studies suggest that even full-fledged implementation of Industry 4.0 will not reduce the human element within the system. Rather, due to the continuous automation of manufacturing processes, the number of workspaces with a high level of complexity will increase, which results in the need of high level of education of the staff. Therefore, the employees will now require a different skill set [24; 25].

Another key issue relies on stakeholder engagement in the implementation process of a Smart Factory. Employees, customers, suppliers, partners are all involved in the transition to a Smart Factory and top management should engage them in the definition of priorities.

Culture

Every organization is guided by its culture and values [26]. The process should begin with building a sufficient digital culture within factory, based on flexibility, open-mind, ability to change [16]. This step consists not only of training staff and improving their knowledge but also encouraging teams to become change agents [9]. Change in the factory requires full understanding of the concept of 'Smart Factory' within all the organization levels and clear leadership. The challenges of change are mainly related to vertical and horizontal integration. During the implementation of vertical integration, various subsystems within an organization become one entity at the virtual level, resulting in commonality in terms of organizational culture. Horizontal integration is another key issue since it brings together organizations of different cultures, with a profound impact of organization culture on its supply chain [27].

Goals

The Smart Factory concept is based on integrated processes which should improve both flexibility and efficiency. Additionally, the idea of a smart production centre is very often presented as an opportunity to improve sustainability and customer satisfaction through customization and high product/service quality. These goals, as well as the successful implementation of the concept are reached through integration (Vertical, Horizontal and End-To-End Integration) [9] and job redesign.

Processes/procedures

In a Smart Factory, all processes are designed to be flexible, smart, intelligent, self-regulating and self-configuring [12]. Design of the processes is strictly related to vertical, horizontal and end-to-end integration [9]. To cite an example, in the production process the material parts can be tracked on a real-time basis by various subsystems within the organization and/or in its supply chain [1]. Of course, this redesign must take into account the human component of the system, since processes are concretely applied by employees, oriented to the customer satisfaction, and influenced by suppliers and business partners.

Technology

Technology for implementing Industry 4.0 will range from data collection, analysis, decision making, self-regulation, networking, reporting, integration with cyber-physical systems, controlling, organizing etc. The implementation of a Smart Factory requires a proper network infrastructure, smart controllers, analytics software with integrated information systems and the utilisation of new technologies, including: IoT, cloud computing, Big Data and technology using artificial intelligence [9]. Integrating these technologies with industrial automation, organizations are able to achieve a huge improvement of industry. With powerful microprocessors and AI technologies, the products and machines become smart in the sense that they not only have abilities of computing, communication, and control but also have autonomy and sociality [16]. These smart artifacts are interconnected with each other and with the Internet and enable some requirements of the Smart Factory [28]:

- Interoperability: it is necessary to communicate efficiently using IoT and IoS between, 1) CPS within the enterprise and 2) an enterprise, CPS and people.
- Virtualization: it provides support for people to control physical processes by CPS and to create a virtual copy of the physical world, based on real-time data.
- Decentralization: it is required due to the soaring demand for customized products, which hinders central controlling and managing. On-going monitoring of systems and possibility of identifying items (thanks to RFID) provide high level of flow control.
- Real-Time Capability - concerns the need for collecting and analysing solid and up-to date information in real time. Current situation in the enterprise is permanently supervised and, as a consequence, the company may react immediately to any machine failure.

Infrastructure/building

The integration of smart production systems with other functional business subsystems of the organization will create a need for smart infrastructure in terms of digital networks, sensors, networking products and services such as software's, routers, control units, etc. [29]. Moreover, the digital infrastructure required for the digitizing the entire supply chain must strategically acquire and deployed [9]. Notably, the degree of digitization among partners may vary by the organization. Moreover, buildings and layout within the Smart Factory should be strategically designed in order to support the production process, by being agile and flexible, and the digital infrastructure.

2.1 The framework

In table 1 we summarize our framework. According to Venkatraman approach [30], in this framework we suggest there could be different levels of business/IT transformation to implement a Smart Factory. In this framework each component of the socio-technical approach is argued in a evolution path that starts from the aspiration stage (in which organizations undertake a path of digital transformation), to the awareness stage (in which firms start to interiorize the principles of Smart Factory, firstly focusing on the inside), to the maturity stage (in which organizations fully interiorize all the principles of Industry 4.0 and pursue both internal and external integration).

Notably, each component of the framework can be at a different evolution step (i.e. aspiration, awareness, maturity). According to Odważny, Szymańska & Cyplik [9] the implementation process of the Smart Factory concept (from the aspiration to the maturity phase) needs to be developed as an incremental evolution, since revolutionary approach is undesirable.

Table 1. The framework.

Socio-technical components	Aspiration	Awareness	Maturity
People	Team has qualified individuals including IT specialists and automation engineers.	Operational employees have analytic skills and operate with available IT software.	No operational employees in the machine park. Staff consists of expert. Employees are controlling the process and react to system warnings, if necessary.
Goals	High automation and efficiency Stakeholder satisfaction (top management defines processes in order	Vertical integration Employee involvement (employees, at all organization levels, define processes in order to	Horizontal, vertical and end-to-end digital integration Stakeholder engagement (all stakeholder, both

	to increase employee and customer satisfaction)	increase employee and customer satisfaction)	internal and external to the firms boundaries, define processes in order to increase employees, partners and customers satisfaction)
Culture	Digital culture Culture based on flexibility, openmind, ability to change	Integrated culture within the organization Culture based on flexibility, openmind, ability to change	Integrated culture among different organizations Culture based on flexibility, openmind, ability to change
Processes/ procedures	Automation of some processes or part of them	Full integration of internal processes	Full integration of both internal and external processes
Technology	Automation and robotics of single processes or part of them.	-IoT implemented gradually. More elements are included in the net. -Simulation models are used in decision process -RFID is widely used in the factory for track and trace.	Full integration of all installed tools and technologies
Infrastructure/ buildings	Sensors, unit controls, etc. for the digitizing, monitoring and remote controlling of some processes or parts of them	Physical and digital infrastructure for digitizing the internal processes	Digital infrastructure required for the digitizing of the entire supply chain

3 Methodology

In order to test our framework, we applied the model to a case study. The interpretative qualitative method has been used due to its strengths in providing insights in individual experiences and life settings [31]. Furthermore, a case study research strategy has been used [32] and was motivated by the aim to increase the empirical knowledge on what components are involved in the implementation of a Smart Factory and how they are related to each other.

The case study is based on the experience of Tor.Met, a firm in the Northern Italy founded in 1987 and with a team of more than thirty highly qualified people for their jobs.

Tor.Met produces bar turned parts in the main non-ferrous metals (B2B sector). Brass and steel in all alloys but also plastic material: the refinement of production techniques makes it possible to produce numerous turned parts in Tor.Met for different uses, based on the needs of customers.

After a careful project analysis, evaluation of the raw material and identification of the most suitable working methods to follow, the production is set. In Tor.Met they are attentive to the evolution of the production market and the most cutting-edge technologies that they adopt to have a machine park that is ready to respond to the most specific needs of their customers. Coherently to these aims, the firm is recently moving to a new building. The new factory will be developed following the Smart Factory principles.

This case study is emblematic since the firm, already highly digitalized in the production process, is now approaching a transformation process to implement a Smart Factory.

Data were collected through semi-structured interviews to the CEO and the Marketing and Communication Manager in the spring 2021 (face-to-face interviews of about 3 hours, all recorded and then analysed), a set of articles in local and national newspapers, and other firm's documents. For data analysis we adopted the Gioia's methodology [33] and to aggregate the concepts in macro themes and dimensions. Our analysis consisted of multiple, iterative readings of interviews transcripts, and the identification of dimensions linked to the six components of the socio-technical model.

4 Results and discussion

Our findings suggest there are some challenges to manage in order to reach the maturity phase. First of all, in order to implement a Smart Factory, to design the technical parts is 'easy'. Engineering consultants as well as technology suppliers play a crucial role in designing the infrastructure and in defining the technological assets. However, top management has only a partial support in how to strategically manage the human components (people and culture) related to the implementation of a Smart Factory. Moreover, we found many challenges in jointly manage all the socio-technical components in the Smart Factory. The orientation of technology management strategy with the organizational goals, infrastructure, culture, processes and people should be judiciously carried out. To date, planning is a responsibility of the CEO, who is only partially supported by both technical consultants and by some key internal players (operational employees). Another key issue, that makes even more complex the jointly analysis of all the components, is the different evolution steps in which each component is in the transition process to the Smart Factory. In Table 2 we summarized main results of our case study analysis.

Table 2. Results

Socio-technical component	Description	Evolution step
People	<p>Currently, in Tor.Met there are some operational employees in the production process that are particularly familiar to the new technologies. These actors are supporting the top management in the transition to the Smart Factory, acting also as change agents.</p> <p>Tor.Met is developing an intensive formation program to transform all their operational employees in experts. Notably, automation of the Smart Factory will not lead to a reduction of employment. In the CEO words “Thanks to the Smart Factory we will be able to strengthen our production processes and, thus, we expected to significantly increase our business. In the transition phase, we are hiring new people, since we need new competencies. Nobody will be fired”. According to the CEO, people are the most important component in the Smart Factory and it is the driving force of change in firms: “Firms grow and change thanks to people”. As a consequence, employee engagement is a crucial aspect, managed by the CEO and increased through continuous listening. Anyway, in Tor.Met the focus on people goes beyond employees but embraces all firm’s stakeholders. As an example, near to the Factory there will be a sport center.</p>	From awareness to maturity
Goals	<p>According to the technical components, in the past Tor.Met focused mainly on high automation and efficiency. To design the new Smart Factory Tor, Met aims to reach vertical integration of all internal sub-systems. According to the CEO, to reach horizontal and end-to-end digital integration could be medium-long term goals. However, currently the new factory is designed with a focus on internal integration. According to the human and social components, “employee will be the main wealth and as such they will be treated”¹. One goal of the Smart Factory is related to the job enrichment of operational employees: they will control the process and react to system warnings.</p>	From aspiration to awareness

¹ Source: <https://www.lastampa.it/topnews/edizioni-locali/verbano-cusio-ossola/2021/03/10/news/la-tor-met-investe-5-milioni-di-euro-a-casale-corte-cerro-accanto-al-nuovo-stabilimento-ci-sara-anche-una-pista-di-atletica-1.40008186>

Culture	Digital culture is spread across the organization in an uneven way. Only some operational employees have strong digital competencies. However, according to the CEO the transition to Smart Factory is efficiently supported by an organizational culture based on flexibility, open-mind and ability to change. In the CEO opinion, the small organization (about 30 employees) and a clan culture [strong culture that gives emphasis on shared values and on trust among employees [34], will support the diffusion of a social context suitable for a sustainable implementation of a Smart Factory. To reach this goal, Tor.Met relies above all on the key role of some operational employees as change agents and on training programs. “We strongly believe in our corporate identity and our employees, at all organizational levels, are part of a strong community” (CEO)	Awareness
Processes/ procedures	In the ‘old’ factory Tor.Met already adopts a high automation of some processes or part of them. In the new Smart Factory processes are redesigned to reach a full integration of all internal processes. Business process reengineering is managed by some key internal employees (both at the operational and at the managerial level) and the technology suppliers involved. “Operational employees are crucial in the processes redesign since they really know the work, what are the process that should be improved, and how. They know what should be the new system requirements [...] technology suppliers know what are the most adequate IT solutions to our needs”. However, the strategic management of all the processes is a key issue for the top management. “Since the technical and the human aspects should be jointly considered, only the top management deeply understand both the processes and the people within the organization” (CEO).	Awareness
Technology	In Tor.Met robotics is implemented gradually. In the Smart Factory simulation models will be used in decision process as well as RFID technology for track and trace.	From aspiration to awareness
Infrastructure/ buildings	Physical and digital infrastructure are evolving gradually. In the first phase, in the Smart Factory there will be sensors, remote controls, etc. for the production processes. Only some business processes will be involved in the integration processes. Afterword, other processes will be integrated in the medium-long term.	Aspiration

5 Conclusions

Adopting a socio-technical perspective, in this study we proposed a framework that describes the evolutionary path to design a sustainable architecture for integration in a Smart Factory. We argue that the implementation of Smart Factory is, and should be, an incremental process. A revolutionary approach is undesirable since each component of the socio-technical subsystems can change in different ways and with different timings. Our findings suggest to adopt an incremental process of change in order to better support the constant fit between the changes in the human-social area and in the technical one. Firms that succeed in managing this constant fit in the transition process to the Smart Factory can be fully regarded as organizations sustainable also in their socio-technical dimension [35]. In particular, we identified three evolution steps, i.e. Aspiration, Awareness and Maturity. For each step we described the evolution of each component of the socio-technical model. Finally, the framework is tested through an exploratory case study of firm, already highly digitalized in the production process, that is now approaching a transformation process to implement a new Smart Factory.

This work has some important academic and managerial implications. From a theoretical point of view, to our knowledge in managerial literature there is a lack of contributions that apply the socio-technical perspective using the six-dimensional model. A first attempt in this way is offered by Sony & Naik [2]. The authors suggest a design mechanism for three types of integration mechanism in Industry 4.0 by considering the socio-technical systems impact on people, infrastructure, technology, processes, culture and goals. However, their conceptual paper, based on a framework developed by the literature review, didn't focus on how to implement the practical aspects of their framework. Our analysis aims at enriching the managerial literature through a framework that combines the socio-technical approach and Industry 4.0, and that suggest a model procedure. From a managerial perspective, we propose a framework which may be used as a supportive tool for managerial staff in the transformation to Smart Factories.

We are also aware of some limits of our study, that will become the basis to future developments in our analyses. Firstly, the single case study doesn't allow any generalizations. Currently, we are testing the framework in other organizations in different steps in their journey to become Smart Factories. Secondly, our case study relies on a firm that is now designing the new Smart Factory. We will deepen our analysis of the case study when the process of implementation of the Smart Factory will be finished. In this way, we will be able to analyse the entire process of implementation. In future analyses we will also focus on the organizational, strategical and technological challenges that this implementation will bring.

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