Industry 4.0 paradigm: The viewpoint of the small and medium enterprises

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Abstract
The pervasive diffusion of Information and Communication technologies (ICT) and automation technologies are the prerequisite for the preconized fourth industrial revolution: the Industry 4.0 (I4.0). Despite the economical efforts of several governments all over the world, still there are few companies, especially small and medium enterprises (SMEs), that adopt or intend to adopt in the near future I4.0 solutions. This work focus on key issues for implementing the I4.0 solutions in SMEs by using a specific case example as a test bench of an Italian small manufacturing company. Requirements and constraints derived from the field experience are generalised to provide a clear view of the profound potentialities and difficulties of the first industrial revolution announced instead of being historically recognised. A preliminary classification is then provided in view to start conceiving a library of Industry 4.0 formal patterns to identify the maturity of a SME for deploying Industry 4.0 concepts and technologies.

Keywords: Small and Medium Enterprises, Industry 4.0, Cyber Physical Systems, Smart Systems Interoperability

I. MOTIVATION

The widespread diffusion of Information and Communication technologies give the chance to implement “smartness” into the factory and to provide new tools for a predictive manufacturing approach: the core of the Industry 4.0 (I4.0) announced revolution [1]. The potentialities of I4.0 lie is to ensure a better flexibility and scalability of manufacturing systems through information technologies and industrial automation [2], [3]. This is the reason why a number of Governments all around the world are funding I4.0 solutions implementation with middle/long term investment (e.g. Industrie 4.0, Manufacturing USA, Industrie du Futur, Industrial Internet of Things, Made in China 2025, Fabbrica intelligente-Industria 4.0). Despite these efforts, few companies, particularly SMEs, adopt or intend to adopt in the near future I4.0 solutions [4]–[6], [9]. Small and medium enterprises (SMEs) represent a backbone for several economies all over the world; this is true in particular for Europe, where for the nonfinancial sectors SMEs represents the 99,8% (92,8% Micro, 6% Small and 1% Medium) of the total companies, provide the 57,4% of the added value and represent the 66,8% of the total workforce. The SMEs account for 59% of the workforce in the manufacturing sector and provide the 44% of the added value in the same sector [7]. I f SMEs cannot align to I4.0 solutions this can seriously affect the economic growth of a country [1], [8], [5], [6].

II. RESEARCH QUESTIONS

Provided the need to encourage and support SMEs to adopt the I4.0 paradigm, it is necessary to clearly analyse the complexity to adopt I4.0 solutions and contemporarily its benefits for these kind of companies. The true problems for the I4.0 paradigm implementation are related to the nature of the SMEs: these are often characterized by poorly formalized processes, by independent and/or legacy hardware and software systems and by smaller economical capabilities with respect to large companies. Often SMEs lack internal IT competences and the necessary technological knowledge. Descending from the above, the present paper speculates on the following subject:

What are criticalities for the adoption of the I4.0 paradigm in SMEs?

Speculating from the experience derived from a I4.0 on-going project within an Italian SME producing and commercializing aluminium accessories for windows and doors (Master Italy s.r.l.), the true questions to be faced and the true needs to respond for implementing an I4.0 approach within a small company are discussed. Despite the number of scientific works on I4.0 so far, in fact, none of these provide this pragmatic viewpoint to appreciate the complexity of a paradigm shift and the degree it is capable to respond the true needs of efficiency and effectiveness on the field from the company more than following an axiomatic statement of smartness.

III. METHODOLOGY

The first approach was a set of personal interviews and the explicating the field experience in the Italian Company to generalise SME's expected advantages in implementing the I4.0 paradigm that resulted as follows:

- To analyze the different production lines, in order to identify problems that, if compared, determine the exponential improvement in performance of the whole system;
- To evaluate the possible actions to take, when the production processes are exposed to external events;
- To make decisions and make more accurate forecasts in terms of production and consumptions;
- To identify and quantify the resources that contribute to the increase in efficiency of the systems;
- To check and supervise the use of resources in the individual phases of the production process;
- To share and integrate the information among all members of the company;
- To optimize the business performance.

Descending from these, a set of requirements were traced for the implementation of the I4.0 paradigm in SMEs derived from a wide bibliographical analysis. This needs were summarised into three main I4.0 solution requirements to meet the SMEs requests, and thus to promote their adoption:

- minimal invasiveness: I4.0 solutions must rest on (and not replace) the existing systems,
  hardware and software (ERP, MES, SCADA, etc.) [9], [4];

- turnkey: I4.0 solutions needs a minimal intervention of the enduser at changing the use scenarios, i.e. they must embed the necessary knowledge for the different application classes [9], [10];
- extensibility: I4.0 solutions must to be flexible for the subsequent interventions, so to support a gradual approach; i.e. they must to ensure the possibility to reutilize all the components if we want to scale up the overall system.

Several commercial and academic solutions were compared accordingly, as reported in Table 1, according to the degree of satisfaction (High, Medium, Low). All the analysed solutions are characterised by the use of Cyber Physical Systems (CPS) [1], merging the real and the virtual world [11].

TABLE I: CPS'S INDUSTRIAL APPLICATIONS

	Minimally invasiveness	**Turnkey**	**Extensible**
General Electric: Predix [12]	High	Low	Low
RTI: Connex DDS [13]	High	Low	Low
Emerson: Syncade[14]	High	Medium	Low
Bosch: Bosch IoT Suite[15]	High	Low	Low
ADACOR [16]	Medium	High	Low
SkillPro [17]	Medium	High	Low
ASG [18]	Medium	Medium	Medium
@MES [19]	Medium	High	Low

IV. CASE STUDY

The case discussed here is the study of an assembly work cell in an Italian small manufacturing company (Master Italy s.r.l.). This case is brought as an example of a generic small manufacturing company, since it embeds all the requirements and needs for the transition from present company state toward the implementation of the I4.0 paradigm. The key to interpret what can be called the "I4.0 transition path" was thought to be the trace of present information flows, understanding their meanings and functionalities. The analysis performed provided an unequivocal support to decide the digitalisation path. The I4.0 transition does not necessarily concern the increase of data /information/knowledge (generically called *info* here) from the field or the automation/integration of the information flows: it should respond to the need of the correct availability to use of this information.

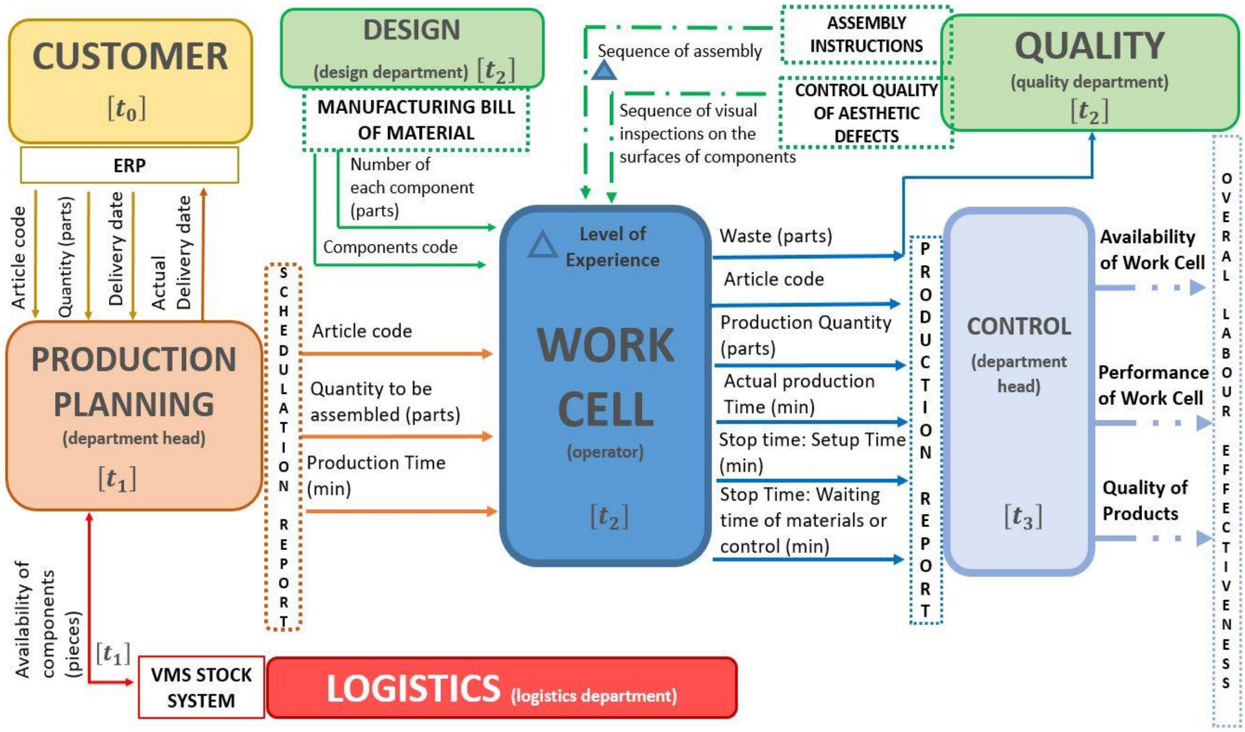

Figure 1: Knowledge, information and following through the work cell (actors in coloured boxes are either single operators or departments). Symbols refers to figure 2

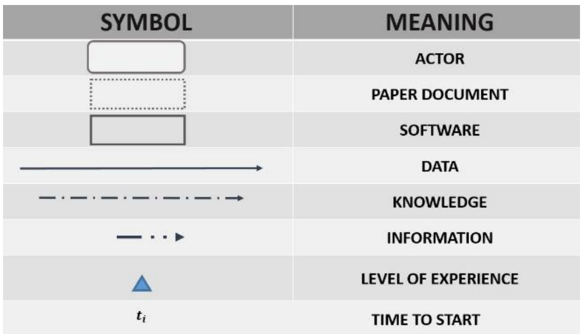

Figure 2: Symbols in figure 1

The logic behind “Fig. 1” is thus to provide the information flows from the work-cell operator’s viewpoint, i.e. his/her needs of information to perform correctly and timely the demanded task. This viewpoint allows a clear functional view of the information and highlights the potentialities, if existing, of the improvements descending from an I4.0 implementation.

The nature, the content as well as the present supports of information are highlighted. The nature of this information are: quality info (related to the control actions of the assembly process); organisational info (related to scheduling and planning of processes); operational info (embedded know-how); traceability info (parts recognition, availability and supplying of components). The support of information was important at this analysis level, since it highlights interoperability problems for the I4.0 implementation.

It is here assumed that, provided this viewpoint and this information classification, as evident, no particular difference but the local inefficiencies there will be between SMEs: the root of the I4.0 implementation problems will be thus the same.

Provided the complexity of the picture in figure 1, it is evident the complexity of ensuring the integrity and the coherence of all the mess of data, information and knowledge, provided their sources (the departments) are different and the scope and time of generation are different.

Descending from this analysis, the main critical issues, grouped according to activity, resulted as follows:

A1. Management of information (generation and storage):

• Not timely detection of the information;

• Low accuracy of information (manual entering and transmission of info)

• The fragmentation of information, coming from different sources (frequently on different supports), because lack of an integrated management system.

A2. Use of info:

• Production info are not automatically updated.

• No real time info of the production status is available.

I4.0 implementation is then expected - for a generic company work-cell - to satisfy the need of optimizing the assembly and packaging operations according to the following requirements:

1. Simplify the programming and the control of production.
2. Increase the productivity.
3. Eliminate the errors during the assembly and packaging operations.
4. Reduce the operator's learning curve.

For the specific company considered the following needs are also expected:

- Acquire the cell production info automatically
- Detection of the actual time of execution and tooling
- Detection of the actual quantity produced.
- Process the real-time data to verify and monitor the progress of production in the cell.
- Measure the actual efficiency, when there is a deviation from the standard (i.e. Time and wastes).

According to this analysis, an I4.0 implementation strategy for the work cell should be done according to the following steps, which are to a certain extent a measure of the readiness of the SME to I4.0 implementation:

1. Control of the instructions of the work sequence by the operator:
Implement devices and/or sensors that indicate the exact number of pieces to withdraw and assembly in each phase, and show to the operator the sequence of assembly operations and / or packaging. An appropriate device to control if all the phases of the assembly/ packaging process are done in the right order is required.

2. Control of the quality of the components:
It is necessary to set up the work cell with devices and/or sensors that:
• Identify autonomously the several quality problems of the components, compared to the standards (dimensions, tolerances, finishes, quantity).
•Alert operators through proper alarm systems about abnormal or out of tolerance situations.
•Analyse and correlate the symptoms and causes of failures and defects in production.
•Support the choice of corrective actions to eliminate the detected failures and defects.

3. Material handling
It is necessary to set up the work cell with devices and/or sensors that:
1. Record consumptions and control of the online stock, avoiding interruptions in production cell, due to the unavailability of the components in the warehouse stock.
2. Generate alarms to alert when you need to supply the material to the workplace, to prevent the operators' interruptions.

V. SOLUTION/DISCUSSION

The industry 4.0 it is thought as the widespread use of sensors for the acquisition, processing and analysis of data at lower and lower costs. The most critical point in this implementation is indeed the definition and selection of a complete set of the info really needed: this should be easily understandable and manageable by the different actors and tools involved, unless an increase of complexity is expected with respect to the present operating conditions.
This situation is clear from the analysis of the case considered, where the complexity relies in the explicating of the experience of the operator more than in the organisational or sensing architecture. Provided the case can be assumed as a generic SME, from the above it is clear that commercial platforms responds partially to the set of on field requirements, providing only some tools for the creation of the I4.0 personalized solutions ([12],[15]). These are infact mainly focused to data mining and communication between resources. These are capable of integrating the existing legacy systems and thus they result generally minimally invasive, even though requiring strong ICT competences (the turnkey requirement is often not fulfilled). Moreover, provided no standard model for the formalization of the managerial and technological knowledge is available so far, commercial platforms does not satisfy a fundamental requirement of having an extensible system. The academic solutions, on the other hand ([16],[19]) are tailored for the designed applications (no extensibility; required strong ICT competences = no turnkey). These latter solutions also only partially fulfill the minimal invasiveness since they do not take into account the interaction with existing legacy information systems, e.g. ERP.
As a summary, the main problem related to the implementation of I4.0 paradigm in SMEs is in the lack of the perception of the link between managerial and technological knowledge, and the satisfaction of production needs ([18], [20], [27]). As a conclusion of this paper is the formalisation of the I4.0 implementation problem for SMEs as a *formalization and standardization problem of managerial and technological knowledge, to make this independent of the specific application and user and thus allow the adoption of general purpose ICT solutions*.
This statement bring to the need of conceiving a sort of library of Industry 4.0 formal patterns to identify, by measuring similarities based on a set of formal criteria and some experience/knowledge (modelled into some domain ontology), the readiness of a SME for deploying Industry 4.0 concepts and technologies and also the proneness of these technology to satisfy the true needs. The adoption of existing Smartness Capability Maturity Model (SCMM), similar to the well known CMMI for guiding process improvement across a project, division, or an entire organisation [28], would then greatly support this decisional process.
Formalisation of SCMM is not provided here, despite the main elements of the SCMM are suggested and highlighted, to leave a future paper to come from the Authors the burden to provide an efficient model.

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