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Industry 4.0 on demand: a value driven methodology to implement Industry 4.0

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Abstract. Technological progress is directing the whole world towards a new way of interacting with information and creating value. From this, the industry (both of products and services) needs to keep up with the times and renew itself. There is talk of *Industry 4.0*, where the digitalization of information through innovative technologies is the key factor for the revolution. In this context, a methodology supporting SMEs in the design and assessment of their I4.0 project portfolio is defined. The methodology adopts a decision making tool exploiting the AHP technique that supports the sorting of the identified projects and the identification of a customized I4.0 roadmap.

Keywords: Industry 4.0 · digitalization · roadmap.

1 Introduction

The concept of Industry 4.0 was first publicly introduced in 2011 by a group of representatives from different fields, under an initiative to enhance the German competitiveness in the manufacturing industry. The idea of a digitally integrated industry [1] was made public at the Hannover Messe Industrie Fair in which it was demonstrated how cyber-physical systems (CPS) could make possible a paradigm shift in the industrial automation sector [2]. From that moment, the academic and industrial world worked relentlessly to transform that vision in a concrete industrial paradigm shift, extending the concept to what today can be described as the increasing digitization and automation of the manufacturing environment, as well as the creation of a digital value chain enabling communication among products, their environment and business partners [3]. Future value creation is located in digitized, real-time capable, intelligent, connected, and autonomous factories ('smart factories') and production networks [4].
While large companies usually have the resources to define and implement structured roadmaps to support the integration of I4.0 technologies to boost value creation, SMEs are more subject to the risk of addressing this challenge with a scattered and inefficient implementation approach [5], based on a technology push approach to innovation instead of on one based on the analysis of the value creating drivers of technology integration. [6]
This paper aims to present a methodology to support SMEs in the path that goes from the identification of inner value drivers that I4.0 technologies can

unveil, up to transforming them into quantitatively assessed and prioritized applied projects. The methodology is then tested within a pharmaceutical company where a roadmap towards the achievement of I4.0 expected goals is defined.

2 Industry 4.0 implementation & value creation approaches

Recently, the consensus obtained by the expected benefits deriving from I4.0 implementation encouraged practitioners and academia to define approaches driving the deployment of the I4.0 framework at industrial level.
Pessl E. et al. [7] proposed a framework based on the individual application of Industry 4.0 actions consisting of a 6-step approach: (i) general Industry 4.0 analysis, (ii) maturity analysis, (iii) determination of the target state, (iv) development and evaluation of measures for each field of action (v) transfer of the target objectives and measures to a Balance Scorecard and (vi) definition of the final roadmap. Exploiting the main characteristics of the considered company, the research focuses on the need of defining the most appropriate roadmap.
Khan R.I. [8] suggests an Industry 4.0 implementation approach for smart manufacturing that consider the development of technology integration prototypes as the main enablers of a successful implementation at industry wide level. The approach follows five different phases: (i) identifying business objectives, (ii) developing prototype, (iii) validation of prototype, (iv) replication of prototype and (v) total rollout.
Extending the scope of the assessment not only to the improvement of production capabilities, but also considering sustainability oriented criteria, Dossou P. [9] developed a framework for implementing Industry 4.0 where the sustainability of future changes is the basis for the future transformation. The framework involves four main steps: (i) brakes detection and analysis, (ii) definition of implementation acceleration levers, (iii) existing SME system modeling and analysis and (iv) definition of the future system and implementation plan. Considering three sub-systems (procurement, manufacturing and logistics) the framework aims at modeling, analyzing and improving each sub-system of the SME being studied and to define best steps for industry 4.0 implementation.
Putting technology at the center, Frank A.G. et al. [10] propose a framework for the identification of adoption patterns of I4.0 technologies in manufacturing firms. After studying how these technologies are used in manufacturing companies and clustering the adoption criteria under two layers of technologies, they argue that the adoption criteria are strictly related to the company dimensions and to capability of integrating a broad number of such technologies.
On the other side, if taking value creation as the main driver of I4.0 implementation, Erol et al. [11] faced the challenge of developing a transition model to I4.0 by developing a three-phase process, guiding companies to understand their specific objectives, the generated value beyond each objective and a series of measures to achieve them. This will lead the company to create a company-specific vision and roadmap. The model includes the following phases: envision (develop a

tailored Industry 4.0 vision), enable (roadmapping of Industry 4.0 strategy and identification of the success factors) and enact (preparation of transformation and proposal of Industry 4.0 projects).
Following a more oriented value creation approach, Tonelli F. et al. [12] developed a methodology related to manufacturing value modeling (MVMM) based on 5 steps: Value Map, Maturity Model, Gap and Process Analysis, Validation and Improvement Areas Definition. Through the value map it is possible to establish the current level of the company and to perform a gap analysis, that allows the creation of value with the aim of building a roadmap of the interventions, defining the priorities and activities to be improved.
Overall, the identified methodologies either do not put value creation as the main driver, or fail in providing a method to quantitatively assess the gaps present in the company, and transform them in a prioritized set of projects. This paper aims at filling this gap by proposing a three steps approach that, starting from high level identification of company status and needs, goes down to the identification and prioritization of projects leading to process improvement.

3 Methodological approach

To address the above outlined issues, we propose a methodological approach as a guiding framework (Fig. 1) for Industry 4.0 strategy design and practical implementation, that takes as main drivers the strategic identification of value creating gaps inside the company and transforms them in managed, quantitatively prioritized, implementation projects. The main goal of the model is to provide companies with a set of methods and tools that are able to guide in the implementation of their I4.0 value driven transition.

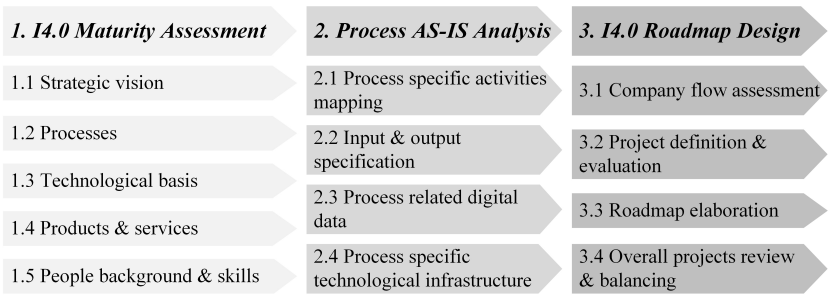

Fig. 1. Methodological Framework

The proposed methodology consists in three macro-phases: (i) I4.0 maturity assessment, (ii) Process AS-IS analysis and (iii) I4.0 Roadmap design. Each of the phases is composed of several steps (Fig. 1) that have to be completed in order to provide the necessary input elements to proceed in the analysis and

roadmap design path. The details of these steps are reported in the following sections.

3.1 I4.0 maturity assessment

The primary step of the methodology aims at assessing the maturity of the company with respect to five main areas influencing the I4.0 transition: strategy, processes, technologies, products & services, and people. The assessment model originates in the work carried out by Canetta et al. [13] has been adapted in order to exploit that methodology as a starting point for the identification of the areas of the company which present the greatest gaps to be solved to foster the transition. The assessment can be carried on either as a remote questionnaire or as an interview, with representatives of the company departments. As output, it provides a radar chart positioning the company under the five mentioned areas and a list of the detected *gaps*. The main *gaps* are those from which the analysis and roadmapping activity should preferably start from (in this regard, the following sections - corresponding to the subsequent phases - cover these gaps). Wherever possible the interview should be conducted with more than one person in the company or in a focus group, in order to mitigate the risk of obtaining a result liable to subjective company vision. Further details about the adopted model can be found in [13].

3.2 Process AS-IS analysis

Shifting to an operational analysis of the process flows, the second step of the methodology goes into the detail of the identified gaps. The formalization of the AS-IS situation (carried out by means of flowcharts built with the support of managers and operators) is the starting point for the following phases aiming at extracting process related value drivers. To this end, the phase considers the mapping of the following elements for each considered process:

- **Process specific activities mapping**: formalization of the activities within the identified process flow;
- **Input & output identification**: recognition of all the physical and digital inputs useful for the realization of the outputs;
- **Process related digital data**: collection of data or documents useful for carrying out the activity;
- **Process specific technological infrastructure**: mapping of technological infrastructure (either IT or OT) that is currently deployed at process level.

3.3 I4.0 roadmap design

The last step of the methodology is intended to guide the company in the actual identification of the sources of value generated from the gaps existent at process level. The identified gaps are then exploited to identify specific I4.0 projects, prioritized by exploiting a dedicated tool based on AHP methodology.

Phase 1: Company flow assessment Among the different flows within the company (inbound logistics, operations, etc) the phase aims to select one and begin its evaluation from the mapping carried out in phase 2. By adopting a design thinking approach [14] [15], a workshop with the main internal stakeholders of the process is then organized. Using the selected flow as guidance, the person appointed to manage the workshop stimulates the discussion collecting the problems associated with each activity, "*pains*", and the related desired improvements, "*gains*". Both *pains* and *gains* are appointed on a whiteboard and are used as starting points for the identification of new potential projects. If necessary, this phase can be carried out in an asynchronous fashion by exploiting available online workshopping tools.

Phase 2 - Project definition & evaluation From the inputs gathered through the workshop (pains & gains), a list of innovation projects meant to address area specific or company wide needs is defined. At this point, with an overview of the projects that should be implemented to improve process operations, the risk of being stuck in the project portfolio selection becomes relevant [16]. In this regard, the methodology implements a decision support tool based on the Analytical Hierarchy Process (AHP) technique to guide decision makers in prioritizing the most relevant projects. AHP is a structured technique for organizing and analyzing complicated decisions, based on mathematics and psychology, developed by Thomas L. Saaty in the 1970s [17]. According to the AHP method, the tool proposes a set of evaluation criteria for each project (the criteria of our case are shown in Fig. 2).

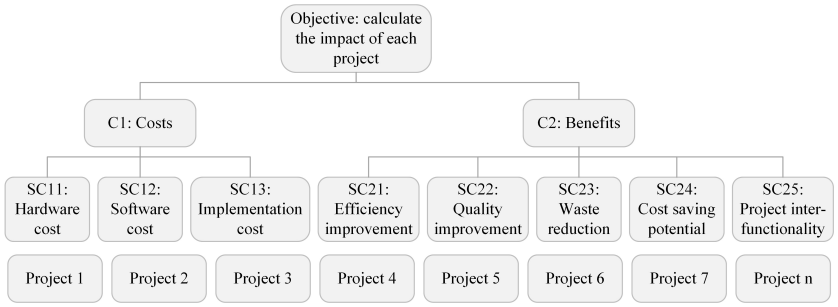

Fig. 2. Criteria adopted

The evaluator assigns a percentage weight to each criterion, then assigns a score that is evaluated by the decision criterion. The score of each decision alternative is the weighted average of the votes of each criterion on the decision for the weight assigned to each criterion. The criteria adopted in our model and shows in Fig. 2 are shortly described in the following table (Table 1).

Table 1. Projects evaluation criteria.

Criteria	Description
SC11	Relevance of the costs related to hardware acquisition
SC12	Relevance of the costs related to software acquisition
SC13	Relevance of the costs related to project implementation
SC21	Potential for Overall Equipment Effectiveness (OEE) improvement
SC22	Potential for quality improvement upon project implementation
SC23	Potential for waste reduction upon project implementation
SC24	Potential for cost reduction upon project implementation
SC25	Extensibility of the project in other company flows

Phase 3 - Roadmap elaboration According to the evaluations carried out in phase 2, a list of quantitatively assessed projects is obtained and used to develop the process specific *roadmap*. Passing from the project specific to the overall vision, projects are firstly ordered according to the score obtained in phase 2, then reviewed to integrate strategic decision making. At this point, a reviewed list of projects can be therefore set up.

Phase 4 - Overall projects review & balancing The last phase can be implemented whenever the methodology is retraced, with the aim of integrating a continuous improvement approach into the process. As the first step of this phase, an extension of Phase 1-3 to the remaining company processes (or to the most strategic ones) should be carried on, with the objective of (i) defining an integrated roadmap composed by the overall company I4.0 projects portfolio and (ii) identifying means of integration or parallelization of the identified projects.

4 Methodology validation

The proposed methodology was applied in a pharmaceutical company as an instrument to create, within one of the plants of the corporate, a preliminary analysis of the needs in terms of digitalization. Involving managerial and more operative people inside the company, the Maturity Model was conducted with average results: the company resulted to have a somewhat limited score in I4.0 strategy and technology, where it reached level 1, but it was better positioned under people, processes, products and services, where it reached level 2. From the results, the main areas of intervention resulted in the strategy, processes and technologies. Since the strategy was identified as something related to the corporate vision and decisional process, the following stages focused on processes and technologies.

The following step conceived the analysis of the plant and the formalization of its processes. To this end, 4 company flows have been selected as the most impacting on the overall business: production, quality control, logistics and quality assurance. For each of them the related flowcharts were created as input to the

analysis of the next phases. One or more representatives of the selected company flows have been therefore involved in two sessions of workshops: the first, carried out with flow responsible and dedicated to identify pain and gains for each specific flow; the second, as a focus group among the different stakeholders, to review the identified value drivers and discuss potential connections. Starting from the identification of the value drivers, a total of 46 I4.0 oriented projects have been identified. Most of them (30) related to the production environment, the remaining almost uniformly divided among the other flows. The potential projects have been then evaluated through the developed analytical tool. Also in this case, the different stakeholders were involved for the assignment of the scores to the decision criteria, then for the evaluation of the projects themselves. For the 46 projects initially identified, three levels of priority were identified. 11 projects resulted to have the highest priority, 24 were in the middle and eventually 11 has been identified as less relevant. Moreover, a particular attention was given to a group of 21 projects which showed potential to be integrated in all the flows (an aspect of fundamental importance for the company). Among the 11 projects considered most relevant, an important number of them was dedicated either to the automated acquisition of production data supporting traceability, or to the transfer of such data to the other involved flows. In particular, the main issues resulting from the carried out the evaluation highlighted the following points to be primarily addressed: the cultural aspect, the available time for the project development and the time dedicated by business experts.

5 Conclusion

In this work we identified a methodology for the identification and assessment of I4.0 related projects within manufacturing companies. It aims to address in particular SMEs that do not have the management processes and / or resources capable of systematically identifying innovation gaps and transforming them into I4.0 integration projects. The results of the methodology envisage therefore a three-phase methodological framework: I4.0 maturity assessment, process AS-IS analysis and I4.0 roadmap design. The third macro-phase provides a "circular" methodology which supports the development of the *roadmap* based on four steps: company flow assessment, project definition and evaluation, roadmap elaboration and overall projects review & balancing. The latter section of the methodology has been designed as a strategy supporting continuous improvement, to be therefore replicated for each corporate process and to be updated periodically. The validation carried out within a pharmaceutical company highlighted the flexibility of the methodology that well applied to the need of identification and prioritization of the I4.0 projects portfolio. As a future development, the impact that the adoption of I4.0 technologies can have on sustainability oriented KPIs will be more explicitly considered. Note that some aspects related to the topic are already considered in this approach: applying the concepts of I4.0 also means less waste, better management of resources, optimization of energy consumption and the use of raw materials and, therefore, emissions.

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