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A method for applying Industry 4.0 in Small Enterprises

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Abstract: In the last years, the main European countries that have launched "Industry 4.0" programs to support the development and the innovation of Small and Medium Enterprises (SMEs). The common goal of these programs is to innovate SMEs in terms of automation (of machines), integration (of lines) and interconnection (of the production system with its management). However, SME managers face great difficulties in accessing funding from an "Industry 4.0" plan, due to lack of information and limits on their knowledge of new information technologies. This paper aims at guiding a manager/technician towards the opportunities offered by "Industry 4.0" in three steps: first, presenting the plan as a decision-making problem, second by illustrating the methodology and finally by describing an application of one SME already financed.

Keywords: Industry 4.0; Cyber Physical Systems; Small and Medium Enterprises, Innovation, digital twin.

1. INTRODUCTION

The development of the European industrial system until the 90s was based, above all, on big enterprises, particularly in the automotive, mechanical and aeronautics sectors, with strong subsidies from governments. The small enterprises have been considered ancillary to the needs of large companies. Since the 1990s the automotive sector has undergone extensive restructuring, with mergers of companies and transfers of production outside Europe. At the same time, various productions of goods and components have seen impetuous growth in competition in the "Far East". In parallel, a large percentage of small enterprises continued to survive by having a small market share. This happened until the 2007 when the crisis decimated small enterprises (European Union, 2017).

The persistence of this crisis and, at the same time, the survival and the growth of many small enterprises with high technology and a notable image of their brand, have brought to the attention of the governments of the main European countries, first and foremost Germany, the importance of small enterprises and the need to support their development and innovation. In the last five years, plans have been launched in various countries to support the development and the innovation of SMEs: until now, the European programs for Industry 4.0 are fifteen all over Europe (Germany, Italy, France, Austria, Belgium, Czech Republic, Denmark, Spain, Hungary, Lithuania, Luxembourg, Holland, Poland, Portugal, Sweden). The common goal of these programs is to innovate SMEs in terms of automation (of machines), integration (of lines) and interconnection (of the production system with its management). However, in the practical application, this innovation plan encounters a problem common to several countries: managers of SMEs, generally owners with technical competencies, do not have the knowledge and skill necessary to define their innovation programs for their own SME, such to satisfy the constraints of the "Industry 4.0" plans (Fatorachian, 2018).

Information Technology (IT) is the heart of all the manufacturing systems with the presence of many technological innovations such as sensors, actuators and computerized information that have been used by manufacturing companies for decades (Naqvi, 2015), but full potential of these technologies has not been realised (Da Xu, 2011) in the current advanced manufacturing processes. This is due to the fact that connectivity and integration of information systems is limited to a relatively homogeneous area, e.g. part manufacturing, or assembling or quality testing (Panetto 2008, Veeramani 1995). Therefore, local information systems (Gruhier, 2017) make it difficult to interconnect and communicate along the production chain (Chen 2008, Vernadat 2009, Panetto 2008). This necessitates the incorporation of Industry 4.0 perspective and its enabling technologies such as Cyber Physical Systems (CPSs) (Leit~ao, 2016) and Internet of Things (IoT) (Reinhart, 2013) into the production process and manufacturing structure (Schlechtendahl, 2015), as it will be shown in the following. Given the inadequate technical skill of typical SME managers, we need a new method to guide them in identifying the most convenient innovation perspective for their company, to analyse how this innovation can be financed in the context of Industry 4.0, to evaluate costs and benefits to be developed in terms of:

a) Which are the measures of Industry 4.0 that favour the connection and the integration of an SME;

b) How an Industry 4.0 measure can be applied to an SME with a certain impact.

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Therefore, this paper is organized as follows: a new logical model of Industry 4.0 is presented (Section 2). This model is formulated in terms of a decision-making process and highlights which decisions the SME manager has to adopt. Among these, there is the choice of the Industry 4.0 measure that could be the most convenient for the production process. To detail the main usable Industry 4.0 measures, the aforementioned logical model is reformulated in terms of a method made up of decision tables (Section 3). By analysing a real applications of Industry 4.0 measures to an Italian SMEs, the difficulties and benefits of Industry 4.0 are discussed in small mechanical production and plant engineering company (Section 4). Section 5 contains some open research problems and perspectives.

2. THE LOGICAL DECISION-MAKING MODEL

The Industry 4.0 program invests all the aspects of the life cycle of companies that want to gain competitiveness through supporting investments in the digitization of production processes, in the research and development of new capital goods and in the creation of start-ups and small innovative companies.

To make an SME manager understandable which types of investment choices are feasible in Industry 4.0, the 1st step is to have a logical model formulated in terms of simple decision making, as illustrated in Fig. 1.

The logical model of the Industry 4.0 decision-making process can be interpreted as follows: known the current state of the production process, the manager decides to choose the measure of Industry 4.0 which he considers most convenient according to the needs of innovation of his SME, by estimating which financing or which tax credit could get. The four main measures Industry 4.0, illustrated correspond to the following choices:

a) buy a new machine in case he wants to increase efficiency and productivity of his production process;

b) develop a research and development program (R&D), if he wants to design new products or define a new work organization;

c) expand the plant with other buildings and also insert operating machines already at disposal or purchased;

d) start a start-up or an innovative SME, if one or more young people with good skills and good organizational training want to start a new high-tech activity.

The decision-making phases in Fig. 1 must be organized in the sequence described below:

1st Phase. Through the collaboration of the SME manager - who knows his process and applied technologies - define a preliminary simplified model of the process itself, possibly formal and simulated via computer, so as to have a preliminary "digital twin", i.e. a virtual or digital model of the physical machine or of the plant that allows to analyse its behaviour for predictive or optimization purposes, being able to perform tests that improve functionality and prevent possible errors in design (Wang, 2018).

2nd Phase. Based on the simulations carried out using the preliminary "digital twin" and data obtained directly from the real production process, choose the Industry 4.0 measure that appears most useful to improve the performance of the process under examination. This choice generally takes place through an iterative process with comparisons between alternative Industry 4.0 measures.

3rd Phase. Using again the simulations implemented for each measure and cited in the 2nd Phase, evaluate the cost for the company of the selected Industry 4.0 measure (i.e. the investment required in money and personnel commitment), and the corresponding financing or tax credit obtainable from the Ministry for Economic Development.

4th Phase. Detail the preliminary model defined in the 1st Phase obtaining a detailed model of the production process and a corresponding "digital twin", in order to calculate a reasonably accurate estimate of the company profit in case of maximum productivity obtainable, for an estimate of the increase in demand obtained from the current trend.

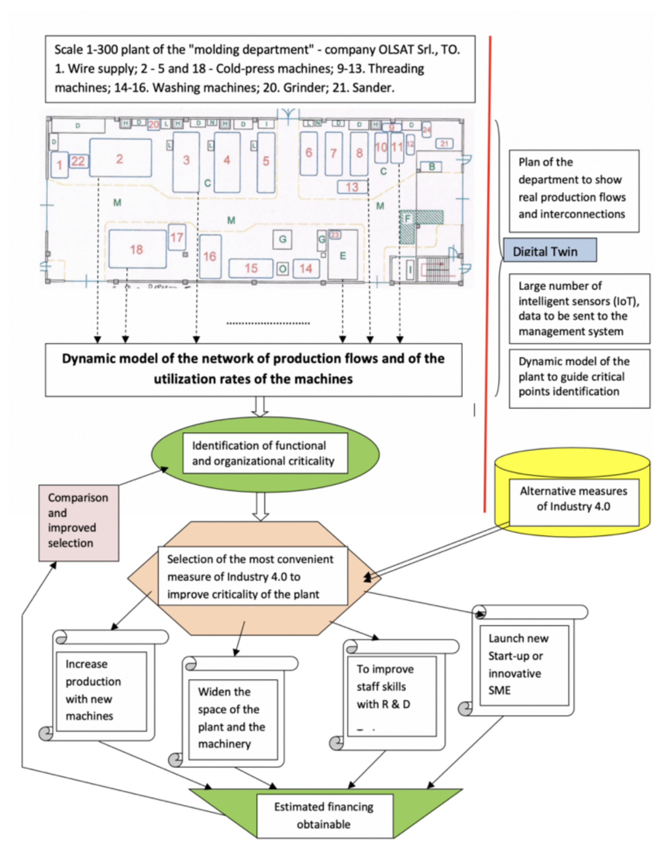

Fig. 1. Logical Model of the Industry 4.0 decisional process.

The 3rd Phase is different depending on Industry 4.0 measures.

<u>Phase 3-A</u>: Purchase of a new working machine. Given the inclusion of a detailed model of the new operating machine in the "digital twin" and obtained the model of the production system after the application of the measure Industry 4.0 type a) in the aforementioned list, the activities can be summarized as follows:

1stActivity. Optimize production flows and machine loads using real demand and productivity data, via Group Technology procedure (Bruno, 2018);

2ndActivity. Optimize, on the graph of the connections between the machines and the internal buyers, the points to take measurements of produced volumes and their quality level, so as to make each part/product traceable, in order to guarantee an "interconnected" production process; this second activity can be implemented through a measurement estimation model based on intelligent and interconnected sensors Internet of Things type (Atzori, 2010);

3rdActivity. Optimize the machining operations to each machine, by receiving part-programs from the CAD/CAM centre, in order to guarantee a totally integrated production process.

Phase 3-B: Execution of a research and development program. The typical application of this phase is related to the design of a new product, with a preliminary definition of the entire life cycle (Bruno, 2016). The activities that must be done are:

1stActivity. Conceptual design of the new product, with strong involvement of the company staff and the manager-technologist;

2ndActivity. Detailed planning and engineering of the new product, based on the skills available in the company;

3rdActivity. Formulation of the production cycle, by using a simulated formal model of the production process in which the new product must be manufactured (in\digital twin" optics), in order to:

- schedule the operations, using the data of the current production process in the model;
- test the adequacy of the production process, calculating times and volumes from the model;
- define proposals for upgrading the current production process by solving a problem of balancing machine loads.

Phase 3-C: Expand the SME production facility. The typical application of this measure of Industry 4.0 is related to the expansion of the premises of a small company whose demand for products has undergone a recent but steady growth. In this case, the main activities must be dedicated to the reorganization of the warehouse and internal logistics (1st activity), which generally constitute the two main elements of the crisis of the SME. This activity will also achieve the estimate of necessary space, and extension of the premises (Circ.13/E, 2017). Subsequently, some machine operating in the production process should be moved to new premises, allowing a reorganization of the logistics routes (2nd activity) As in the two previous cases, the aforementioned activities must first be simulated using, also in this case, a simulated model of the plant, and also having a scale map of the company.

Phase 3-D: Initialize a start-up or an innovative SME. In the case of this measure of Industry 4.0, the aim is to promote a new entrepreneurial culture, especially among young people with high skills (graduates or PhDs), with ownership of patents or innovative software. Therefore, the above requirements of new entrepreneurs who want to draw funding from this measure Industry 4.0 constitute the conditions for access to the measure itself, obtaining advantages such as the free constitution of the company, various deductions on the income acquired in a given number of years, incentives to investments in venture capital (Inter-ministerial Decree, 2016).

3. A METHOD TO DESIGN INNOVATION IN THE CONTEXT OF INDUSTRY 4.0

The selection of the Industry 4.0 measures applicable to the small enterprises by the manager, requires having a method that guides him towards the actions that can be done (Industry 4.0 will be simply denoted I 4.0).

The starting point of the method of using Industry 4.0 based on the experience that the authors have developed within the PMInnova program, an agreement between Politecnico di Torino and Bank of Asti Group devoted to supporting SMEs in innovation and development plans (www.pminnova.eu), is illustrated in Fig. 2 and it must specify:

- The innovation goal of the company
- Technical-organizational consultancy bodies that support the company manager;
- A framework of alternative measures/actions that Industry 4.0 makes available.

Enterprise	Innovation goal			
Technical-organizational consultancy bodies	Universities Research Institutions	Organizational secretariat	Bank Ministry of Economic Development	
Selection of the Industry 4.0 measurement adapted to the company's objective				
Measures of Industry 4.0	Hyper-amortization	Credit for Research and Development	Credit for investments in new premises and machinery	Credit for Start-ups & Innovative SMEs

Fig. 2. Industry 4.0 method.

For each measure, a specific method of describing the action to be implemented is introduced in order to have a clear view of the expected innovation and estimate of the funding that can be obtained in the Industry 4.0 context (2nd step).

In the following, for each measure indicated in Fig. 3, the 2nd step of the method to be applied for the request for funding in terms of procedure and related actions, scope and innovation obtainable is shown.

Measure Industry 4.0 denoted "hyper-amortization" measure is designed to encourage companies that invest in new capital goods to obtain a technological and digital transformation of their production process.

Phase	Action	Goal	Innovation
1st phase	Technological-organizational analysis of the production process	Identify critical issues and improvements	New machine
2nd phase	Inserting the new machine in the process	Interconnection Integration	Application of IoT and CPS/"digital twin"
3rd phase	Evaluation of machine + insertion costs	Estimated fiscal credit obtainable	

Fig. 3. Method I 4.0 for hyper-amortization.

In Fig. 3 it is noted that the technological-organizational analysis is a typical task of the company's consulting body. It contains a description of the company's main products, the network of production flows, machine loading and processing conditions, internal logistics and quality measures in progress. This description, formulated in terms of models typical of the production systems theory (Bruno, 2018), allows to identify both the critical issues of the current system and the possible applicable improvements. Hence the development of the I 4.0 - 2nd step method, in its two successive phases.

Measure I 4.0 “Tax Credit for Research and Development” aims to encourage companies to invest in R&D to improve both their processes and products and the level of knowledge of their staff.

Phase	Action	Goal	Innovation
1st phase	Technological-organizational analysis of the production process	Identify improvements and staff status	Study on how to innovate process and / or product
2nd phase	Evaluation of process developments and personnel qualification	R&D activities planning	Analysis of results and their impact on the company
3rd phase	Costs evaluation	Estimated tax credit	

Fig. 4. I 4.0 Method for Credit in R&D.

The application of the “Tax Credit for Research and Development” measure also requires a method whose starting point is an organizational technological analysis like that in Fig. 4. The purpose of this analysis is different: identify improvements by carefully planning the R&D activities.

Measure I 4.0 “Credit Innovation”, aims to support companies that request bank investments for new plant and equipment at the factory.

The description of Method I 4.0 for Credit to Innovation is very similar to the Method I 4.0 related to the measure “Credit for R&D”.

In Fig. 3, in fact, a technological-organizational analysis of the current production process appears again as a 1st phase action but specifically dedicated to the purpose of identifying the company's expansion needs through the selection of new plants and equipment (“innovation via production capacity”). From here it follows the necessity to program the insertions and the extensions, guaranteeing the interconnection with the existing plant.

Measure I 4.0 “Accelerating innovation through new Start-ups and innovative SMEs” aims to spread a new entrepreneurial culture oriented towards collaboration, innovation and internationalization (Antonelli, 2015).

Phase	Action	Goal	Innovation
1st phase	Support innovative businesses throughout their life cycle	Promote the development of innovative entrepreneurship	New digital constitution mode and free
2nd phase	On-line self-certification of the requirements for start-ups or innovative SMEs	Obtain incentives and investments in venture capital	Tax deductions and reduction of the taxable amount

Fig. 5. I 4.0 Accelerating innovation through new Start-ups and innovative SMEs.

Unlike previous measures, the method of application of measure I 4.0 for start-ups and innovative SMEs results from the collaborative composition of the action of the Ministry of Economic Development on the one hand and of young entrepreneurs who want to start or innovate their business using this measure I 4.0 on the other (Antonelli 2013).

Therefore, the Ministry of Economic Development must define the conditions for setting up new enterprises by specifying the percentage of highly qualified employees (graduates, researchers, PhD students), the percentage of annual costs that the company must devote to research and development and the percentages of tax deductions to be budgeted.

Entrepreneurs, for their part, must provide a description of the innovative start-ups or SMEs by specifying the methods and means of the industrial process and the characteristics of the personnel by acquiring venture capital from investors external to the company.

4. EXPERIENCES AND FINDINGS IN APPLYING INDUSTRY 4.0 MEASURES TO A SME

The company described in this section is part of the group of 130 companies that, from February 2018 to today, have joined the PMInnova program started in February 2018 (Taurino, 2018).

The case refers to an SME (which will be called SME//1) founded in 1989, based in the Turin area, with about 80 employees, dedicated to the production of components for automotive, made by steel, on the basis of a CAD drawings, as inflator for airbags, components for assembling the interior of seats, components for anti-vibration systems. The innovation project was the purchase and introduction into the production process of a machine for printing reels, drilling and internal threading. with 8 programmable complementary units, loading and unloading stations, CNC control and mini PC for connection to the company's management system (cost of about 500,000 euros). As reported in the first phase of Method I4.0 for hyper-amortization, once the technical data of the new machine have been available, the first operation has to identify the critical issues for the machine interconnections. The system of interconnection to the corporate network, to the CAD/CAM design centre is represented by the diagram in Fig. 5.

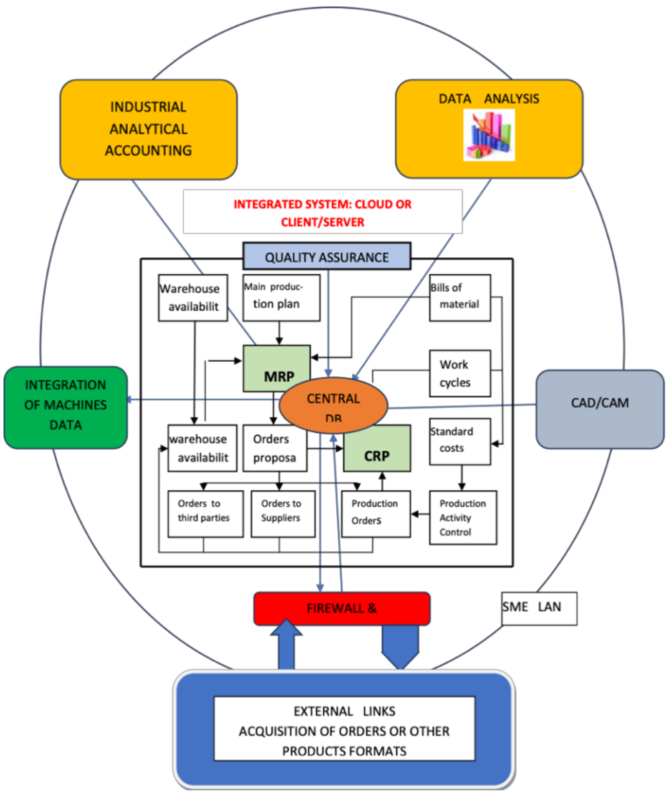

Fig. 5. Scheme showing the interconnections to the corporate network, to the CAD/CAM.

Typically, the goal of any SME manager has to require higher tax credit under the plan "Industry 4.0", a "hyper-amortization" calculated on the value of the purchased machine tool (MISE, 2017). In this project, the most critical requirement - according to the "Industry 4.0" standards, was the "interconnection" to the factory computer systems, with remote loading of instructions and/or parts of programs. According to the system specifications required by "Industry 4.0", the characteristic of the interconnection of the machine with the factory information system has been satisfied since the machine exchanges information with internal systems by means of a link based on documented specifications that gives an illustration of the digital twin of the machine purchased. In addition, to satisfy the other basic requirement, both physical and informative integration has activated: physical integration if the machine is serviced, in input or output, from an automated/handling system; information integration in which the traceability of the products/batches made through dedicated automated tracking systems (e.g. bar-codes, RFID tags, etc.) (2nd phase of Method I4.0 in Fig. 3), that allow the factory management system to record the progress, position of the batches or semi-finished products, exists. Based on the aforesaid characteristics, it has been activated the request for tax credit in the form of "hyper-amortization" according to the following computation in Table 1 (3rd phase of Method I4.0 in Fig. 3):

Table 1. Tax credit "hyper-amortization"

Cost of the purchased machine	500.000€
Over evaluation of 150% from Ind. 4.0	750.000€
Virtual cost of the machine	1.250.000€
Tax saving of 24%	-300.000€
Net investment	+200.000€

5. OPEN RESEARCH PROBLEMS AND PERSPECTIVES

The analysis of the real case of a small company of the Piedmont Region, presented in the previous Section, and the illustration of the challenges to apply the four main measures of Industry 4.0 to SMEs suggest open problems for an industrial research that wants to expand and make the innovation and development policies of the SME more effective. Some recent data from the Italian Ministry for Economic Development give preliminary indications useful for identifying open problems and research developments. The first document is the survey carried out by the Italian Ministry of Economic Development on the use of the various measures of Industry 4.0. According to the report, almost half of the manufacturing companies with over 250 employees made use of Industry 4.0, while only 6% of those with less than 10 employees and 18% of those with 10 to 50 employees did so. These data for the first time highlight the reduced propensity of micro and small businesses to invest in new technologies (https://www.met-economia.it/viavia-indagine-met-2017). On this phenomenon, the report of the Supervisor of Micro and Small Medium Enterprises, appointed ad hoc by the Government, has been tried, with an intervention in which it proposes a revision of the amortization coefficients, modifying the hyper amortization, currently supporting mainly investments in machinery, providing a reward for data-driven innovation of production processes, and a renewed focus on issues of safety at work, ergonomics and collaborative automation. These surveys confirm the opinion of the authors, who conducted in the SME described in Sect. 4 the analysis of the state of the companies and the verification of the requirements to be able to access the measure of Industry 4.0. With reference to the "hyper-amortization" measure requested by the company SME//1, the objective to be achieved is the digitization of the entire production process, with the insertion of three machines for cold moulding. In developing this analysis, the first problem encountered was the definition of the "digital twin" through a formal simulated model of the production process. Above all, it seemed difficult to interconnect the model and the process, in order to transmit real data to the model itself. This is because the company - like the majority of SMEs - has few data collection points. With this in mind, proposing a line of research and industrial development based on the use of intelligent sensors like the Internet of Things (IoT) even in an SME is very promising. The problem immediately following was the definition of a map of measurement points, with specification of the type of information obtainable and of the data format, quantitative or qualitative. This aspect is particularly important for the identification of the model, and therefore of its use. It follows the need to develop an industrial research on procedures for the identification of models of dynamic production processes, from data of a dual nature. Another problem was the management of a very large amount of data collected with small sampling step. For example, approximate data of the

SME//1 company indicate about 30,000 small output products from each of the 5 lines per hour, measured from about 20 measurement points in 15 working hours (two shifts). Therefore about 2000 data / hours collected from each of the measurement points must be channelled, catalogued and evaluated in order to guarantee the traceability of the products. It is essential to find a simple method, that is easily understandable by the manager (usually with not high skill but great technical experience) and easily usable, especially in the face of unforeseen events. In such situations, the best management of the company would be obtained using a method of adaptive control of the work operations in progress and of interactions with suppliers: unfortunately, the search for such a control strategy, applicable in an industrial environment, it seems complex: this should not, however, make a veil of interest. The last Industry 4.0 measure mentioned, or "accelerating innovation by supporting the creation of new start-ups and innovative SMEs", takes on a special character, differentiating itself from the previous ones as support for new entrepreneurship. Usable tools already exist and are linked to the known aspects of business creation. Apart from this last measure, a common conclusion can be drawn for all the others: Industry 4.0 offers a really new opportunity for all companies that want to seize the opportunities connected to the fourth industrial revolution, where the key words of "digitalization of industrial processes" and "enhancement of skills in the development of new products and new technologies" are associated with operational project tools.

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