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Chapter

Innovate Manufacturing SMEs in the Context of Industry 4.0: A Formal Approach

Teresa Taurino and Agostino Villa

Abstract

A few years ago, the "Industry 4.0" programs have been launched in several European countries and USA to support the development and the innovation of 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). For SMEs, it would be a great opportunity. However, SME managers (who usually are at the same time, owners, operations managers, and technicians) 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 chapter aims at guiding a manager/technician toward the opportunities offered by "Industry 4.0" by presenting some formal models on which managers can base their decisions of innovating their SMEs.

Keywords: Industry 4.0, cyber physical systems, interconnection, small and medium enterprises, innovation

1. Introduction

After the great financial crisis started in 2007, plans have been launched in various countries to support the development and the innovation of SMEs: until now, there are 15 European programs for Industry 4.0 all over Europe (Germany, Italy, France, Austria, Belgium, Czech Republic, Denmark, Spain, Hungary, Lithuania, Luxembourg, Holland, Poland, Portugal, and 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 among 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 [1].

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 [2], but full potential of these technologies has not been realized [3] 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, for example, part manufacturing, or assembling or quality testing [4, 5].

Given the inadequate technical skill of typical SME managers, we need a new methodology and related formal models to guide them in identifying the most convenient innovation perspective for their company, to analyze 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. What are the measures of Industry 4.0 that favor 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.

Therefore, this chapter is organized as follows. Section 2 provides an outline of the mail existing literature. Then, a new logical scheme decision-making process to select one of the four alternative measures of the Industry 4.0 program is presented (Section 3). To describe in formal terms the main usable Industry 4.0 measures, the most utilized alternative measures of the aforementioned logical model are reformulated in terms of mathematical models, defined in a sufficiently simple form to be understood by SME managers and technicians (Sections 3.1 and 3.2). By analyzing a real applications of Industry 4.0 to an Italian SME (to be developed within the Italian PMInnova Program, that is, a program to promote innovation and development of SMEs under the official agreement of Politecnico di Torino and the Bank Group of Asti, Biella, Vercelli, North-East Italy), the difficulties and benefits of Industry 4.0 are discussed in a small mechanical production plant (Section 4). Section 5 contains a comparison among Industry 4.0 programs in some European countries. Then, some concluding remarks are reported in Section 7.

2. Outline of main literature results

The Industry 4.0 program, launched in similar forms in 15 European countries, was designed to involve SMEs in the "IV industrial revolution" [6] by pushing companies to apply the new enabling technologies that are developed in three main areas:

• the availability of digital data and analytics of Big Data, together with low-cost sensors and cloud computing;

• robotics and advanced automation, with new man-machine interactions; and

• pushed connectivity, using intelligent sensors (Internet of Things).

Digitization has given a further push to the processes of transformation of the company, along some precise guidelines [1, 7]:

a. interconnection: the machine's ability to exchange information with internal systems (management system, planning systems, and design systems) and external systems (customers, suppliers, and partners), through links based on documented, public, and internationally reconfigured specifications (guidelines);

b. virtualization: a "virtual pair" (digital twin) of the real system or its components is created and supplied with data to predict the evolution of the behavior of the system by means of simulations [8];

c. decentralization: the various cyber and physical components that make up the production system have appropriate strategies (e.g., to correct process drifts) in an autonomous manner;

d. remote interaction: the devices are remotely accessible so as to be able to detect operating data and introduce corrective measures;

e. real time processing and reactions: the presence of functions that allow to collect process data in real time and to adopt the necessary actions or corrections.

Based on the five guidelines that characterize the typical actions of Industry 4.0, a wide literature has been developed according to the following main lines:

- Schematic description of the Industry 4.0 program to highlight the main enablers [1, 9];

- Analysis of the development trajectory from lean manufacturing to Industry 4.0 to explain changes and their usefulness [10–13]; and

- Discussion of any critical issues in the application of Industry 4.0, especially in SMEs [14–16].

With reference to the analysis of the Sommer paper, it is necessary that the researchers make clear that in the practical application of the Industry 4.0 plans, the technology road-map is still not clear in industry and in academy [15]. Some literature reviews show that Industry 4.0 projects only is a cost-driven initiatives; however it is rare to find papers where precise indications on the convenience of using some actions of the Industry 4.0 program are given [17]. This is particularly evident in the case of micro, small and medium-sized enterprises. Usually, the SME manager is also the founder of the company and the holder of the knowledge and techniques on which the industrial process was built and developed. These figures of manager/technician, and owner, are very tied to their original technical knowledge. Therefore, they resist to accept that their company becomes the object of innovation programs that meet the constraints of the "Industry 4.0" plans [1, 17, 18].

Consequently, it is understandable why small enterprises managers ask to have a "method" to guide them in selecting which innovation of their business could be better implemented by applying one of the Industry 4.0 measures.

3. The logical decision-making model

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 the 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 of Industry 4.0 corresponding to the following choices (see the following decisional scheme in **Figure 1**) are:

a. buy a new high-tech machine in case the manager 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;
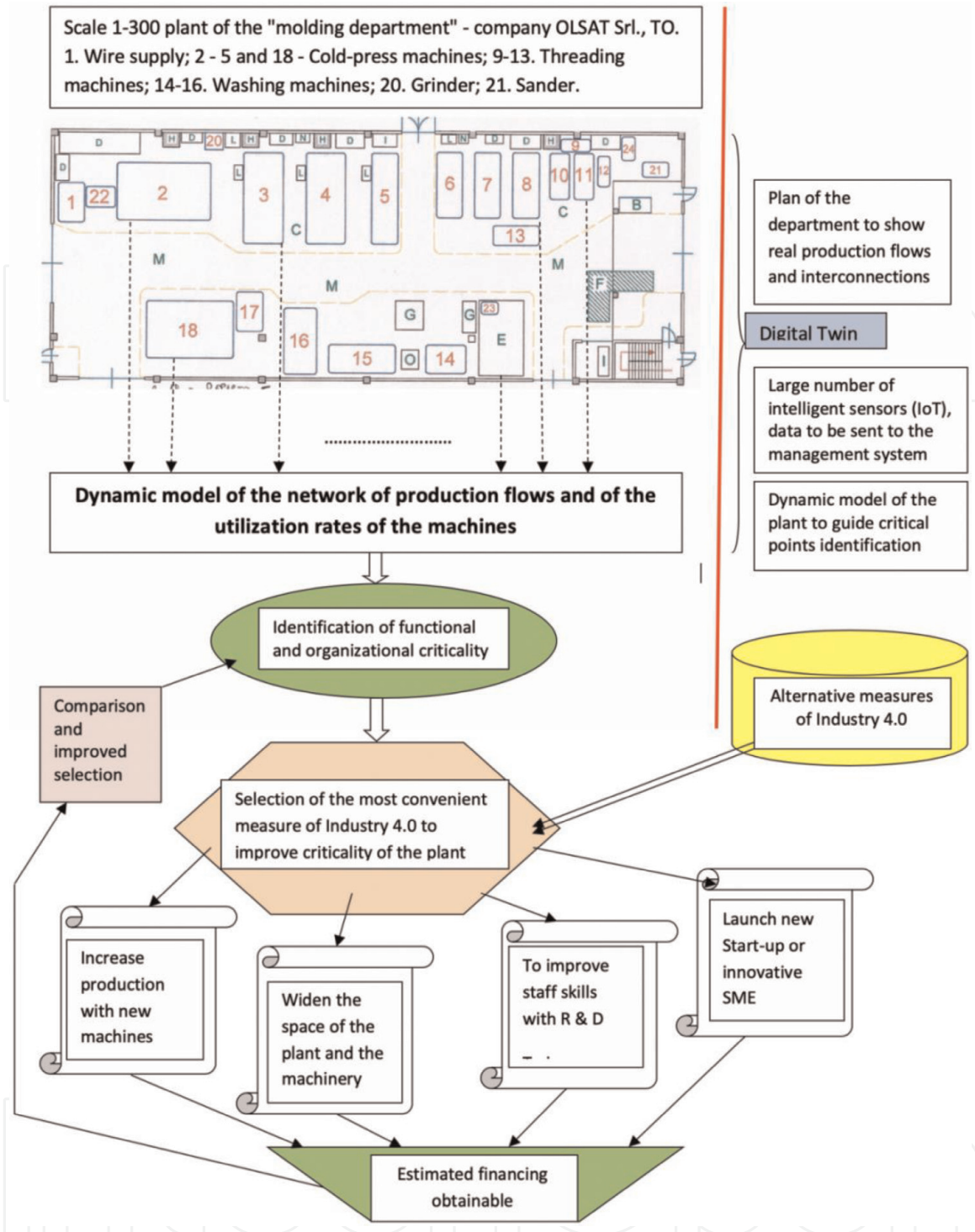
Figure 1.
Logical scheme of the Industry 4.0 decisional process.

c. expand the plant with other buildings and also insert operating machines already at disposal or purchased, if the space of the SME seems to become smaller for the increase of the customers' demand; and

d. found 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.

For sake of simplicity, the approach to select and verify the convenience of asking support for a SME according to one of said four alternative measures of Industry 4.0, will be based by considering the SME production process as organized in terms of a supply chain, that is, a typical organization of the production flows in a

small or micro-enterprise, where simplified interconnections of working machines are preferred (as the Authors have verified in about 80% of the 160 SMEs, that have been analyzed during the last 6 months of 2018 in the PMInnova Program).

In addition, in order to analyze approaches to existing SMEs' innovations, an effective evaluation can be only done among SME modifications obtained according to the first three alternatives (a)–(c) outlined above, the latter (d) being only related to the launch of a new company.

Figure 1 describes a logical scheme according to which the selection of the most convenient measure of the Industry 4.0 program (among the four alternatives above listed) can be done, with the goal of improving the efficiency, effectiveness, and convenience of a given SME.

3.1 SME innovation through new high-tech machine inclusion in the process plant

In case of a SME innovation through interconnection in the exiting process of a new high-tech manufacturing machine that will substitute an older one, the starting point will be the definition of a formal model, possibly simplified (to allow an easy understanding by the SME manager), of the process, by assuming that the new machine is included in a given point of the production line.

Owing to the higher production capacity of the new machine with respect to the others, the production line can be modeled by an equivalent production center. Then, the evaluation of the production capacity increase can be obtained by formulating and solving an Aggregate Production Planning (APP) Problem, as stated in [19, 20]:

$$\min\left\{\sum_{t=1}^{T}\left[w\cdot W_t+o\cdot O_t+\sum_{i=1}^{N}(c_i\cdot I_{i,t})\right]\right\}$$

$$s.t.$$

$$I_{i,t}=I_{i,t-1}+x_{i,t}-d_{i,t}\quad,\forall i,t$$

$$I_{i,0}=I_i^0\quad,\forall i$$

$$\sum_{i=1}^{N}x_{i,t}\cdot a_i\leq W_t+O_t\quad,\forall t$$

$$W_t\leq W^*\quad,\forall t$$

$$O_t\leq O^*\quad,\forall t$$

$$x_{i,t},I_{i,t},W_t,O_t\geq 0\quad,\forall i,t$$

3.1.1 Parameters

c_i unit inventory cost for product i;
$I_{i,t}$ inventory of product i in period t;
d_{it} demand of product i in period t;
$I_{i,0}$ starting inventory level of product i;
O_t straordinary work in period t;
O^* maximum capacity of straordinary work;
o straordinary cost;
W_t ordinary work in period t;

W^* maximum capacity of ordinary work;
w ordinary cost;
a_i processing time of product i;

3.1.2 Decision variable

$x_{i,t}$ produced quantity of product i in period t.

The above stated APP problem also includes the quantity of labor (and its bounds) because the inclusion of a new high-tech machine in a production process reflects either in a reduction of the workforce or in a modification of the employees' skills, effects that must be taken into account in the global evaluation of the cost-benefits balance.

In case of constant demand, the above general APP problem can be approximated as:

$$d_{i,t} = d_i \ (\text{domanda costante})$$

$$\text{costo prevalente} - c_i$$

$$\widetilde{J} = \sum_{i=1}^{N} \sum_{t=1}^{T} c_i \cdot I_{i,t}$$

With simple solution given by:

$$x_{i,t} = \text{costante} = d_i - \frac{I_i^0}{T}$$

$$I_{i,t} = I_i^0 - \frac{I_i^0}{T-t}, \quad t = 1,\ldots,T-1$$

$$I_{i,T} = 0$$

$$W_t = W^*$$

$$O_t = O^*$$

The resulting solution conditions allows to compare different alternatives of new different high-tech machines, depending on the production rates assured by each one of them and the necessary personnel.

3.2 Plan of a research and development program to include a new product in the existing mix

If the SME manager feels the need to expand his production mix to include a new product, the problems to be solved are mainly two: (a) designing the new product in order to use as many existing production operations, and related machines as possible and (b) estimate demand for the new product, rebalancing the production flows within the machine graph so as to avoid the creation of—or make less critical—bottlenecks.

It is not discussed here, due to space requirements and because already analyzed by the authors in a previous paper [21], the first problem, whose solution is obtained by a "composition" of the operations of processing and assembly of the new product, trying to draw them from "Bills of Materials" of products already in the works.

About the second problem, this requires an analysis of the production flows with the presence of the increased mix: something that can be obtained from a Production Flow Analysis model [22].

The following data are necessary to analyze the production flows within the plant, for every manufactured product, p: (a) sequence (ordered list) of the utilized resources, LR_p and (b) the standard (average) volumes required by market, V_p.

These data summed up in the *Map of Production Mix*, defined by:

$$MMP = \begin{array}{|c|c|c|} \hline \cdots & \cdots & \cdots \\ P & LR_p & V_p \\ \cdots & \cdots & \cdots \\ \hline \end{array}$$

Based on such data, one can apply the PFA steps as follows:

a. From the List of Resources of the product p, LR_p, one has to fill the *map product-resources*, otherwise called *Functional Map of Layout* (since it shows as the available resources are used to work the mix of products under examination) is defined as follows:

   $MFL_{p,r}$ = 1, if the product p "uses" resource r,
        = 0, otherwise.

b. *To the Functional Map of Layout, the Map of Work Requests, $MRL_{p,r}$, corresponds, as defined by:*

   $MFL_{p,r}$ = 1, if the product p "uses" resource r,
        = 0, *otherwise*.

c. parallel, again from the List of Resources, the *Structural Map of Layout*, $MSL_{r,s}$, that is the matrix of connections among the work centers included in the layout, is defined as follows:

   $MSL_{r,s/p} \rightarrow$ contains the set of products p which utilize the work center r and then the work center s;
        = 0, otherwise.

By using said maps, one can apply the following analysis considerations:

i. The Structural Map of Layout allows to recognize all work centers to which several production flows are directed; they could be potential bottlenecks or, at least, congested centers;

ii. The Functional Map of Layout is the basic matrix for the clustering procedure to identify product families and work cells;

iii. The Map of Work Requests is used in the procedure to identify bottlenecks, by estimating the requests for work at each work center.

In this sufficiently simple way, the manager can verify the impact of the new product on the pattern of existing production flows, and estimate the cost of including said new product in its own production mix.

3.3 Expanding the SME production space

The typical application of this measure of Industry 4.0 is related to the expansion of the plant space 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 (see the first activity), which generally constitute the two main elements of the crisis of the SME. From this activity, the estimate of necessary space and extension of the plant will also be achieved. Subsequently, some machine operating in the production process should be moved to new space, allowing a reorganization of the logistics paths (i.e., production flows). As in the two previous cases, an evaluation of the aforementioned activities could be obtained by the same PFA model adopted in the second type of Industry 4.0 measure.

4. A real application

Started in February 2018, the PMInnova Program [18] has so far registered more than 160 SMEs in its archive, and for 60 of them Politecnico di Torino has analyzed the current technical-organizational-functional status and evaluated the feasibility of their innovation and development plans in an "Industry 4.0" perspective [23].

An interesting "success case" (i.e., an innovation project by inclusion of a new high-tech machine in the existing plant, that have been already approved by the "Industry 4.0" reviewers) is shown in detail, by only omitting the company name for confidentiality reasons, but by using real data and information.

The success case refers to an SME (which we will call SME//1) founded in 1989, located in the Turin area, with about 70 employees, dedicated to the production of components for automotive, made by steel, on the basis of a CAD drawings. The finished product is obtained from a steel wire with a cold molding process and, if required, a chip removal. Examples of products of SME//1 are: inflators for airbags, small components for assembling the interior of seats, small components for anti-vibration systems, and joining tools.

The innovation project of SME//1 was the purchase and introduction into the production process of a machine for printing reels, drilling, and internal threading. With eight programmable complementary units, loading and unloading stations, CNC control and mini PC for connection to the company's management system. The system of interconnection to the corporate network, to the CAD/CAM design center and, through rewalls, to outside, is represented by the diagram in **Figure 2**.

The model described in Section 3.1 has been used as "formal tools" to develop the evaluation of the impact of the new machine in the existing process. In practice, said model have been used to compute the innovated production capacity: to this aim, some software tools already at disposal of the SME have been applied for obtaining real internal order transmission to the machine, once the production plan computation has been done, the MRP application in order to translate the production plan into internal orders, and the CRP to verify the model-based estimation of the production capacity increase.

In this project, the most critical requirement—according to the "Industry 4.0" standards—to which the machine had to satisfy, 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
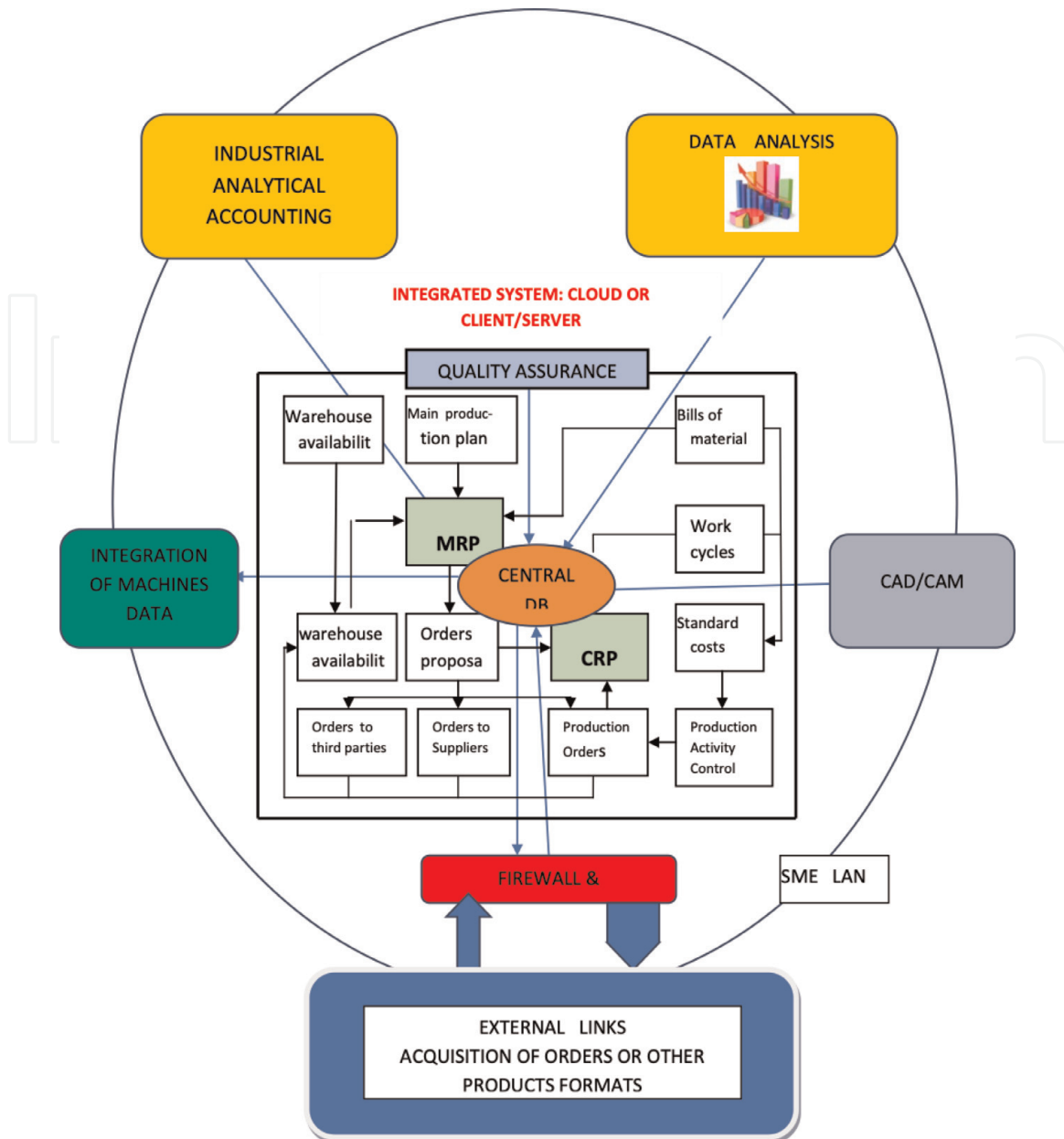
Figure 2.
Scheme showing the main interconnections to the corporate network, to the CAD/CAM.

system through remote loading of instructions and/or parts of programs, is satisfied
if the machine exchanges information with internal systems (e.g., management
system, planning systems, product design and development systems, monitoring,
even remotely, and control, other plant machines, etc.). Moreover, to satisfy other
Industry 4.0 requirement, both physical and informative integration has to be
assured, such to guarantee the traceability of the products/batches made through
dedicated automated tracking systems (e.g., bar-codes, RFID tags, etc.) [24, 25].

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€

Table 1.
Tax credit "hyper-amortization" according computation done for the SME//1.

On the financial point of view, obviously, the SME//1 manager will require higher tax credit possible under the plan "Industry 4.0": to this aim, a "hyper-amortization" has been computed, based on the value of the purchased machine tool, according to the computation in **Table 1**:

5. Comparison of the funding measures of "Industry 4.0" in the main European countries

While in Section 4, the analysis of applications of the "Industry 4.0" plan has been referred to an Italian success case, now a picture of the industrial sectors and services that have used the Industry 4.0 funding opportunities in other industrialized European countries is outlined.

First comparative data are available from the various countries with reference to July 2017, in percentages of growth or less referred to the year 2016. From the first quarter of 2016, it is observed that the gross domestic product (GDP) is in constant growth in Germany, France, United Kingdom, United States, and Italy, with an average increase of around 0.3% in these countries, while the highest percentage of industrial growth is observed in Japan (+0.6%) [26].

In terms of the effects of the different interventions of the "Industry 4.0" measures in the major European countries, a particularly interesting variety can be seen. Italy, with its plan strongly based on maximum savings and tax credit, appears among the leading countries for fiscal support to businesses. In its "Industry 4.0", Germany has not focused on tax credits to stimulate research, but above all on direct funds disbursed by tender and on the financing of KfW—Kreditanstalt für Wiederaufbau [27, 28] to businesses. The federal government has planned the construction of 16 competence centers (5 already active) linked to the production specialization of the Lander. But the Italian model looks more like another German network of excellence, the Research Campuses that develop public-private partnerships with universities. France with "Industrie du Future" represents a model closer to Italy for some incentive choices, starting from super-amortization and tax credit [29]. It does not have a platform specifically dedicated to Industry 4.0, but the United Kingdom has recently changed gear on industrial policy with the green book "Building our industrial strategy" (U.K. Government, Building our Industry Strategy, 2017). GBP 4.7 billion is planned for research by 2020–2021. Great Britain has also made extensive use of tax credits over the last few decades, but now, the new strategy's pillar is the support to commercialization of the results of the innovation of the companies, entrusted to the "Catapults Center" (HVM Catapult—High Value Manufacturing, see web site, 2018). Unlike Italy, the whole strategy of the Netherlands started from the identification of nine leading sectors. To develop them, 19 consortia were created in public-private partnerships that take care of the planning, under them the Field Labs operate, laboratories serving companies [30].

6. Open research problems and perspectives

The analysis of the real cases of two small companies 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 10–50 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 main 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, concerning the ability of SMEs managers to access the measures 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 molding. 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, the proposal of 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.

Another problem was the management of a very large number 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 channeled, cataloged, and evaluated in order to guarantee the traceability of the products. The amount of data and the speed necessary to treat them opens another line of industrial research.

A common conclusion can be drawn from the above analysis: 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. However, researchers and managers have to find a common language, and analyze together tools for the project, for the evaluation, and for the possible application of new machines for very fast and very accurate processing, which can be easily interconnected with others in an existing plant, and are equipped with sensors that follow the movements of components and products, allowing complete traceability This aspect—search for a common language—is perhaps the problem that needs the fastest possible solution.

Author details

Teresa Taurino and Agostino Villa*
The Polytechnic University of Turin (Italian: Politecnico di Torino), Italy

*Address all correspondence to: agostino.villa@polito.it

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