Smart Sustainable Manufacturing: a new Laboratory-Factory concept to test Industry 4.0 principles

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***Abstract*— Manufacturing enterprises are presently faced with an array of industry 4.0 (I4.0) challenges. "Digital requirements" need to be really assessed by an accurate analysis and deep understanding of the operational and technological criticalities in the manufacturing operations. This may thus allow to effectively design and implement a digital twin that supports the transformation. The goal of the article is to present and analyze the criteria adopted in a design for the transformation of a real setting of an Italian company into a I4.0 testing learning-laboratory. The idea behind is that this laboratory-factory may play a key role in developing new solutions for the automation and the implementation of the I4.0 paradigm and it is a viable solution for the learning factory.**

Keywords: Industry 4.0, Laboratory-Factory, Learning Factory, Smart Production, Digital Manufacturing.

1. MOTIVATION

Industry 4.0 was announced at the Hannover Messe in 2011 [1]. Kagermann et al. [2] define Industry 4.0 as: *"networks of manufacturing resources (manufacturing machinery, robots, conveyor and warehousing systems and production facilities) that are autonomous, capable of controlling themselves in response to different situations, self-configuring, knowledge-based, sensor-equipped and spatially dispersed and that also incorporate the relevant planning and management systems"*.

Industry 4.0 is a new evolution for the companies. This evolution involves the introduction of several technologies in the manufacturing industry – big data, 3D printing, augmented reality, collaborative robots, Cyber physical system (CPS), and so on [3].

The first challenge, for manufacturing companies, is to understand the rationale behind these new technologies, how, when and where these could be applied and why these are truly beneficial to the manufacturing industry. In particular, small and medium sized enterprises (SMEs) have the difficulty to be highly skilled in applications and technologies of Industry 4.0. This is caused by the fact that those companies usually don't have the possibility to invest in emerging technologies like an early adaptor, in order not to lose money by focusing on the wrong technologies [4].

The second challenge is to develop I4.0 competences in SME's and this will be one of the focal areas for progress. Companies need to become quickly suitable to the new market conditions. This ability of the company is highly dependent on the ability of employees [5]. To develop employees' competencies, traditional teaching methods show limited effects [6].

The new factory needs the development of problem solving skills [7] and less physical strength. Therefore, the third challenge is to facilitate the learning of new tasks and skills.

Human actors in a future production scenario will need specific competencies to cope with the new challenges regarding technological and organizational developments.

2. RESEARCH QUESTIONS

Industry 4.0 will lead to an increased automation of routine tasks which implies that workers will have to focus on creative, innovative and communicative tasks.

It is necessary to stop production so that production never stops. It means equipping each machine with a system and training every worker so as to be able to stop the production process at the first sign of some anomalous condition (predictive manufacturing).

How the companies are able to react on above mentioned challenges?

Manufacturing companies, in particular SMEs, need further training in modern technologies, enabling Industry 4.0 scenarios and methods to optimize their production processes.

3. METHODOLOGY

This paper is the result of a project done in cooperation with the SME Italian company: Master Italy s.r.l. It was founded in 1986. The products are hardware aluminum for windows and doors.
In this paper, we propose a solution to transform a real manufacturing company into a learning laboratory factory (LLF).

Future manufacturing systems will need to become more autonomous. In order to make this happen, the autonomous systems will need the access to realistic models of the current state of the process. It allows the understanding of the behavior of the process in the real world [8] - typically called the "Digital Twin". The solution here proposed for the Learning laboratory factory (LLF) is based on a “virtual technological mock-up” of the production stages so as to simulate potential operating scenarios and devise potential execution problems.

It is necessary to rethink the concept of what a factory is. Factories can be a learning laboratory factory.
What is a learning factory? What is a laboratory factory?
In 1994, the National Science Foundation (NSF) in USA coined and patented the term “learning factory”.
According to Wagner et al. [10], the term “learning factory” has two words “learning” and “factory” and it is used for systems that have elements of both.
The common definition is that the learning factory is a real learning environment which allows a balanced relationship in conveying specialized theoretical and analytical knowledge as well as hands-on experience [11].
The potentials of learning factories are education and training, research, and innovation transfer.
The main goals of learning factories are either technological and organizational innovation (if used for research), or an effective competency development (if used for education and training) [12].
Universality, mobility, modularity, scalability and compatibility were identified as the first order parameters for ideal classification of a learning factory [10], [13]**.**
During the last years learning factories have already been used during several practical trainings on different topics within production processes (e.g. lean management and resource efficiency).
Vienna University has decided to build the Industry 4.0 Pilot Factory. It will serve both as a research, a teaching and training platform with regard to future production [14]**.**
Learning factories can clearly have a positive influence on students’ performances in comparison with traditional teaching. Cachay et al. [11] examined how the learning factory concept impacted students' performance in application. The EAFIT University defines a model to develop the learning factory 4.0 into an academic context [15].
Many universities look at an existing production line as a starting point in order to implement learning factory Industry 4.0: Aalborg University [3], University of Applied Sciences Darmstadt [16], RWTH Aachen University [17]. This are equipped with machines, materials and tools established to realize real physical products to support research projects about industry 4.0.
The IFA Learning Factory at Hannover University [11] defines how cyber-physical systems in combination with logistic models can improve planning, controlling and monitoring production. Other learning factories with focus on aspects of Cyber Physical Production Systems in learning factories are for example:

- CPPS learning factory at Paderborn University [18].
- Learning factory at Braunschweig University [19].
- Teaching Factory at Patras University [20].

Faller and Feldmüller [4] developed an Industry 4.0 learning factory at Bochum University covering the topics of technical and organizational integration of field level, control level, management level and C-level.

The learning factories comprise physical and digital environments. The physical environment includes real system components like machines, logistics, information flow, energy flow modules, products and people. Integrated planning, modeling, visualization and simulation tools are parts of the digital environment. Both physical and digital environments should also be integrated (Wagner,2017). That offers new possibilities to transfer digitally created solutions to a real system for testing, evaluation and demonstration. Furthermore, there should be an automatic feedback from the real system components to the digital environment to plan adaptation and change (e.g ESB Logistics Learning Factory at Reutlingen University [21]**.**

The limits of the current learning factory concepts considering [21]:

- ➢ resources needed for learning factories
- ➢ mapping ability of issues in learning factories
- ➢ scalability of learning factory approaches
- ➢ mobility of learning factory approaches
- ➢ effectiveness of learning factories

A laboratory factory is an organization dedicated to:

- ➢ knowledge creation;
- ➢ knowledge collection;
- ➢ knowledge control;

embedded in physical equipment and processes and embodied in people [22].
The laboratory factory supports education and training to let the industrial participants and employees discover industry 4.0 principles and technologies and apply them directly on problems in a real production environment.

Employees in the laboratory can test and try their idea on real production line.

The laboratory factory offers to employees the possibility to analyze and solve production problems and in this way, it is possible to:

- Collect and integrate internal knowledge;
- Do some field experience and innovate (changing the status quo);
- Integrate external knowledge;

4. SOLUTION/DISCUSSION

How learning laboratory factory concept can be implemented on the existing real production line? What are the benefits and limits of its application? People don't learn the technology but learn through the technology.

The Learning Laboratory Master solution here proposed consists of a realistic production environment "augmented" with technological knowledge. In this approach a laboratory-factory is represented by the physical settings through their "virtual representation". Then they may interact each other according to specific properties and rules. Accordingly, the mock-up line space is composed of:

- A fleet of machines, including technological processes and components.
  The technological processes are:
  - Aluminum die casting;
  - Blasting;
  - Drilling;
  - Assembly lines;

- The product is the angular fixing bracket used to tighten aluminum, including:
  - Version numbers;
  - Size and shape;

- Human actions, including:
  - Condition Monitoring of previously and presently collected data;
  - Controller parameters machine performance (e.g. product quality measurement, OEE indicator);
  - Maintenance activities;
  - Logistic activities;
  - Human controlled operating parameters and/or model patter;

Workers are engaged in ordinary activities where the level of knowledge is very low like the data collection, data transcription and data processing. According to a study conducted by Schuh et al. [23], production data feedback is currently submitted in written and not digital form in 59% of small and medium sized enterprises and 30% of large enterprises.
Through Industry 4.0 is possible to implement in the learning laboratory Master IT systems (e.g. MES system) and/or sensors to have real time data within a cyber-physical system.

Productions can be effectively planned and scheduled when the employees possess the high knowledge about methods and interactions constraints. In addition, also the employees involved in maintenance activities possess the high knowledge because they have to be able to understand the problems, to implement a standard procedure when the problem is known and to identify a new procedure when the problem is unknown.

Through Industry 4.0 is possible to implement technologies that reduce the complexity of the task and the process of learning becomes easier and faster.

The First 4.0 use case of the factory-laboratory in Master is the ADVANCED SCHEDULING.
The simulator identifies the optimal sequence-planning considering the constraints of the process, like cycle time and setup, and the capacity of the workstations, and customers' requirements. The system also allocates resources like material and staff.
The knowledge is shared and in this way all employee is able to plan and optimize the production.
Thanks to this kind of technology, employees learn the technology and learn through the technology.

The second use case is the REAL TIME PROCESSING DATA.
The data collection is possible thanks to low-cost, small, easily available sensors. A MES is a platform for transforming data collected on the shop-floor into information.
MES is in charge of collecting the data gathered on the shop-floor, analyze it through mathematical techniques, and extract the information necessary to provide an exhaustive picture real time of the current state of the process.
In this way, employees can make decisions to control the process with the necessary rapidity.

The third use case of the factory-laboratory is the ASSET MONITORING. The analysis is performed in real-time and are displayed in graphic dashboards through mobile devices like tablets and smartphones.
In this way, every employee can control in every moment the process and he can improve it.

For predictive manufacturing it is necessary to know deeply the process. In the figure 1, the red circles are the available technological parameters, the green circles are available technological parameters after the implementation of MES.

It is necessary to have a realistic model of the process to understand:
1. the behavior of the process;
2. the correlations between technological parameters;
3. the correlations between parameters and effects like quality defects.

Thanks to the model it is possible to select new important technological parameters to measure.
The blue circles in the figure 1 are unavailable parameters selected through the model.
It means to equip each machine with new sensors and it allows to create the correct digital twin ("virtual technological mock-up").

The digital twin is the factory-laboratory because all parameters are available, and employees can simulate and test new solutions and evaluate "what happen if".
Before the changes are executed in the physical factory environment, the gathered data from the shop floor level are aggregated, analyzed and interpreted in the digital environment.

The solution tested in the laboratory-factory will be then implemented in the real world. The laboratory-factory is a learning environment because employee know what they can do and why. At the same time, while implementing solutions they improve and update the model and consequently the digital environment in a continuous loop.

5. CONCLUSIONS

In conclusion, the factory-laboratory introduced in Master company can be closely linked to potential innovations, as long as new prototypes or product, or even technologies can be tested and then easily applied though CPPS. A continuous upgrading plan of this concept is still in process to provide a clear evidence of the soundness of the idea here proposed.

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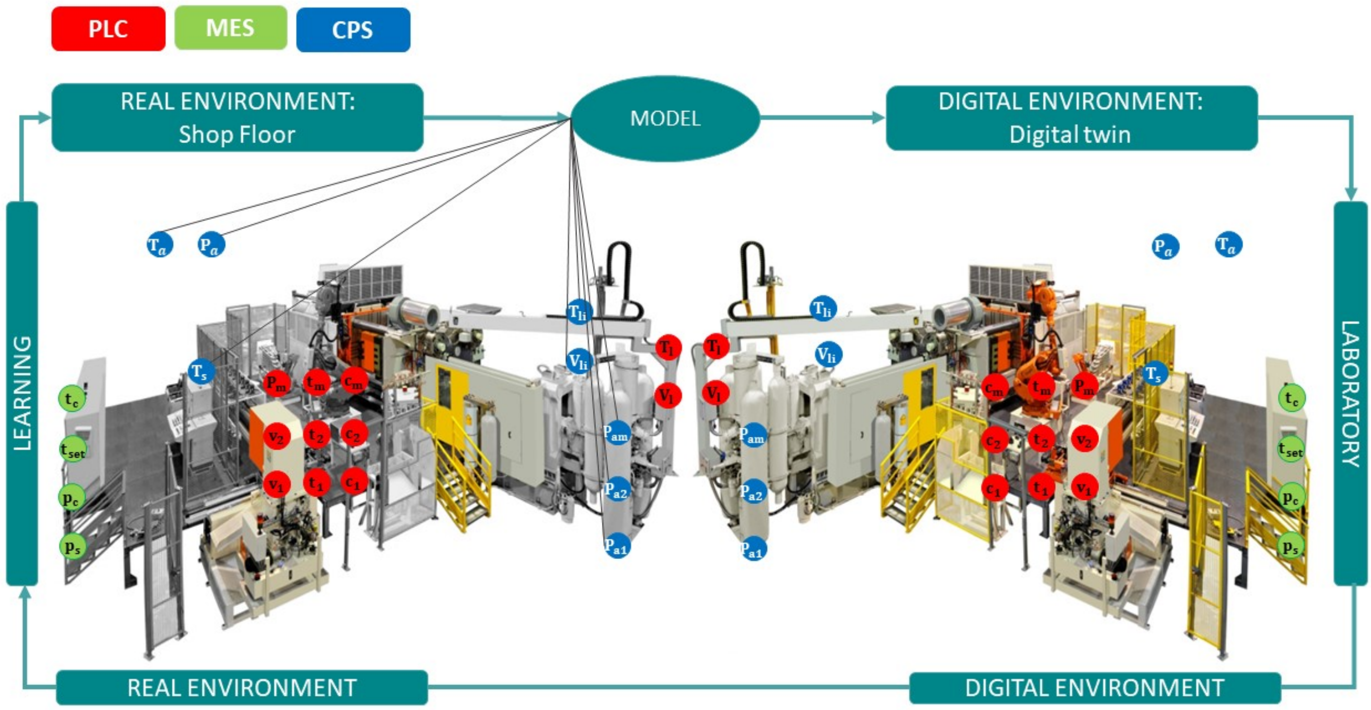

Figure 1. Virtual technological mock-up