Sustainable Industry 4.0 Methodology for Improving SMEs' Performance

Clément Soudé[1], Paul-Eric Dossou[1,2](✉), Gaspard Laouenan[1], and Baptiste Duquenne[1]

[1] Icam, Site of Grand Paris Sud, 77127 Lieusaint, France
paul-eric.dossou@icam.fr
[2] University of Gustave Eiffel, Champs-Sur-Marne, 77420 Paris, France

Abstract. Industry 4.0 concepts have been elaborated in response to an increasing rate of customized demands, in order to keep high industrial performance for enterprises. These concepts are based on the introduction of new technologies such as collaborative robotics, artificial intelligence, big data or internet of things, in the manufacturing performance improvement. Indeed, the addition of organizational methods in the improvement contributes to the company's positive digital transformation. For instance, lean manufacturing, with reduction of wastes and value-added management, corresponds to a methodology that could be exploited for increasing the performance of SMEs. This paper focuses on how to put sustainability as the kernel of company digital transformation and new technologies as a support for humans in the future manufacturing. Through a use case, this paper presents the concepts of smart manufacturing and flexibility 4.0 for sustainably optimizing the company performance. After a literature review on industry 4.0, flexibilization 4.0, smart manufacturing and lean manufacturing, the concepts developed in this frame will be exposed. Then, the intelligent system being developed for supporting the SME digital transformation will be presented. An application in the electronic card production sector will be shown.

Keywords: Industry of Engineering · Industry 4.0 · Robotics · Cobotics · Flexibilization

1 Introduction

Many industrial revolutions took place since the middle of the 18th century such as the first revolution based on mechanization, the second revolution for developing mass production and the third revolution that introduces automation and robotics in manufacturing systems. The fourth industrial revolution has started in 2011 [1], and is characterized by the use of new technologies such as artificial intelligence [2], cyber physical systems [3], and internet of things [4] for increasing the supply and production chains performance. Then, organizational methods such as lean manufacturing [5] could be used for transforming the companies during the implementation of new technologies.

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This paper proposes to integrate sustainability (social, societal, and environmental dimensions) as the main criterion for the company digital transformation in response to the brakes of SMES in the industry 4.0 concepts implementation in their companies. A sustainable digital transformation framework for the implementation of industry 4.0 concepts has been developed. However, implementation of industry 4.0 concepts, being very costly for SMEs, might alongside require the implementation of lean manufacturing with continuous improvement in order to control and ensure the company performance improvement. The Smart manufacturing and Lean 4.0 methodology is based on [6] this philosophy. Flexibilization 4.0 corresponds to the adaptation of the production lines including new technologies to the customer demands for increasing the company performance.

After a literature review, this paper will present the sustainable framework for industry 4.0 concepts implementation in SMEs. Then, the concepts of flexibilization 4.0 destined to increase the company performance through the agility of the production processes will be explained. An illustration of these concepts will be exposed by exploiting a demonstrator being developed for validating use cases of companies.

2 Literature Review

This article aims to develop and validate a sustainable methodology for transforming digitally the SMEs by implementing new technologies. Many Industry 4.0 concepts have been elaborated and implemented in companies, but are not sufficiently used in SMEs. The following part presents the existing concepts that can be used for defining the sustainable methodology adapted to SME digital transformation.

2.1 The Concepts of Industry 4.0 in the Production Manufacturing

SMEs face a new societal paradigm where mass customization [7] requires transformations towards more flexible organizations. Industry 4.0 pillars [8] contribute to the production processes digital transformation with new technologies. The company production lines are well-managed with the use of sensors and connected objects for collecting data and taking the adapted decisions. However, these concepts meet brakes for SME development. New technologies such as collaborative robot (cobot), mobile robots, IoTs, Cyber-physical systems, artificial vision or big data are expensive. Despite the benefits of industry 4.0 concepts, SMEs can hesitate to implement them in their production systems. Beyond the economic aspect, other sustainable issues with industry 4.0 tools are also a brake for the digital transformation of SMEs. On a social and societal level, the low acceptability of new technologies by human operators also contribute to the fear of company managers for introducing them in their company. A focus is made in [9] on the level of implementation of industry 4.0 tools and shows the SMEs resistance. Nevertheless, these different technologies can help SME to improve the benefits of companies.

For instance, reporting and supervision are used to improve the efficiency of corrective interventions. Big Data [10] is used to improve decision making for predictive maintenance applications. Indeed, both structured data that can be managed by a data warehouse, and unstructured data integrated in a data lake are contained in the company database and are involved in the company transformation. Digital twins could be used as an aided tool for seeing the impacts of potential changes before their real implementation in the company [11]. As described in [10], a digital twin is "a virtual mode and comprehensive depiction of the system used to understand the performance parameters, for improving processes and effectively enhance value-added activities". This simulation allows to control each step of a process and identify issues or bottlenecks. It is one of the first steps to optimize a company and identify wastes. However, industry 4.0 is not only based on tools but also on organizational methods such as lean manufacturing, smart manufacturing, etc.

2.2 Organizational Methodologies in the Production Manufacturing

Indeed, Just-in-time (JIT) is one of the methods for improving the company flows by focusing on the customer demand and organizing the flow optimization through the non-value-added reduction. This context involves the production manufacturing to be able to change very quickly according to customer demands. Flexibilization in the production processes becomes a problem that can be solved with industry 4.0 concepts [12], leading to the rise of new methodologies. For instance, Smart manufacturing introduces different types of technologies controlling each stage of a product's life cycle in manufacturing such as semiconductor production [13]. Just-in-time philosophy [14] integrates theory of constraints, SMED (Single Minute Exchange of Die) and Kanban tools. It contributes to reorganize the production processes from the customer demand and reducing wastes. Lean manufacturing methodology [14] more lager than the previous adds other concepts such as TPM (Total Production Management), Jidoka, five zeros tool, and waste reduction (7 muda). DMAIC (define, measure, analyze, improve, control) is used for improving quality performance of processes [15]. KAIZEN [16] allows to constantly reduce wastes on a production line, as well as to perpetuate the solutions. Tools such as 5 WHY, Ishikawa Diagram, which are Lean Manufacturing tools, could also be used for increasing the product, processes, and the system quality. A combination of these organizational methods will allow to define how the company system could be restructured efficiently in the context of industry 4.0.

2.3 Performance Measure in the Context of Industry 4.0

The actual state of the company being transformed needs to be measured for knowing exactly the potential improvement that could be realized. Then, the future state, after the use of industry 4.0 concepts could be designed and its performance measured. Different indicators could contribute to this measure. Overall Equipment Effectiveness allows to measure a single machine state or the complete production line performance. The measure consists in multiplying three factors: availability, performance and quality [17].

$$\text{OEE} = \text{Availability} * \text{Performance} * \text{Quality} \tag{1}$$

The availability contributes to define the level of occupation of a machine or a physical process. The performance corresponds to the degree of efficiency of a machine or a physical process. And the quality parameter measures the level of product or process quality. The OEE indicator allows to detect defaults in the production line and to take the right decision for improving the machine or process performance [18]. Another indicator to measure performance in a company is, return of capital employed (ROCE). This indicator makes it possible to judge the investment choices made with all the capital used by the company. In addition to these criteria, and to the classical triptych (quality, cost and delivery time), the social, societal and environmental aspects have to be integrated in the company transformation. Changes brought by Industry 4.0 are positive for the performance of a company. The imported changes are not only technological but also organizational, another major point of the 4.0 industry is the flexibility of the means.

2.4 Flexibility in Industry 4.0

Companies need personalization in their product to attract more customers. Production line must change to be able to produce all different types of custom products. As referred in [19], companies have to change their traditional way of producing. Big companies can use automation together with methodologies presented above to increase their performance. However, it is not very common for SMEs in France yet [20]. For instance, the ratio of robot implementation is only 177 robots for 10000 employees because they are expensive. Industry 4.0 and flexibilization 4.0 aims to reorganize production and logistics flows to create interconnected flows and optimize the production process. These changes allow to ease the company production [21]. The product diversification and the customer expectations involve the company production lines adaptation. Digital twins, as explained previously, could contribute to define the best new reorganization for ensuring the customer demands. It implies fully flexible production lines, as mentioned in [19]. Then, the production line can be transformed with limited risk according to the customer's demands. This way, it can integrate cobots and modern production machines (including IoTs and sensors). Alongside this new type of line, software like MES (Manufacturing Execution System) and ERP (Enterprise Resource Planning) [22] can help Manufacturing Companies to optimize their process [23] and achieve the 5 Zero principles. A cobot, a machine or a human could be affected to different processes according to the production objectives.

2.5 Artificial Intelligence in Industry 4.0

Artificial intelligence (AI) is one of the pillars of industry 4.0. For instance, it allows to optimize predictive maintenance, processes and quality control (Fig. 1). AI is used at all levels of the smart manufacturing, such as the production tracking, the machines state by exploiting IoTs for collecting data. Artificial intelligence in smart manufacturing can also determine the shortest route for robots, and fleet management. AI finds applications in all parts the production and management system of a company. For example, on an operational level, it can assist humans and reduce fatigue with collaborative robots [24].

Further use of AI can help for analytical decision-making by also integrating human intuitive reasoning abilities [25].

Ecological approach of AI. The artificial intelligence in a company can also reduce energy consumption. For example, the affiliate of Google, DeepMind, uses artificial intelligence to control the cooling system of data centers which is the main energy consumption. This use of artificial intelligence could reduce the consumption of electricity and make 15% of saving power usage effectiveness (PUE). Dallaire-Nicholas et al. [26] the PUE is the ratio between the energy use and energy consumption of a data center.

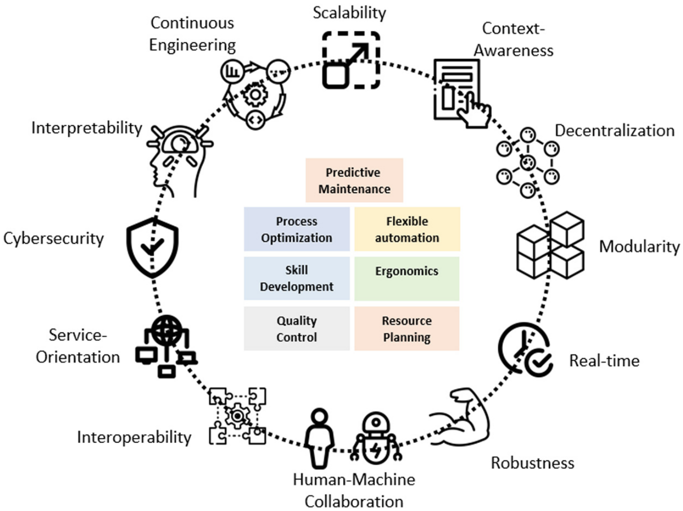

Fig. 1. Addons of artificial intelligence on industry [19]

3 Methodology

3.1 Sustainable Framework

This paper proposes to integrate sustainability as an important criterion in the SME digital transformation. Sustainability corresponds to environmental, social and economic criteria as suggested by the Triple Bottom Line. The sustainable criterion has been detailed in [27] and is composed of social, societal and environmental dimension. The sustainable framework as presented in [28] has been developed (Fig. 2) for convincing SMEs to implement Industry 4.0 concepts to improve their performance. Three axes of transformation have been defined. The first is the physical transformation including the combination of lean manufacturing tools with DMAIC and DOE for increasing the company performance by using organizational methodologies. The second is the decisional transformation and exploits GRAI methodology for structuring the decisions that would be taken in the company. The third is defined as the informational transformation and includes the integration of software tools and new technology in the company changes. As a global system, the SME transformation corresponds to the definition of the existing situation and then the use of specific tools to transform the company. An approach has been used for this implementation and consists in 4 steps. The first step evaluates the current state of the SME with the use of quality, cost, lead time, social, societal, environmental and degree of modernization criteria for measuring the company performance. Then, the next step corresponds to the definition of the adapted transformations according to the company objectives. Then, a strategy based on the use of a digital twin and the test of use cases is exploited for validating the potential transformations. Finally, the sustainable digital transformations are implemented in the company and the future state of the company performance is measured for showing its improvement. New technologies such as non-intrusive IOT sensors are introduced in the company process for collecting appropriate data in order to take right decisions. For instance, they could be used for making smart the manufacturing and exploiting AI for predicting predictive maintenance.

An intelligent system is being developed for supporting the sustainable framework in the company performance improvement by transforming digitally the enterprise. The architecture of the intelligent system has been presented in [27].

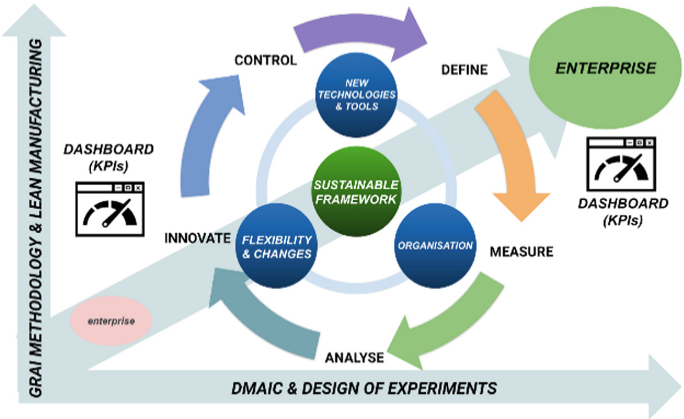

Fig. 2. Sustainable digital transformation framework for SMEs

3.2 Research-Action Approach

This paper aims to propose a research-action approach for accompanying SMEs in their sustainable transformation. It focuses on experimentation results for transforming and validating concepts elaborated on the sustainable and digital transformation. The objective is to reproduce in laboratory an industrial manufacturing that could be used for solving SME use cases. The existing situation of a SME could be reproduced on the demonstrator and tested. The solutions could be simulated by exploiting production manufacturing simulation tools for elaborating a digital twin. After the solution validation by the company, this solution could be tested on a real production system. Indeed, two production lines have been elaborated for supporting this approach: an electronic card and a small robot production lines. These production lines combine cobots and human works for validating social and societal aspects. The platform is also composed of energy optimization system, introducing an environmental dimension in the company. A 3D printer area is used for elaborating parts of the robots. A packing machine is used for both products. Two stacker cranes (raw materials storage and component storage for manual tasks) and one small warehouse have been elaborated for treating procurement aspects. Both raw materials and final products are transported by using mobile robots. This industrial manufacturing is also composed of informational systems (MES, WMS and ERP) for facilitating the interaction between the manufacturing system and the production system management. The intelligent system being developed includes a human machine interface tool that has been described in [27] and serves as an interface with the software tools implemented in the company, new technologies and people.

4 Use Cases

The approach presented above has been tested on SMEs and the industry 4.0 demonstrator (manufacturing system) is being used for finding solutions to company use cases. The sustainable methodology for industry 4.0 Implementation in SMEs allows to find the company brakes and solve some of their use cases giving them the possibility to see the benefic impact of industry 4.0 on their company. Indeed, the focus has been made on sustainability and new technologies exploitations, but also organizational aspects have been implemented in the company studied. The following parts presents some of use cases that have been tested for companies by integrating social sustainability in the company digital transformation.

4.1 Open Source Software for Interoperable Tools and Ergonomic HMI

To ensure communication between the cobots and the production manufacturing software such as MES, Robot Operating System (ROS) has been used in combination to the intelligent system being developed. ROS contains a set of software libraries and open-source tools for robot applications. ROS uses different features as shown in the Fig. 3. Master (e.g. MES) is a node declaration and registration service that allows other nodes (e.g. robots, sensors) to recognize and exchange information between them. Nodes exchange data with a publish-subscribe model.

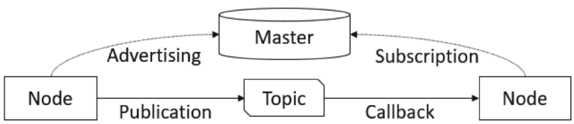

Fig. 3. Principle of communication with ROS

These principles contribute to the development for the company of a specific interface (with a decision-aided system) to manage the machines and tools to ensure collaboration with operators within the workshop [27]. The social sustainable criterion is used for this transformation. Indeed, the operator through the development of an HMI can manage all tasks associated to his post but also information related to cobots and new technologies but also information systems. With collaborative robots, the handling by the operator can be facilitate. Human adaptability is used to easily reconfigure trajectories for the cobot and an ergonomic HMI is designed to simplify the use of the arm for the operator according to the MES specifications. To be more flexible, AMRs can transport the cobot on different workstations with its tools. Artificial vision is used for calibrating the robot at the workstation and locate new work pieces to work accordingly. The HMI and the decisional system ensure interoperability between workstations and allows the operator to focus on value-added tasks.

4.2 Flexibilizing the 3D Printing Workstation with Mobile Robots

The second use case is about flexibilization. Turtlebots, small ROS-driven AMRs, have been used to bring components for the assembly of robots on a collaborative workstation. Multiple AMRs are required to have the maximum efficiency and work with multiple human operators. A robotic arm prepares batches of components from a central stacker crane to the table. The AMRs can distribute them to the operators. Developing an ergonomic interface that allows to manage all the AMRs on the table and being able to manage collisions, robot status, position, and transfer via a HMI, screen or augmented reality, defects and instructions related to the components. It also allows the implementation of fleet management software with components management in a MES and in the ERP. It helps robot design the robot. This use case (Fig. 4.) has been tested ad implementing in the company that proposes it. The solving of this use case involves the exploitation of social sustainability as criterion of transformation in addition to new technologies such as artificial intelligence and cobotics. Humans are mainly affected to added value tasks and cobots or robot can manage non-added value tasks, if they are not suppressed (lean manufacturing implementation through value stream mapping). Indeed, the development of a specific stacker cranes and the use of mobile robots allows to optimize the components transportation to a manual working post. Artificial intelligence and vision are used for managing the orders required by operators.

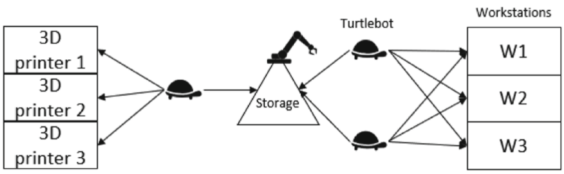

Fig. 4. Flexibility of workstations with ROS for assembly and 3D printing processes

5 Conclusion

This paper focuses on the exploitation of a sustainable framework for increasing SME performance through industry 4.0 concepts implementation. A manufacturing system for solving use cases for SMEs in order to encourage them in their digital transformation has been elaborated. A research-action approach has been developed for solving their use cases. The intelligent system supporting the sustainable methodology for industry 4.0 concepts implementation is being developed. The ergonomic HMI and decision-aided tool that communicates with the MES, robots and machines in the use cases has been presented. Further research should study acceptability of the tools in situations derived from the framework's criterion such as degree of modernization. The methodology for convincing operators, managers and directors of the SME will be developed from this research.

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