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Driving process innovation: a structured method for improving efficiency in SMEs

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Abstract

This paper proposes a method to drive process innovation toward the increase in efficiency of a production plant.
The work defines a structured method, supported by a classification tool, to correctly organize whole plant information with a mayor focus on energy consumptions. The method was tested in a medium enterprise with the target to increase the efficiency of the entire production plant. The method is the basis for a web application tool. A correct data management permits to plan the best practices to improve processes and systems involved in terms of environmental and economic impacts, meaning a process sustainable innovation.

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Keywords: process innovation; energy efficiency; data management; lean manufacturing; energy measurement.

1. Introduction

The efficiency in terms of costs and carbon dioxide emissions are the most important drivers of firms on 21th century. World regulations are tighter year by year and to remain on the market firms have to improve efficiency by newer working methods, processes and products. However, newer solutions are not enough to fit this challenge, there is the real need of innovation. As defined by Carlile [1], novelty pushes innovation but not all of novelties embed innovative values. In this paper, focusing on the production process, the key aspects for moving toward innovation are identified. Acquiring new powerful machinery, increasing speed of drills or reducing number of human controlled operations are only novelties that not automatically mean innovative solution; innovation has to be planned. It will be shown that innovation means firstly having a deep knowledge of the current state of processes in order to completely avoid mistakes in the future. The paper proposes a method to plan actions toward effective innovative solution on a production plant. Plant sustainability is the final goal that the method embeds; with this perspective, the idea of sustainable innovation will be introduced. After a clarification of the innovation meaning, main criticalities in the field of energy efficiency and process data acquisition will be identified. The paper shows a methodology for a detailed manufacturing data acquisition process. Data will be classified through a specific tool that encompass the whole knowledge about a firm production. The work proposes the philosophy and the interfaces used by the tool for data management. The presented tool permits to understand cost trends, classifying processes and machineries and putting in relation productivity with energy consumptions. Moreover, a report could be generated to understand the environmental impact of the production site related to the energy flows needed for the product development. The method proposed is firstly applied to an Italian SME in the sector of carbon fibre component production.

2. State of the art

2.1. Toward the sustainable innovation

A suggestive definition of innovation was given by Kao in 2007 [2]: he defines the idea of innovation as the ability of

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individuals, company or entire nations to continuously create their desired future. Therefore, a novelty become innovation if it affects positively the future generation. Different planes of innovation exist; in the present paper the focus is on the process one. Process innovation includes the implementation of significantly improved production or delivery method. Changes in processes mean also implementing new techniques, equipment or software [3]. The innovation on the mentioned plane can be mainly of two different kinds: incremental or radical [4]. Incremental process innovation consists in implementing continuous optimization to the production process remaining in the original level of production technology. Radical innovation occurs when a process is completely changed and there is the switch off of an old process, to implement a newer process that embeds new techniques for improved products. Yamamoto in 2013 [5] argued about the topic of Manufacturing process innovation (MPI). Such document defines four types of process innovation depending on the different levels of solutions introduced. On 2010 Polder et al. [6] proposed a model that put in relation product, process and organizational innovation. They asserted that positive effects of product and process innovation exist when combined with an organizational innovation. Actually, it exists a further direction that innovation can follow that permits to reach the sustainability: in such case, it is introduced the sustainable innovation. Sustainable innovation is a process where sustainability considerations (environmental, social, and financial) are integrated into company systems. It is applied to products, services and technologies, as well as new business and organisation models [7]. Brown in 2009 [8] defined the innovation as the propeller of manufacturing sustainability. The proposed method is thought with this last perspective and it tends to favour the process sustainability. The method moreover has the basis on a double rail, linking lean thinking with sustainability. Few works exist with such relationship and how lean thinking pushes manufacturing sustainability; these are collected within the work of Hartini and Ciptomulyono of 2015 [9]. Furthermore, interlinks and similarities between lean and "green" are pointed out by Kurdve et al. [10]. On the latter work, sustainability aspects are integrated into the company-specific production systems.

2.2. Lean Manufacturing

As mentioned, the method described in this paper refers to lean manufacturing. The work of Sahah and Ward of 2003 [11] clearly describes such topic, including a description of several tools related to lean manufacturing philosophy aiming at reducing manufacturing wastes. Lean manufacturing, in fact, focuses on avoiding seven cardinal wastes and on respecting customers, employees and suppliers [12]. The final goal of lean manufacturing is to be highly responsive to customer demand by reducing waste [13]. The seven wastes by lean manufacturing are argued firstly by Liker [14]. Wastes are meant as limits for a production system. One of the seven wastes is the inventory. Referring to Womack [15], it is important to optimize the inventory process in order to not occur in "infobesity", having more data than the ones really needed. The efficiency of the inventory phase moving toward production sustainable innovation is one of the main goal of the present work. Considering manufacturing system, a key driver for innovation would be the energy efficiency. Nowadays, such assertion gains value since the increasing of industrial consumptions highlighted into the document of the International Energy Agency [16]. Referring on 2013, the consumptions of industries were 2702 Mtoe, at a worldwide level.

2.3. Energy Efficiency

The increasing pressure as regards the availability of fossil fuels, energy prices and emerging environmental legislation are leading manufacturers to adopt solutions to reduce their energy consumption as well as their carbon footprint [17]. Energy efficiency has been the primary factor in driving down energy consumption in IEA countries over the last decade [18]. Patterson [19] defines the energy efficiency as the ratio of the useful output of a process to the energy input into a process. He defined several indicators to evaluate this performance, namely measures of energy efficiency performance (MEEPs). Introducing these measurements in a real industry context means dealing with energy management. An interesting energy management study pointing out criteria and MEEP to choice was proposed by Tanaka in 2008 [20]. The work by Thiede et al. [21] proposes a method to assess then optimize energy efficiency of a production system; the latter focuses on electric energy and a map of energy flows was carried out. A roadmap for improving energy efficiency was proposed by Ghadimi et al.[22]; materials and energy flows there were remarked as very important issue to fully understand. The method proposed by the present paper could boost the previous approaches, permitting moreover to have a simplified and structured data acquisition phase, favoring the repeatability, in future, of the innovation procedure. Main standard about energy management is the ISO 50001:2011 [23]; such document specifies requirements applicable to energy use and consumption, including measurement, documentation and reporting, design and procurement practices for equipment, systems, processes and personnel that contribute to energy performance. This paper considers the mentioned standard and develop a structured method to boost the execution of such guidelines. Finally, few case studies are already available in literature with the aim to manage energy in a manufacturing system (de Carvalho and de Oliveira Gomes[24], Xie et al. [25], Haragovics and Mizsey [26], Jovanovic et al. [27]). Such studies are focused on specific systems. This paper wants to propose a method that will be effective not only on a singular case study, but replicable on different manufacturing systems.

3. Method for improving process efficiency

In order to make the manufacturing process innovation able to achieve tangible benefits from an environmental and economic point of view, the full knowledge of business flows and current inefficiencies is necessary. For this aim, a structured approach that favors the process innovation starting from the mapping and classification of all processes and machineries of a production system has been developed. This method permits to analyse the energy consumptions, identifying the major causes of waste and proposing new sustainable solutions. It consists of six steps and follows a top-down approach (i.e., from the company as a whole to the specific machine), as shown in

. Step by step the detail of information increase, but a higher level of accuracy can be reached. This explains the inverted pyramidal structure: the more the tip is near, the more the knowledge of the process is deep. The method has to be applied on a company production plant and starts once the boundaries of the study are defined.

The first step is the creation of the visual model of the production flows. It is necessary to clearly define the actual state of the system, contextualizing the company in terms of products, processes, and resources. Step 1 allows understanding what the company produces and how. For this aim, the ICAM DEFinition Methodology (IDEF0) could be exploited. It is an intuitive approach to represent the production plant with a set of diagrams (i.e., functions), arrows (i.e., input, output, control, and mechanism) and glossary, which are correlated to each other. In addition, each function can be detailed according to the analysis goals and boundaries. It is worth to specify that the creation of a valid model is strictly related to the reliability of the information sources. For this reason, the company layout, the production manager feedback and the operators experience should be exploited as well as the direct observation of the production process. The "go and see" (Genchi Gembutsu) approach by the lean philosophy favours the completion of this step [14].

Step 2 consists in the monitoring of energy consumptions by identifying the means able to provide these data (e.g., bill, meters, energy manger, etc.). It allows having an overall vision about the total consumptions. Furthermore, it could be useful to classify the latter by time slot, use purpose and energy typology (i.e., active and reactive) in order to easily identified possible anomalies.

However, a correct allocation of the consumption embeds the knowledge of all the machineries present in the production plant and the relative characteristics. For this reason, Step 3 aims to collect all the machines specifications such as name, power, operating time, etc. by means of the consultation of machine plates and manuals, plant design documents, etc. Also the plant manager should be involved in this task. A classification of the machineries by process could be carried out in order to simplify the hot spots identification.

In the same way, the products characteristics are relevant in the consumptions allocation process. For this aim, it could be useful to define several product families, which are groups of goods that undergo similar production processes, have similar physical characteristics or share marketing strategies (Step 4). In this case, the classification criterion should be the one that more influences the consumptions variability (e.g., weight, volume, complexity, etc.).

The results of the last two steps allow estimating the energy consumption by company department and process and, consequently, tune results of the previous analysis (Step 5). However, the resulting esteems could significantly differ from the amount of the invoices because of the consideration of nominal data. For this reason, the plant and maintenance mangers as well as the operators should be involved in order to do accurate assumptions. On the other hand, the planning and execution of a campaign measurement could increase the goodness of the results. Scouting the measurement instruments and identifying the impacts of such campaign it is very important to establish the benefit-cost ratio and verifying its technical and economic feasibility. Moreover, the ISO 14955:2014 [28] has to be taken into account for a proper measurement phase.

The last step of the method consists in the evaluation of the analysis of the results in order to understand what really needs innovation, identify which processes/machineries embed critical situations and define possible corrective strategies. For this aim, the TRIZ tools could be adopted and several analyses carried out such as the LCA, the root cause analysis, etc. Implementing such tools in this step could open to new sustainable and innovative solutions. At this point, the plant manager and the general manger should be involved.

It is worth to highlight that the proposed method is flexible and customizable according to the company needs, reality and expectations. Indeed, it tends to be valid for every kind of manufacturing processes and not depend of the company dimension. Each company can choose the level of detail that wants to achieve and will decide the starting point according to the results already obtained.

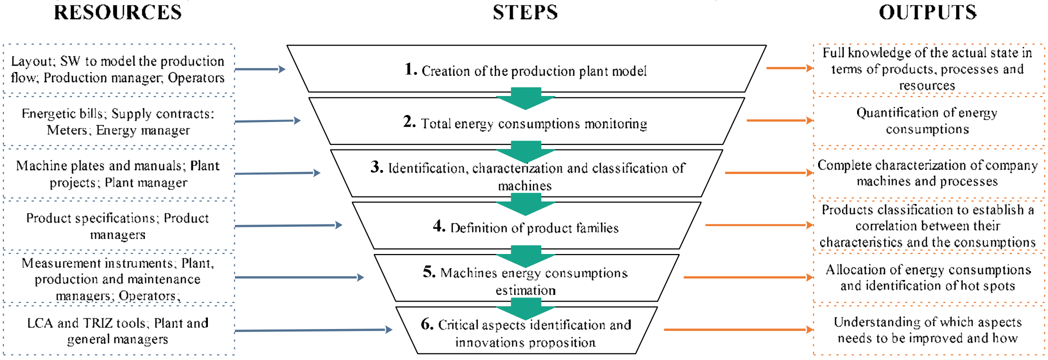

Fig. 1 – Method to increase the process efficiency

4. Data acquisition tool

Ensuring a proper information flow is an essential prerequisite to make the proposed method valid and efficient. For this aim, a dedicated tool able to support the acquisition and elaboration of data phases has been developed. It allows both collecting data by the most common software used by companies (e.g., ERP, MRP, Resources planning SW, etc.) and guiding the operators in the acquisition of new ones.

The first ones can be retrieved by the company database and mainly refer to operations (e.g., name, process phase, installed power, etc.) and products (e.g., P/N, materials, treatments, etc.). If not already available, they have to be collected and organized into specific sheets (machine sheet and product sheet), as suggested in Fig. 2. Such sheets have been structured in order to easily give access to the essential information and avoid the information overload. The manually inserted data will be stored in a repository facilitating every future assessment. It is the picture of the firm. The second ones mainly concern the real energy consumptions and have to be collected by the operator in charge of the measurement campaign. The tool supports him in this task guiding through the compilation of the proposed data acquisition sheet. The latter contains data related to the context (i.e., date, shift work, operator), the product (i.e., P/N, serial number) and the ongoing process, which could be a specific treatment or a planned/unplanned maintenance work. In addition, for the process, the start/end and energy consumption (active and reactive) are defined. Once filled the datasheets of all machines, the process performances can be easily evaluated and the relative criticalities identified. Such sheets allow also correlating the production flow with the energy consumptions in order to suggest a better resources scheduling.

Moreover, data gathered with the measurement campaign allow updating the machine sheet with the last consumption values, establishing a "bidirectional communication" with the database. Such structure, allow linking different information in order to proper allocate consumptions and, consequently, identifying the causes of a specific consumption trend (e.g., under/over production, machine/process inefficiencies, wrong resources scheduling, etc.).

It is worth to specify that the real benefits of the proposed tool can be appreciated by automating the information flow and the compilation of the data acquisition sheets in order to favour high-level analysis. Moreover, the installation of dedicated sensors could enrich the potentialities of the tool.

Fig. 2 – Data acquisition sheet

5. Case study

The case study proposed in this paper involves an Italian manufacturing company that works in the field of composite materials. Such sector is highly energy consuming, due to the usage of several resources during the production process and the exploitation of industrial ovens and autoclaves, which work full-time all days. Moreover, the composite materials market share in general is increasing, above all the application of carbon fiber, thanks to typical high performances of this material in terms of lightness and mechanical strength. According to this trend, the manufacturing company involved in such case study had the aim to investigate the main resources flows in its plant in order to operate several actions to optimise them toward the entire plant efficiency from an energetic point of view. Moreover, the result of this study and investigation should lay the groundwork to build one or more plants, according to energy efficiency principles. According to both approaches previously described and the company needs, the method was applied in all its steps, from the process modelling to the identification of the main criticalities.

Step 1. The production manager modeled the entire production plant, identifying the main functional areas involved: Inspection & Storage, Cutting, Rolling & Baking, Extraction, Mechanical manufacturing, Bonding, Finishing & Approves. Thanks to the IDEF0 model of the plant, the general flow from raw materials to the final product was carried out (Fig. 3), defining which are the main production constraints and the required resources. In this way, for each functional area involved in such workflow model detailed information were gained.

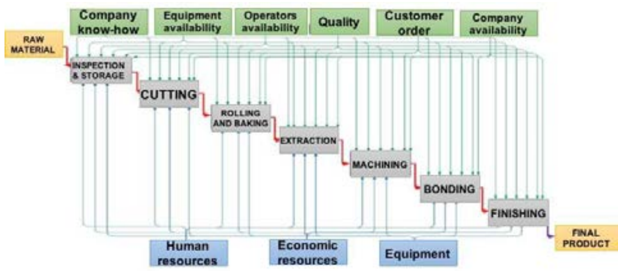

Fig. 3 – IDEF0 model of the company production plant

Step 2. This second phase expected to collect all the general information about energy consumption within the plant. The latter has only one source of energy that is the Italian electric energy grid, indeed, no plant for the energy self-production is provided. The energy bills along at least one year have been analyzed. It allowed understanding the trend of energy consumption during the time-period considered and where the consumptions are mainly clustered.

The energy bills analysis pointed out the more critical areas of the plant as shown by Fig. 4.

This analysis allows understanding the most impacting area within the company and helps the production manager to reach faster energy efficiency and the related cost saving. In that case, *baking* impacts for a 55% on the whole production and *rolling* is the second one with a 18% of impact.

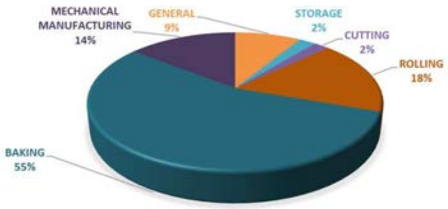

Fig. 4 – Energy consumption for each functional area

Step 3. In this phase, according to the results of the previous step, the production manager has investigated the Baking area. This has meant analysing each machinery that concerns such area, collecting all the data required to identify the energy profile for that specific machinery. This task was possible filling a tailored "Machine sheet". For this specific tool the data required were:

- Machinery general information as name, brand and code;
- Machinery specific information as capacity, test pressure, maximum operating pressure, operating temperature;
- Production process phase in which the machinery is implemented;
- Power [Watt];
- Operating time (i.e., 8h, 16h, 24h);
- Resources exploited (i.e., energy, gas, water, compressed air);
- Actions like updated and/or improvements;
- Maintenance actions;
- Revision date.

Other data as "Average consumption", "Start-up power consumption" and "Stand-by consumption" should be measured in step 5, after conducting the specific measure campaign, which allows identifying the machineries energy consuming. An example of the "Machine sheet" described is proposed in Fig. 5, where the data of an autoclave belonging to the Baking area are classified. Within the sheet are identified: which resources needs the autoclave, autoclave maintenance operations, and the machine location within the production plant is specified. The latter information are fundamental and will be used in future assessments. In fact, it is important to store sheets for future analysis. Effort made in this first assessment are added value for the future ones.

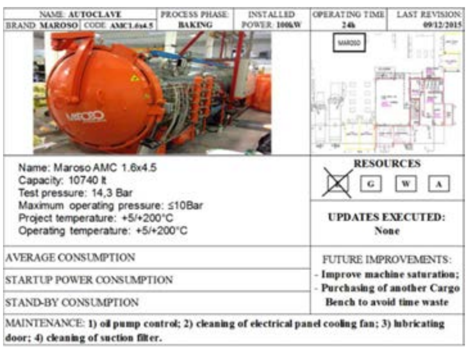

Fig. 5 – Machine sheet to collect all the related specifications

Listing all the machineries sheets allows plant manager to collect information of the entire industrial process.

Step 4. The aim of this step is to investigate how the products production and costs are affected by the energy consumption investigated. Due to the typology of the involved company, which produces a wide amount of products per year, the products have been grouped in different families. In this way, it is simpler to match an energy consumption to a specific product family. Several criteria to identify the product families could be used so the choice was driven by the aim of the current analysis and several trials are explored before to find the best one. For example, the weight and the volume were firstly investigated, but both were not usable because currently the company does not have the link between the product and the relative weight or volume in a digital format. Finally, after other trails, the products have been clustered according to their production phases. According to this criterion the main product families identified are four and they are described below:

- Family 1 (*Rolling*, *Baking*, *Sliming*, *Finishing*), which involves the 65% of products;
- Family 2 (*Rolling*, *Baking*, *Sliming*, *Finishing*, *Bonding*, *Baking*), which involves the 25% of products;
- Family 3 (*Rolling*, *Baking*, *Sliming*, *Finishing*, *Mechanical manufacturing*), which involves the 5% of products;
- Family 4 (*Rolling*, *Baking*, *Sliming*, *Finishing*, *Bonding*, *Baking*, *Mechanical manufacturing*), which involves the 5% of products.

Step 5. In this phase, the real machineries consumptions are measured. The measuring campaign was conducted on all the machineries belonging to the Baking area. To reach this aim, the specific measurement tools were firstly analyzed, and then selected. The results of such measured campaign are shown in Fig. 6. The graph gives the right view about how much the main Baking's machineries exploit electric energy. Among them, the Autoclave MAROSO is the most impactful machinery.

In order to understand how the measured campaign was conducted on the Baking area, the Table 1 is presented below. It represents the "Data acquisition sheet", another tool arranged by the authors.

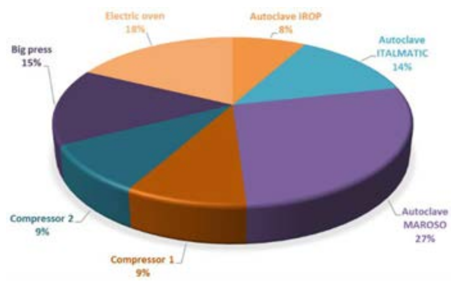

Fig. 6 – Energy consumption [kWh] per each machinery in Baking area

Here, all the data about the measurement conducted on the Autoclave MAROSO are collected: namely date, shift work, start and finish of the process, its duration and the related energy consumption measured onsite.

Table 1. Data acquisition sheet

DATE	SHIFT WORK	OPERATOR	ON GOING PROCESS	START TREATMENT	END TREATMENT	DURATION	ENERGY CONSUMPTION [kWh]
01/09/2015	2676	00001	BAKING	05.34.00	07.58.00	02.24.00	90,45
01/09/2015	2677	00002	BAKING	10.44.00	13.03.00	02.19.00	91,28
01/09/2015	2678	00002	BAKING	15.07.00	17.29.00	02.22.00	92,54

Step 6. In this step, the data collected were analyzed in deep to identify the main criticalities of the plant and define the improvement actions. According to the data collected on the Baking area, the main criticalities recognized are two:

- The autoclaves compressors are used also for small topping up of compressed air, therefore, there are several daily switch on with related power peaks that generate an avoidable energy consumption;
- All the autoclaves in the Baking area have a low saturation, indeed, they are exploited for about 60-70% of installed power.

5.1. Results

Data collected about energy consumption and the related analyses conducted by plant manager were very useful to identify what are the main criticalities in the plant and how to improve or avoid them. Indeed, the results of this method application prove that the process innovations to improve energy efficiency and, thus, the economic impacts were not replacing the current machineries technology, but optimize the existing ones. This entails that without any investments, a significant improvement in resources exploitation and costs saving is possible.

6. Conclusions and future work

This paper presented a method to move industries toward sustainable innovation. The method has its basis on a triple bottom line: sustainability, lean and innovation. A step by step procedure was shown and applied on a real use case to test its efficiency. The method leads to innovation passing thorough a complete knowledge of the actual state of the system. Without an effective knowledge of the as-is scenario related to product and processes of a firm, no innovation is possible. The proposed assessment method requires so much manpower and time only for the first as-is analysis: the acquisition tool stores all the data for faster future improvements. Nevertheless, initial efforts are largely payed back by future costs reduction. The focus with the case of study was on the electric energy efficiency, but it is only one of the few aspects to improve in order to achieve a whole system sustainability. A future work will be the implementation of the mentioned tools on a software platform. The automation of the procedure permits to store data on a dedicated database and increase the speed toward reliable actions for a more sustainable future. It is crucial to speed up energy efficiency of industries to lower the huge amount of resources are actually needed to produce goods. It is in everyone's interest guaranteeing a sustainable future for a proper growth of the planet.

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