



Toolkit for simultaneously improving production and environmental efficiencies

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Abstract

Environmental efficiency should not be treated independently of production efficiency. Several studies have demonstrated that lean management can be a major part of the answer to improving the environmental performance of companies. In this context, this work integrates existing methodologies and approaches from lean thinking, Industry 4.0 and mathematical optimization and then presents a toolkit for integrating, measuring, controlling and improving production and environmental performance in companies. The proposed approach is the result of previous investigations and is being validated in companies in the agri-food sector.

Keywords Lean · Green · Optimization · Industry 4.0 · Training · Efficiency

1 Introduction

It is crucial for manufacturers to prevent the overuse of resources. In the absence of positive environmental initiatives, manufacturing activities will lead to the creation of enormous amounts of waste, the exploitation of natural resources and the over-consumption of energy (Abdul-Rashid et al. 2017). According to the International

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Energy Agency (IEA 2015), the manufacturing industry contributes 36% of CO₂ emissions worldwide.

Manufacturing managers have adopted various strategies for limiting the impact of their operations and products on the natural environment (Vachon and Klassen 2008). However, a company's environmental efficiency cannot be measured independently of production efficiency or in isolation from the company's context (Muñoz-Villamizar et al. 2018a). The literature indicates that the implementation of green and lean practices helps organizations enhance their business performance while creating environmental, social and economic benefits (Cherrafi et al. 2017; Muñoz-Villamizar et al. 2019). In addition, it is expected that the Industry 4.0 paradigm will foster a higher degree of environmental measurement in the factories of the future through the implementation of technological solutions (Lasi et al. 2014). For this reason, any company's proposal for implementing monitoring, measurement and analysis in the factory should consider this paradigm. Finally, the development and utilization of optimization approaches have been implemented as an important aid in decision-making (Zhang and Reimann 2013) in order to evaluate tradeoffs between economic cost and environmental impact (Fahimnia et al. 2015; Trdin and Bohanec 2018).

In this context, this paper presents an innovative toolkit which adapts traditional lean tools to technological devices, training strategies and optimization approaches, with the aim of enhancing and speeding up environmental and production improvement in a green and lean context. The paper is organized as follows. Section 2 briefly presents the current development status of green and lean approaches in companies. The general green and lean framework is presented and compared with the traditional lean framework in Sect. 3. The toolkit is briefly explained in Sect. 4, and the main conclusions and future work are presented in Sect. 5.

2 Lean and green: their current status in companies

Previous studies have indicated that recycling, remanufacturing, waste reduction, environmental design, and market surveillance for environmental issues are the environmental practices that most strongly affect company performance (Montabon et al. 2007).

Consequently, green management has emerged as a management approach to reducing the negative ecological impact of an organization's products and services as well as improving the environmental efficiency of their operations, while still achieving their financial objectives (Garza-Reyes et al. 2016). At the same time, Hajmohammad et al. (2013) concluded that using lean manufacturing practices to establish an appropriate operating context is a suitable path for facilitating the implementation, adoption and measurement of environmental practices and improving a plant's environmental performance. Thus, it seems reasonable to assume that combining lean and green techniques will enhance environmental and production efficiency.

Unfortunately, we find that this assumption is not as widespread in manufacturing companies as expected. However, we recently conducted a 3-year (2015–2017)

study in which we analyzed the implementation of green and lean practices in the Basque Country (Muñoz-Villamizar et al. 2018a). Through the data we collected from semi-structured interviews with 58 companies, we concluded that even companies with advanced manufacturing practices do not take a proactive approach to environmental development.

3 Proposed model for lean-green improvement

Figure 1 compares the classical lean manufacturing model and our proposed extended model for lean and green improvement. According to Dennis (2016), the objectives of this classic lean system (the roof) are to deliver the highest quality to the customer, at the lowest cost and in the shortest lead time. The foundation is stability and standardization, which involves engaged and motivated team members; the walls are the just-in-time delivery of product parts (i.e., to implement a production system that uses the required material, produces at the customer’s rhythm and delivers just when it is required) and Jidoka (i.e., automation of the production process with human intelligence) (Dennis 2016).

Turning to the components of our proposed lean-green model, in terms of objectives, we have added a fourth objective—environmental sustainability—to the three from the lean model. Hence, the four objectives in the lean-green approach are quality, cost, delivery times and environmental sustainability. In terms of the foundation, the lean-green model maintains the lean model’s commitment from all members of the company, from senior management down to the shop floor, while also incorporating lean and green commitment through the use of innovative learning strategies, such as serious games, which combine production and environmental training programs.

The biggest differences between the models are seen in the walls or supporting tools (i.e., our toolkit, explained in detail below). In the left wall, Overall Equipment

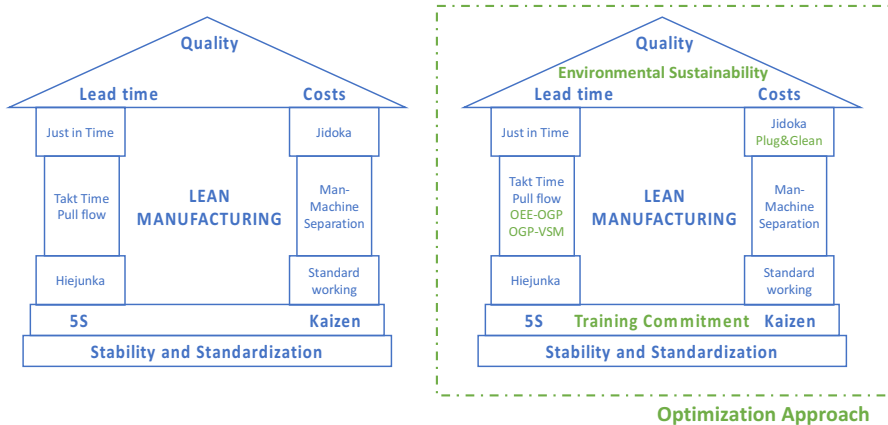


Fig. 1 Classic lean (Dennis 2016) versus our proposed extended lean-green model

Effectiveness (OEE) and Overall Green Performance (OGP) are used to measure the production and environmental efficiencies of the system, respectively. In addition, an environmental value stream mapping (or e-VSM) is applied to these areas to determine the takt time and waste reduction. Finally, on the right wall of our proposal, we have developed a wireless system called Plug&Glean (P&GL, described below), which supports the improvement team's ability to identify environmental wastes and production wastes at the same time.

Our lean-green model has been validated using a multi-objective optimization approach in order to identify and evaluate various alternative high-quality approximations to optimal solutions (Pareto optimal or efficient frontier) in order to support the final decision (Mejia-Argueta et al. 2018). That is, the goal is to define the best lean and/or green alternatives to be implemented after evaluating the tradeoffs between economic cost and environmental impact.

4 Toolkit description

4.1 Training and commitment

The success of lean and green practices critically depends on employee participation, proper training and the commitment of top management. Jabbour (2015) claims that managers must invest in environmental training if they want to improve their company's environmental management.

Serious environmental management games have been found to improve the understanding of practical environmental sustainability challenges by offering opportunities to obtain first-hand experiences that may otherwise be too costly, difficult or dangerous to reproduce in reality (Madani et al. 2017).

Pizz@green is a serious game jointly developed by the University of Navarra and Iksasplay (Fig. 2), a company dedicated to the development of educational games (Santos et al. 2018).

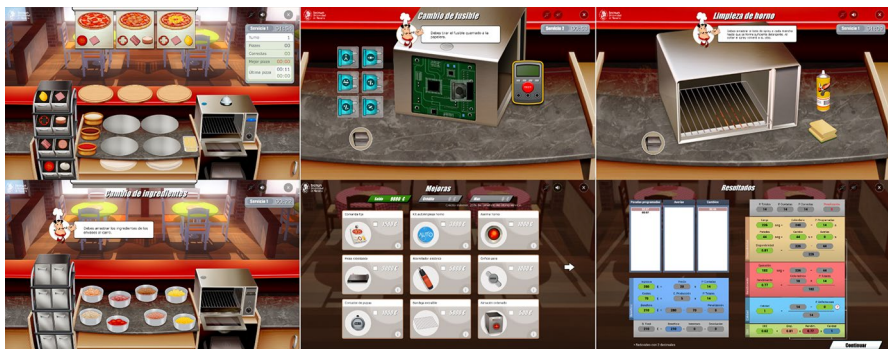


Fig. 2 Pizz@green screenshots

The game attempts to evaluate the effects that the actions carried out in a common production process, such as preparing pizzas, have on production and the environment. The game simultaneously measures productivity and environmental efficiency, based on improvements made to the pizza production process. These improvements are chosen by the players as the game progresses. The first trials carried out in companies demonstrate that workers start including environmental aspects in the production system if the impact of those improvements positively affects productivity.

Pizz@green is a single-player game, where the player must prepare pizzas according to a list of three different orders over the course of three rounds, each lasting 10 min. The order list is updated every time a correct pizza is made. The player has sixteen different ingredients (e.g., ham, bacon, beef, chicken, pepperoni, cheese, pineapple, mushroom, tomato, red pepper, green pepper, etc.), eight of which are available in each round; there are also two types of dough (i.e., thin and thick) and three types of sauces (i.e., tomato, BBQ and creamy garlic). Random combination of all these components generate the list of three different orders.

The user's performance data is stored as a dashboard of the pizza shop. The user sees this report at the end of the game (see Fig. 3). This allows users to understand that continuously monitoring equipment facilitates decision-making processes. Besides, this also evaluates the consequences, in general performance, of the decisions they have made by analyzing the evolution of all results.



Fig. 3 Pizz@green reports

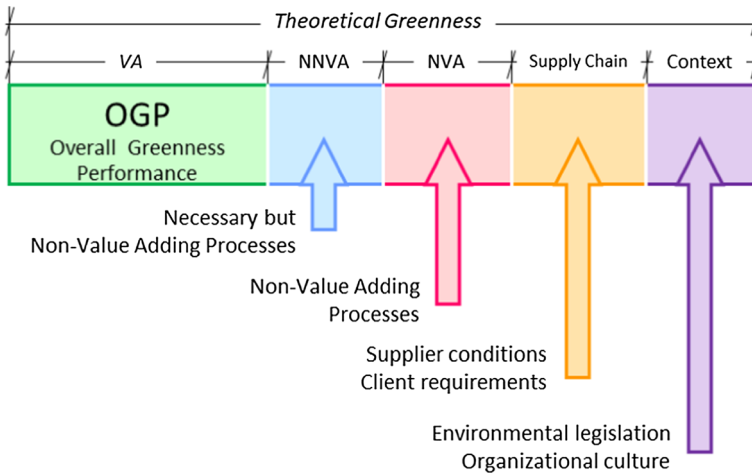


Fig. 4 OGP timeline. *Source:* Adapted from Muñoz-Villamizar et al. (2018b)

Table 1 Definition of the OGP categories. *Source:* Adapted from Muñoz-Villamizar et al. (2018b)

Category	Definition
VA	Consumption/emission of the value adding processes
NNVA	Consumption/emission of the necessary but non-value adding processes
NVA	Consumption/emission of the non-value adding processes
Supply chain	Requirements or conditions in the supply chain
Company context	Computes consumption/emission related to culture of working people and due to regulations constraints

4.2 OEE and OGP (overall greenness performance)

Environmental efficiency should not be treated independently from production efficiency. The consumption of resources like energy and water should be monitored simultaneously with production. In this context, our toolkit combines the traditional OEE rate, which improves equipment effectiveness (Nakajima 1988), with OGP (Overall Greenness Performance), an OEE-based metric proposed in Muñoz-Villamizar et al. (2018b). Although OEE is traditionally used by practitioners as an operational measure for monitoring production performance, it can also be used as a metric for process improvement activities in other contexts (Muñoz-Villamizar et al. 2018c).

Using the concept of value adding, OGP classifies the consumption and waste of a company's processes according to the categories presented in Fig. 4 and Table 1. This classification allows companies to better identify and focus on improvement activities. OGP can measure the consumption of resources (e.g., energy or water). However, a company's decision-makers should define beforehand which measures will be used.

4.3 e-VSM

Value stream mapping (VSM) is a tool used to map a production process or an entire supply chain network. It maps not only material flows but also the information flows that signal and control production (Braglia et al. 2006). VSM seems to successfully and effectively integrate lean and green (environmental) management (Ng et al. 2015). The environmental benefits of VSM are a reduction in waste through fewer defects, less scrap, low energy usage, etc. (Vinodh et al. 2011).

Our environmental VSM (e-VSM) tool is presented in Fig. 5. The idea of this tool is to integrate the OGP metric (green analysis) in order to measure, control and evaluate production and environmental performances according to a company's context. If the results of the green analysis show that an environmental waste is not eliminated but instead increases, it will be necessary to create a new future map where the applied alternatives seek a balance between improving productivity and improving environmental performance. We call this map the Lean-Green State Map. As lean-green states become reality, a new FSM should be drawn, thereby leading to the continuous improvement of both production and environmental efficiencies. In summary, the approach we propose creates a suitable base for moving towards functioning environmental sustainability in manufacturers.

4.4 Plug&Glean

A key challenge in measuring production and environmental efficiency is selecting meaningful and effective tools (Montabon et al. 2007). Industry 4.0 allows manufacturing systems to make smart decisions through real-time communication and cooperation with humans, machines and sensors (Zhong et al. 2017). In this context, our toolkit uses the Plug&Glean (plug and green-lean) device (see Fig. 6) presented in Santos et al. (2019). This device provides an easy and flexible way to collect data from equipment (plug) in order to measure productivity (i.e., production cycles, stoppage events, quantity of pieces produced) and also environmental aspects (i.e., energy and water consumption or water quality) in order to direct alternative improvement activities (lean methodology).

In Fig. 7, the classic idle time analysis in a worker-machine diagram is combined with the energy consumption of a press machine, based on a real case analyzed with the Plug&Glean device. The long column (red) shows the real cycle, the short

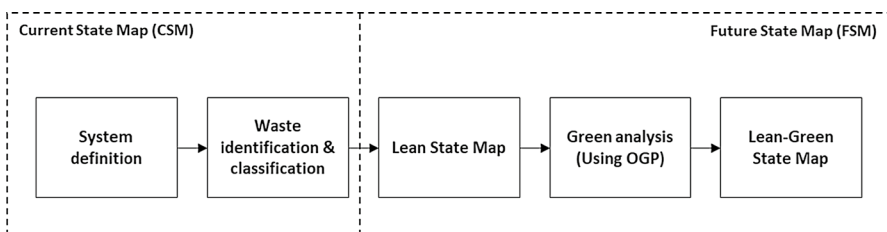


Fig. 5 e-VSM generic approach



Fig. 6 Plug&Glean device developed in the LIFE MCUBO project

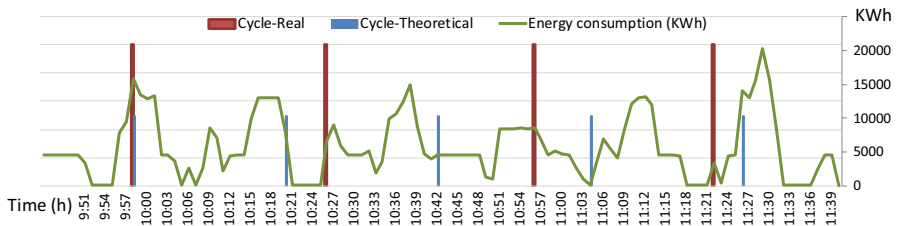


Fig. 7 Example of the simultaneous analysis of productivity and energy consumption (color figure online)

column (blue) the theoretical cycle, and the line (green) energy consumption. It was expected that the consumption cycle would coincide/align with the real cycle. However, in the process illustrated in the graph, the machine increases energy consumption if the waiting time is too long due to maintaining the temperature of the press. A strategy based only on productivity would reduce the number of workers while increasing the waiting time. As a result, the overall lean and green improvement strategy may recommend assigning a worker to the machine if the overall impact is better.

4.5 Lean-green optimization

Finally, a methodological approach for the strategic evaluation of the lean-green improvement alternatives that is similar to Bohanec et al. (2016) is presented in Fig. 8. The approach is based on mixed-integer linear programming (MILP) and consists of three stages. Stage 1 defines the characteristics of each lean and/or green alternative. Stage 2 determines which alternatives to implement by using the proposed MILP model. Finally, Stage 3 evaluates the relationship between the economic cost and the

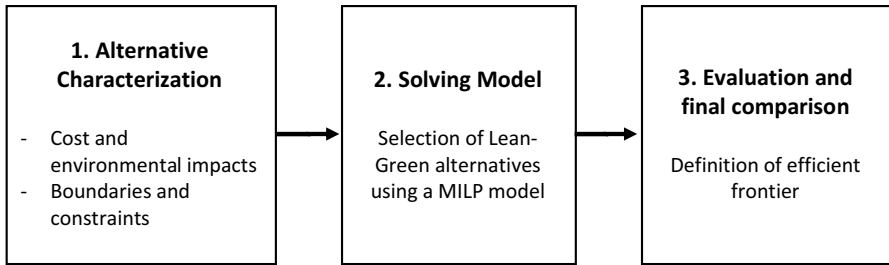


Fig. 8 Flowchart of MILP model application

environmental impact through an efficient frontier (i.e., Pareto frontier). The details of each stage are described in the following paragraphs.

In the Stage 1, we identify the key elements of the case under study. That is, the cost and environmental impact of each alternative and the restrictions or constraints (e.g., budget, environmental regulation, etc.) of the company being evaluated. In Stage 2, parameters and decision variables used in the base MILP model are defined as follows:

Set:

- i* Set of Lean/Green alternatives $\{1, 2, \dots, n\}$
- k* Set of constrains $\{0, \dots, m\}$

Parameters:

- c_i Economic cost of alternative *i*
- e_i Environmental impact of alternative *i*
- p_{ik} Participation of alternative *i* in constraint *k*
- min_k Minimum value of restriction *k*
- max_k Maximum value of restriction *k*

Binary variables:

$$Y_i = \left\{ \begin{array}{l} 1, \text{ if alternative } i \text{ is selected} \\ 0, \text{ otherwise} \end{array} \right\}$$

Decision variables:

- f_1 Economic cost
- f_2 Environmental impact

The mathematical model of the problem can be formulated as follows:

$$f_1 = \sum_i Y_i * c_i \tag{1}$$

$$f_2 = \sum_i Y_i * e_i \quad (2)$$

$$\sum_i Y_i * p_{ik} \geq \min_k; \quad \forall k \quad (3)$$

$$\sum_i Y_i * p_{ik} \leq \max_k; \quad \forall k \quad (4)$$

$$Y_i \in \{0, 1\}; \quad \forall i \quad (5)$$

Constraints (1) and (2) compute the economic cost and the environmental impact of the selected alternatives. Constraints (3) and (4) ensure that minimum and maximum constraints are achieved, respectively. Finally, Constraint (5) ensures that variables only take binary values.

Finally, in Stage 3, we build an approximation to a Pareto frontier in order to support the final decision. In this step, the weighted-sum method is applied to solve the proposed multicriteria model. This method builds an approximate efficient frontier using weighted linear convex combinations of the proposed criteria by formulating $\min Z = \alpha f_1 + (1 - \alpha)f_2$, where α is the weight for cost and $1 - \alpha$ is the weight for environmental impact. Cost and environmental impact values (i.e., f_1 and f_2 , respectively) are normalized by dividing them by their individual optimum, and the weights (i.e., α and $1 - \alpha$) are variated to obtain the efficient frontier (Mejia-Argueta et al. 2018). Considering this Pareto frontier, the best solution will be the one that best suits the needs of decision-makers.

5 Conclusions and future work

The toolkit presented in this paper will help companies add environmental language to traditional improvement systems, and as a consequence companies will be able to simultaneously improve their production and environmental efficiencies. The toolkit is based on well-known tools (serious games, VSM, OEE, multi-objective optimization) and an innovative monitoring system. This is an example of how the Industry 4.0 revolution can be combined with lean thinking. The entire framework is being validated in four different companies in the agri-food sector and it will be fully implemented in the next 2 years.

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