Muñoz-Villamizar, A.; Santos, J.; García Sabater, JJ.; Lleo, A.; Grau, P. (2019). Green value stream mapping approach to improving productivity and environmental performance. International Journal of Productivity and Performance Management. 68(3):608-625. https://doi.org/10.1108/IJPPM-06-2018-0216

Green value stream mapping approach to improving productivity and environmental performance

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Abstract

Purpose – The purpose of this paper is to introduce a new methodology called overall greenness performance for value stream mapping (OGP-VSM). Using value-added concepts, this approach has the potential to integrate, measure, control and improve productive and environmental performance in accordance with a company's context.
Design/methodology/approach – The OGP-VSM approach was developed by reviewing and integrating the environmental aspects of existing lean thinking tools and approaches.
Findings – This research revealed the lack of practical integration between productive and environmental performance. Using OGP-VSM, managers can see that environmental practices have a direct impact on productivity. OGP-VSM allows a balance to be found between lean and green practices in order to achieve the simultaneous improvement of productivity and environmental performance.
Practical implications – The proposed approach is applied to a case study in an automotive company in Spain and lays the groundwork for moving toward functional environmental sustainability in manufacturers.
Originality/value – Companies are increasingly implementing environmentally focused practices. Pursuing environmentally friendly (green) performance poses several challenges, but it also affords opportunities to create new methodologies for generating a competitive advantage for manufacturing companies. There are a limited number of approaches to drawing together the elements and attributes that are essential for a holistic, practical and long-lasting improvement of environmental performance in the manufacturing sector.

Keywords Production, Environmental sustainability, Lean management, Environmental performance, Value stream map

Paper type Research paper

1. Introduction

Academic and corporate awareness of environmental issues has increased significantly in recent years (Pipatprapa *et al.*, 2017). Furthermore, large corporations and small businesses alike are under increasing pressure to improve their resource consumption and reduce their

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The work presented in this paper was carried out within the framework of the LIFE MCUBO research project funded by the European Union (LIFE15 ENV/ES/000379), through the LIFE programme. In addition, the authors would like to acknowledge the support received from AdP, the Special Patrimonial Fund at Universidad de La Sabana and the doctoral grant from TECNUN Escuela de Ingenieros, Universidad de Navarra.

environmental footprint (Handfield *et al.*, 1997). In the current global market, thanks to regulations, NGOs and consumer requirements, there is much concern about the impact of production processes on the environment. Thus, environmental awareness has emerged as a new competitive criterion and the improvement of the environmental performance of companies is a business imperative (Cherrafi *et al.*, 2016; Garza-Reyes, 2015). However, the issue of how to carry out practices (i.e. planning and implementing) that improve environmental performance may be a costly endeavor if certain economic factors (e.g. ratio between the full revenue and the full costs) are not taken into consideration (Simpson and Power, 2005).

In this context, several studies have demonstrated that lean management can be a major part of the answer to improving environmental performance (Cherrafi *et al.*, 2017). In fact, lean and environmental practices share striking parallels due to the similar approach that both lean and green take toward reducing waste. Lean management focuses on waste as it applies to the inefficiency of processes, whereas environmental management focuses more on pollution in the form of air emissions and solid and hazardous waste (Molina-Azorín, Tarí, Claver-Cortés and López-Gamero, 2009). Moreover, there are several cases where companies have widely used, and very often in combination, lean and environmental practices (Verrier *et al.*, 2014).

Although a number of companies have integrated these types of practices, managers still require indicators that can provide data and inform their decision-making (Domingo and Aguado, 2015). Consequently, their companies remain reluctant to incorporate environmental improvements or do not exploit the potential of environmental management. Moreover, several companies are satisfied with simply having an environmental management system through a certification such as ISO 14001, and many others do not even have such a system (Ormazabal *et al.*, 2018). Muñoz-Villamizar, Santos, Viles and Ormazábal (2018) argue for the necessity of integrating a measure of environmental efficiency with productivity. However, to do that, companies first need appropriate approaches for integrating productivity and environmental performance.

Pursuing environmentally friendly performance means that companies must meet several challenges, but it also affords them opportunities to create market differentiation thanks to improved brand image and to increased credibility in business relationships (Lintukangas *et al.*, 2015; Claver *et al.*, 2007). However, the determinants and impacts of environmental efficiency are not yet fully understood (Jiang *et al.*, 2016). Given the increasing environmental pressures, companies cannot respond with classical economic or narrowly focused strategies; instead they need to use new and innovative techniques (Skellern *et al.*, 2017).

In this context, this paper proposes a new, innovative approach called overall greenness performance for value stream mapping (OGP-VSM), which shows companies how they can integrate environmental efficiency with productivity. This paper is organized as follows. Section 2 provides a review of some of the major issues that are pertinent to the concepts of environmental performance and lean management, as well as the basic tools that make up the approach. The approach itself is presented in Section 3 and applied to a case study in Section 4. Finally, the main conclusions of this study and the opportunities for further research are presented in Section 5.

2. Background

2.1 Environmental performance and lean management

There is a growing need to integrate environmental alternatives into research and practice in almost every area of knowledge. According to Carvalho *et al.* (2017), companies that are interested in improving their environmental performance will reap several advantages, including the ability to obtain a higher price for their environmentally sensitive products, an improvement in their corporate image, the development of new markets and a competitive edge. Consequently, environmental management has emerged as a philosophy and management approach for reducing the negative ecological impact of an organization's products and services and improving the environmental efficiency of their operations, while still achieving their financial objectives (Duarte and Cruz-Machado, 2017). However, companies often limit environmental management to addressing aspects such as resource use, energy practice, and product and waste management (Alayón *et al.*, 2017). Furthermore, most managers still see environmental waste minimization as a "necessary evil" that they must practice simply to avoid legal sanctions (Tilina *et al.*, 2014), rather than viewing it as an opportunity to be more competitive. Because managers are not aware of the evidence that shows that benefits exceed costs, they are reluctant to be environmentally proactive (Muñoz-Villamizar, Santos, Viles and Ormazábal, 2018; Montabon *et al.*, 2007).

The approaches that draw together elements and attributes that are essential to a holistic, practical and long-lasting improvement of environmental performance in the manufacturing sector are few and of limited scope (Skellern *et al.*, 2017). To address this gap, there is a great need for methodologies and approaches that integrate, measure, control and improve productive and environmental performances (Muñoz-Villamizar, Santos, Viles and Ormazábal, 2018). These integrated approaches to simultaneously improving productivity and environmental performance add a number of benefits to those that would be achieved by applying approaches independently. Among these benefits, Molina-Azorín, Tarí, Claver-Cortés and López-Gamero (2009) suggested the following: an improvement in the efficiency and effectiveness of the organization, avoiding the duplication of effort, the alignment of goals, processes and resources, and the availability of joint training and improved communication between all organizational levels. Furthermore, Cherrafi *et al.* (2016), Sunder (2016) and Sunder *et al.* (2018) showed that the integration of two continuous improvement methodologies and/or management philosophies is a way for organizations to increase the speed and effectiveness of any process, service or project within the organization and could help increase revenue, reduce costs and improve collaboration. In this context, lean production systems can be constituted as important tools for putting certain environmental principles into practice (Alayón *et al.*, 2017).

As lean management can be defined as a system that identifies and eliminates waste (i.e. anything that does not add value from the customers' perspective), aligning it with the green paradigm and its approaches and tools seems natural (Garza-Reyes *et al.*, 2016). Lean management has been implemented worldwide to manage competitive businesses (Folinas *et al.*, 2014). It is considered one of the most influential paradigms in manufacturing (Forrester *et al.*, 2010) and a way to create opportunities for developing resource-efficient manufacturing systems (Netland *et al.*, 2015; Andersson and Bellgran, 2015). One of the goals of lean is to use fewer resources to generate the same outcome. This is clearly environmentally friendly, as fewer materials are used in production and there are reductions in waste, resource consumption and pollution costs (King and Lenox, 2001). Additionally, lean and environmental management systems have common implementation practices (e.g. leadership, training, and permanent self-assessment and improvement) (Molina-Azorín, Tarí, Claver-Cortés and López-Gamero, 2009).

In recent years, many studies related to quantitative approaches in lean and green have been published. For example, Diaz-Elsayed *et al.* (2013) proposed a simulation-based approach for incorporating both lean and green strategies into a manufacturing system. Fahimnia *et al.* (2015) and Carvalho *et al.* (2017) presented different mathematical models designed to overcome the trade-offs between lean and green practices. Thanki and Thakkar (2016) proposed a value–value load diagram for modeling and evaluating the operational (lean) and environmental performance of a production system. Fercoq *et al.* (2016) presented a quantitative study of lean-green integration focused on waste reduction techniques in manufacturing processes. Furthermore, Sartal *et al.* (2017) explored the influence of environmental and information technologies on lean routines to improve industrial performance.

The evidence presented so far suggests that the objective of improving both productivity and environmental performance can be reached by eliminating waste, reducing costs and improving efficiency through lean strategies (Qi *et al.*, 2009). Some of the more commonly used lean techniques are: poka-yoke, total quality management, Kanban, Takt time, kaizen, statistical process control, 5S, value stream mapping (VSM), and jidoka, among many others (Folinas *et al.*, 2014). Plenert (2007) and Abdulmalek and Rajgopal (2007) placed special significance on the usefulness of VSM as a key tool in lean manufacturing.

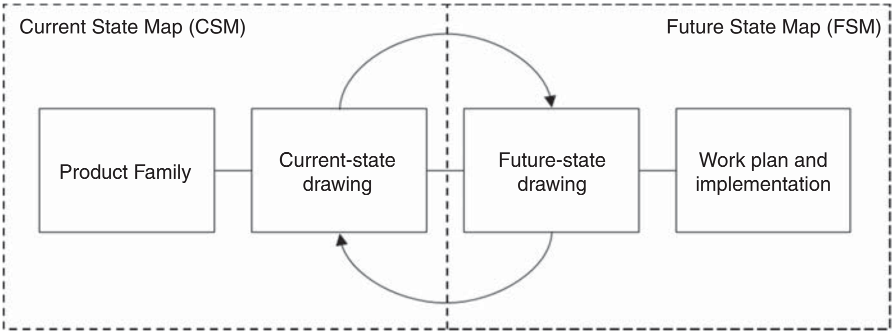
In order to improve lean and green performance, Ng *et al.* (2015) pointed out that several researchers have developed methodologies which rely on VSM. The authors pointed out that VSM allows production flows to be visualized, thus highlighting opportunities for improvement and clearly exposing waste. Moreover, in the scientific literature, VSM seems to be successful at effectively integrating lean and green (environmental) management (Simons and Mason, 2003; Ng *et al.*, 2015; Thanki and Thakkar, 2016).

2.2 Value stream mapping

As defined by Tapping and Shuker (2003), the "value stream encompasses all the actions (both value-added and non-value-added) that are necessary to bring a product or service from the original concept through the development and/or manufacturing processes to the receipt of payment." VSM is a tool used to map a productive 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 was developed by adapting mapping tools from other disciplines (e.g. industrial engineering) and through visual maps based on Toyota's in-house practices (Mason *et al.*, 2008).

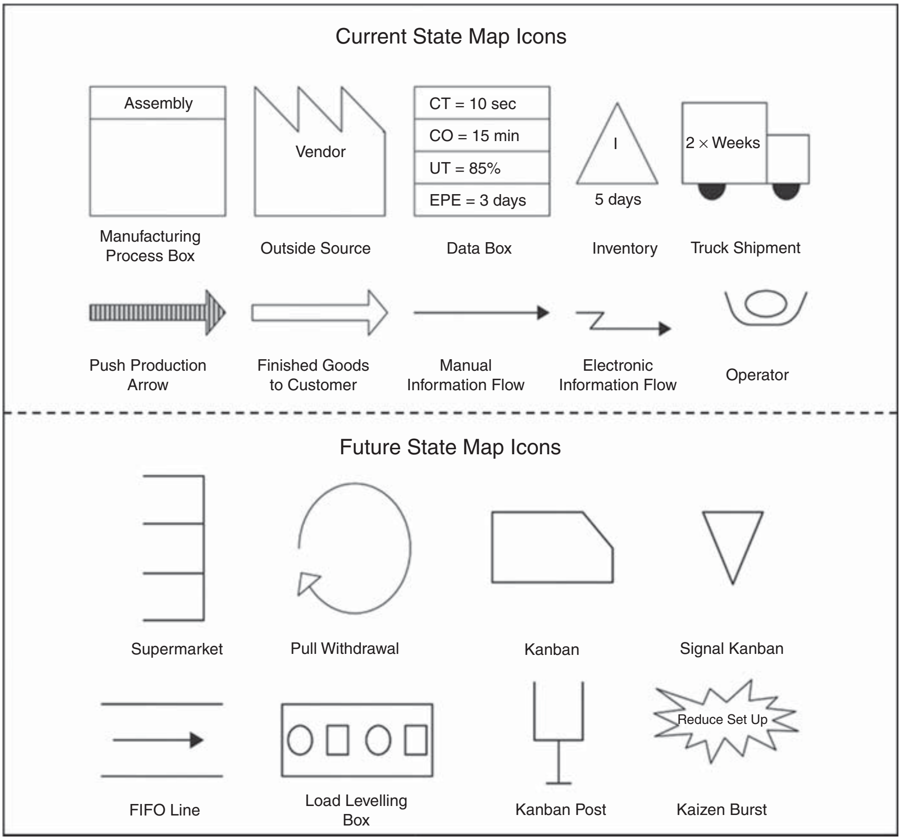
Rother and Shook (1998) were the first to define the steps for VSM (see Figure 1). The "Current State Map" (CSM) is drawn by collecting information for a product family on the shop floor, where a family is a group of products that pass through similar processing steps. In the "Future State Map" (FSM) the individual processes are linked to their customers, either through continuous flow without inventories (i.e. one-piece flow) or pull (i.e. Kanban), and only what customers need is produced only when they need it (i.e. just-in-time). The final step is to prepare and implement a one-page-plan for achieving the future state. According to the authors, the final goal is to introduce a "lean value stream," and drawing the current and future states are overlapping efforts. "As future states become reality, a new FSM should be drawn. That is, continuous improvement at the value-stream level" (Rother and Shook, 1998).

Later, Braglia *et al.* (2006) summarized a step-by-step procedure for performing a VSM analysis. Based on Rother and Shook (1998), the first step consists of selecting a product family as the target for improvement. Second, the CSM is constructed for the selected product(s) value stream. The next step consists of identifying and analyzing the waste encountered along the value stream. Finally, the FSM is drawn to represent the ideal production process without the removed waste. Both CSM and FSM should be drawn using a set of standard icons (see Figure 2).



Source: Adapted from Rother and Shook (1998)

Figure 1.
Initial VSM steps



Source: Adapted from Braglia *et al.* (2006)

As mentioned in Section 2.1, VSM has been widely used to develop manufacturing processes without wastes in the production flow. According to Vinodh *et al.* (2011), the environmental benefits of VSM are a reduction in waste through fewer defects, fewer scraps, low energy usage, etc. Thus, several VSM-based tools and approaches have been developed to help companies meet sustainability targets. Table I summarizes a literature review of VSM approaches and methods that contemplate environmental elements or metrics.

As Jiang *et al.* (2016) pointed out, the existing literature has only paid attention to calculating efficiency and has ignored the possible interaction between desirable productive efficiency and environmental efficiency. To the best of our knowledge, there are no tools or approaches that directly seek to integrate and improve productive and environmental performance. Furthermore, most approaches focus on independent metrics such as CO_2 emissions or energy consumption. Therefore, it can be stated that the current indicators of the VSM tools may not correctly relate productivity and environmental factors.

2.3 Productivity, value-added and overall greenness performance metric

Productivity can be defined as the ratio of process output to input. Although there is no disagreement on the general notion of productivity, there is neither a unique purpose nor a single measure for it (OECD, 2001). According to Maroto-Sánchez (2012), productivity was

Authors	Proposed metric/Approach
Simons and Mason (2003), Mason *et al.* (2008)	Sustainable VSM to minimize CO2 emissions
US EPA (2007)	Toolkit to assist organizations in reducing greenhouse gas emissions and energy use
Wills (2009)	Green value stream mapping, which places boxes containing environmental information under VSM
Miller *et al.* (2010)	Evaluation of the environmental impacts of lean tools (including VSM) using simulation
Marudhamuthu and Krishnaswamy (2011)	Increase in productivity and source reduction through lean tools (including VSM) in the garment industry
US EPA (2011)	Toolkit to assist organizations in reducing water use, costs, and risk
Vinodh *et al.* (2011)	Eliminate environmental waste through VSM and 7S (5S + Safety + Sustainability) implementation
Faulkner and Badurdeen (2014), Brown *et al.* (2014)	Sustainable VSM (Sus-VSM) to visualize and assess manufacturing performance from the triple-bottom-line perspective
Folinas *et al.* (2014)	Reduce waste, evaluating the non-value-added consumption of water and energy across organizational boundaries
Ng *et al.* (2015)	VSM and carbon-value efficiency metric to integrate Lean and Green practices
Garza-Reyes *et al.* (2016)	Sustainable transportation VSM to apply lean and green paradigms in the transport and logistics sector
Thanki and Thakkar (2016)	Value–value load diagram for modeling and evaluating operational and environmental performance using VSM and material flow cost accounting
Powell *et al.* (2017)	VSM, data-driven improvement cycle and Six Sigma strategy to improve environmental sustainability

Table I. Summary of environmental variations of VMS

traditionally related to productive efficiency, insofar as it analyzes the extent to which the use of resources in order to create a particular end product is optimal. For example, Santos *et al.* (2018) argued that, often the main objective of measuring productivity is to make inferences about the efficiency of a firm, an organization, or an industry. However, as Maroto-Sánchez (2012) pointed out, the concept of effectiveness is gradually being incorporated into this definition, where effectiveness is understood as the way in which companies' processes conform to the requirements and demands of consumers. That is, productivity depends intrinsically on the value of products and services (Maroto-Sánchez, 2012). Thus, the definition that is of particular relevance in industry is the one that uses the value-added concept (i.e. processes that the consumer is willing to pay for) to measure productivity (OECD, 2001).

In this context, given that environmental performance should not be treated independent of productive performance, Muñoz-Villamizar, Santos and Montoya-Torres (2018) proposed the overall greenness performance (OGP) metric. The OGP is a lean-based hierarchy of metrics that relates a company's resource consumption and waste emissions (i.e. environmental performance) with its production level. Using the value-added concept, the OGP classifies a company's consumption and waste processes according to the categories presented in Figure 3 and Table II. The most commonly employed variables in environmental performance are input-oriented (resource consumption) and output-oriented (emissions, toxic waste, oil and chemical spills, and discharges that are recovered, treated or recycled) (Molina-Azorín, Tarí, Claver-Cortés and López-Gamero, 2009). Thus, the resources/emissions that are measured should be defined in advance by decision makers, in order to define the critical environmental aspects of the company.

3. Methodology: the OGP-VSM approach

This paper presents a new, innovative approach and framework called OGP-VSM, with the aim of demonstrating how combining the OGP metric and VSM can improve both productivity and

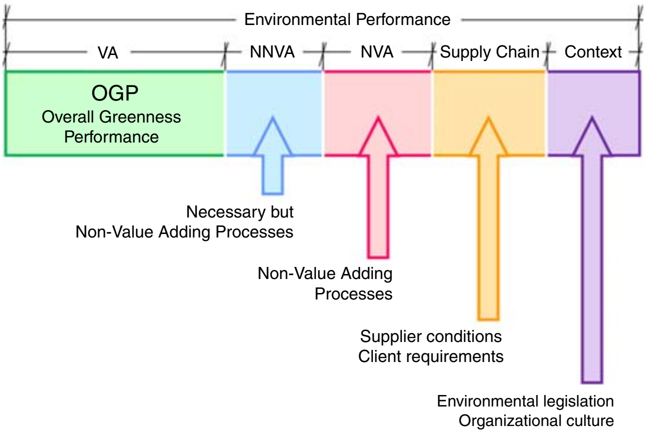


Figure 3.
OGP

Source: Adapted from Muñoz-Villamizar, Santos and Montoya-Torres (2018)

Table II.
Definition of OGP categories

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 (e.g. restrictions on packaging or transportation)
Company context	Computes consumption/emission related to culture of working people and regulations constraints

Source: Adapted from Muñoz-Villamizar, Santos and Montoya-Torres (2018)

environmental performance. OGP-VSM is a visual representation of processes within a pathway, and it can be considered to be a visual map of all activities related to the production of a given product, starting with raw material and ending with the end consumer. The enhanced mapping approach illustrates how the activities are linked to each other and provides performance-related information. That is, it shows costs and compression time for productivity along with resource consumption and waste for environmental performance.

A schematic representation of our proposed five-phase OGP-VSM approach is shown in Figure 4. Our version of VSM combines procedures from both Rother and Shook (1998) and Braglia *et al.* (2006), which were presented in sub-Section 2.2.

3.1 System definition (current state)

To begin the mapping process, the product family to be evaluated must be defined. Most companies' systems are labeled by their attributes and each one possesses its own fundamental characteristics (Hancock and Algozzine, 2016). That is, each family follows a separate value stream (Tapping and Shuker, 2003) and goes across different organizational boundaries within the company (Rother and Shook, 1998). Thus, the boundaries of analysis must be clearly defined. Limits might include, for example, from raw material acquisition to after-sales service.

Current state mapping begins at the shop floor level, where process categories like "assembly" or "welding" are drawn instead of recording each processing step. Next, the

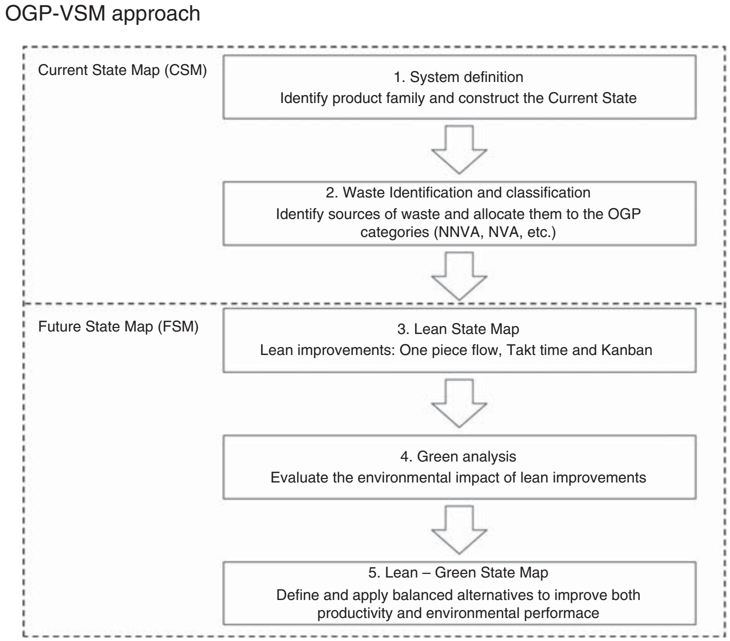


Figure 4. Global generic approach

components, resources, steps and data for the processes should be correctly specified according to what the company wants (de Mast and Lokkerbol, 2012). That is, the company's decision makers should define beforehand which lean and environmental metrics (i.e. key metrics) will be used. The metrics that best suit each company depend a great deal on the particulars of the company's situation (Tapping and Shuker, 2003). Table III presents some basic metrics that some companies could find useful. It must be noted that, unlike metrics for productivity evaluation, different environmental metrics might be more relevant depending on the industrial sector (Faulkner and Badurdeen, 2014). Brown *et al.* (2014) have suggest that instead of having a full set of industry-specific metrics, it is better to focus on a smaller and more widely applicable set of metrics. Nevertheless, other metrics such as water pollutants, toxic/hazardous chemical usage, scrap, etc., can be used with the proposed approach. In order to be consistent with the literature, the CSM is drawn using the icons presented in Figure 2.

3.2 Waste identification and classification

In order to draw the CSM, the wastes in the current state need to be observed and the targets for future lean and environmental implementations need to be identified. Thus, in this phase,

Category	Definition (units)
Productivity	
Compression time	Speed with which goods and commodities move through the process (min/product)
Costs	Economic cost per process (USD/product)
Environmental	
Energy use	Specific to energy source such as kilowatt hours (kwh/product)
Water use	Volume of water used (gallons/product)
Air emissions	Emissions generated (kg CO_2/product)

Table III. Productivity and environmental performance metrics the seven classic wastes (i.e. overproduction, waiting, transport, inappropriate processing, unnecessary inventory, unnecessary motion, defects) are identified and allocated to the OGP categories (i.e. VA, NNVA, NVA, supply chain and context; see Figure 3). Conventional VSM does not focus on resources consumed and wasted (Vinodh *et al.*, 2011), but by using OGP and an icon that indicates environmental waste, the VSM could be extended to metrics associated with the use of energy, water and/or materials. Thus, OGP consumption and emissions metrics should be added to the CSM. Each waste is targeted specifically to help identify the appropriate lean tool to assist in its elimination (Tapping and Shuker, 2003). In order to identify environmental wastes in the VSM, the drop icon (which is called the environmental burst, following the icons shown in Figure 2) in Figure 5 is used.

3.3 Lean State Map

A future "Lean State Map" is designed to represent the ideal production process, where identified waste has been eliminated and environmental impacts are not considered. The development of this "pure-lean" map is governed by three simple (but difficult to implement) principles: work at takt time (i.e. pace of customer demand); implement one-piece flow (continuous flow without inventories); and use pull flow where it is not possible to create continuous flow (i.e. Kanban).

3.4 Green analysis

It has been widely demonstrated that the lean methodology guides improvements in productive efficiency (Santos *et al.*, 2006). Nevertheless, in certain situations, the strict application of lean production concepts leads to the loss of energy or natural resources, which should be avoided as much as possible. One clear example is associated with replenishment frequency, which in lean supply chains is promoted by just-in-time practices (Carvalho *et al.*, 2010). More frequent delivery of small orders allows waste to be minimized and lead-time to be reduced, but more orders require more deliveries, more vehicles for transportation and, consequently, more carbon emissions (Carvalho *et al.*, 2017). Once the Lean State Map has been created, managers must determine what outcome arises from following the pure-lean methodology; namely, whether the previously identified environmental waste has been eliminated, improved or increased or if a new waste has been created. In this step, the metrics defined at the outset will show the impacts and allow the current and the future states to be compared from an environmental point of view.

3.5 Lean-green state map

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. Finally, a one-page implementation plan that describes how to achieve this future state is defined.

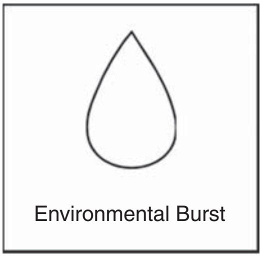


Figure 5.
Proposed icon for environmental waste

4. Case study

Research on relating productivity and environmental performance has been mostly theoretical and anecdotal (Molina-Azorín, Claver-Cortés, López-Gamero and Tarí, 2009). Empirical approaches, such as case studies and action research, are needed to promote in-depth understanding of the impact that integrating environmental performance has on companies' development (Morioka and de Carvalho, 2016). A case study allows a problem to be investigated in a real-life context, thus helping to build and validate knowledge in practice and in theory (Seth *et al.*, 2017). Following upon the previous discussion on how to construct the OGP-VSM, this section applies the proposed approach to a manufacturing context. The company selected is a tier-1 supplier in the automotive sector and it manufactures bumpers for an automotive original equipment manufacturer (OEM). In total, 90 percent of its turnover comes from the manufacture of parts for final assembly, while the rest is from parts for spare parts.

The main production processes are plastic injection, painting, polishing and final assembly, and the final products are shipped in sequence to the main customer. The injection process is the typical process used in this type of company, i.e. injection machines give shape to the product from pellets purchased from large suppliers. The main plastic injection process uses the pellets and other small auxiliary parts, which are injected in the company. These auxiliary parts will not be represented in the main flow of the map, following the indications of Rother and Shook (1998). Once the main parts are injected, they are sent to painting or the spare parts section.

The painting process is performed on a carousel where the pieces are flamed, primed, painted, varnished and dried. For the purposes of the case study, the five painting tasks will be considered as a single paining process. It is a complex process, where the most critical task is the color change, which involves losses of both time and materials (solvents). Once painted, parts are polished and checked. Defective products are repaired and polished again, or discarded. The polishing process is not synchronized with the painting process, and it will be considered as a separate process in the value chain map (despite not adding value).

The final processes are assembly and shipping. Both processes will be considered as a single process since the products are assembled in sequence, i.e. following the order in which they will be assembled in the assembly line. The painted bumper is taken from a warehouse and the features requested by the customer (e.g. headlights, sensors) are added. Once the product is assembled and in its final state, it is placed on a rack and loaded directly onto a truck. Orders must be dispatched within one hour to the OEM, which is located less than two kilometers away by road. Finally, as a manufacturer of original equipment, the bumper manufacturer delivers parts to the OEM's local warehouses for worldwide distribution.

4.1 System definition

The product family selected for our case study consists of the front and rear bumpers for three different car models. The product family includes all variants of the bumpers depending on the finish and color of each model. The system's limits are set from raw material procurement to delivery to customer. In addition, as mentioned in the previous section, the bumper manufacturing system is divided into four major processes: plastic injection, painting, polishing and final assembly. The products are delivered in sequence to the OEM (just-in-time scheduling). The productivity metrics selected to evaluate the system's performance are cycle time (CT), changeover time (CO) and lead time. In addition, the percentage of time that the machine is running for the injection process, that is, the up time (UP), was computed. In terms of environmental metrics, energy consumption, solvent consumption and CO_2 emissions were selected.

The map of the process's value chain was drawn up as follows:

(1) There is a set of four pellet silos for raw material storage, which is supplied twice a week. The capacity of the silos guarantees production for six days. The company

provides the supplier with a six-month plan and establishes a shipping program two weeks in advance.

(2) The raw material is carried by pipes to a set of four identical injection machines, where the different bumper parts are injected.

(3) Next, bumper parts are stored in a warehouse, which has an average-production capacity of three days for each of the injected parts.

(4) The next process is painting, where the parts are prepared, painted, varnished and baked in a tunnel. Unlike the injection process, all the parts (regardless of model) that are going to be painted the same color are grouped and processed together.

(5) After the painting process, the bumper parts go through the polishing process, where they are thoroughly reviewed. Good parts are sent to the post-polishing warehouse, and defective parts that can be reworked manually are repaired before being sent to the next process.

(6) The post-polishing warehouse also has a three-day average-production capacity.

(7) The assembly process is sequenced according to customer demand (just-in-sequence strategy). Orders are delivered to the OEM by truck four times per shift (i.e. 12 times per day) on a route that is approximately 2 km long.

Figure 6 shows the classic representation of the process, following the methodology proposed by Rother and Shook (1998).

4.2 Waste identification and classification

Figure 7 shows the waste identified for the case study company and the OGP category (i.e. NNVA, NVA, supply chain or company context) assigned to each instance of waste:

- In the first warehouse a high amount of stock is observed, due to the capacity of the truck. This full-load-truck waste is assigned to "supply chain" category.
- In the injection process, long times are observed for the batch change, which leads to machine delays.
- The injection molds are heated up during the batch change, increasing the time for this process.
- At the painting carousel, workers are sometimes idle. This waste is assigned to NVA.

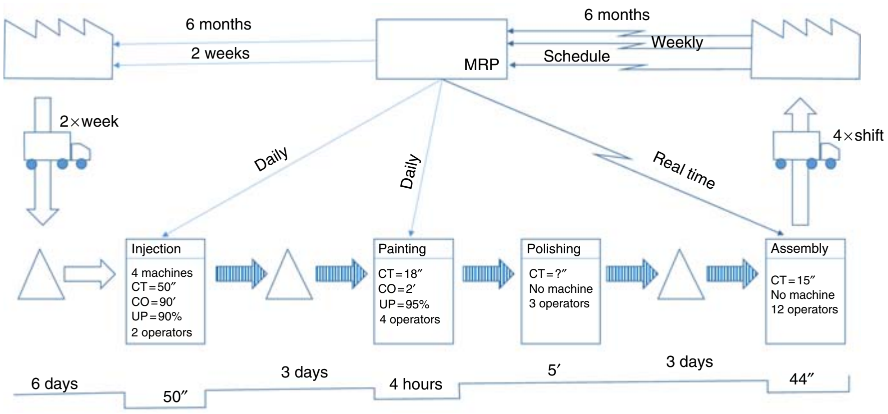


Figure 6.
Initial CSM of the case study

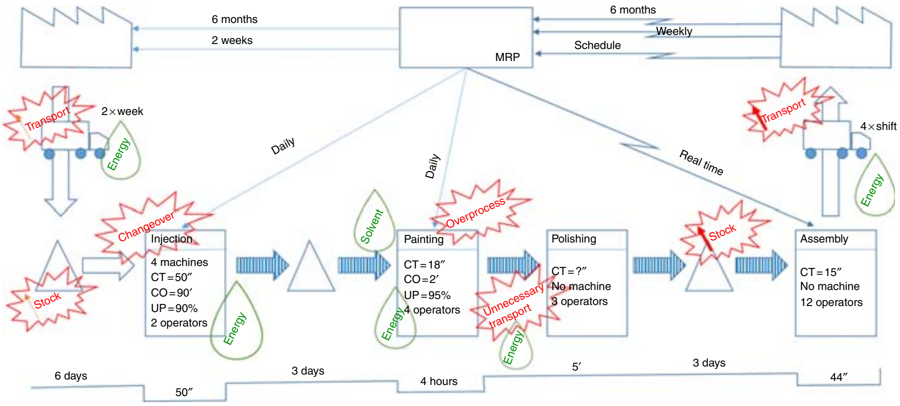


Figure 7.
Waste in CSM

- The batch change for the painting carousel presents two types of environmental waste: energy (heating the furnace) and the consumption of chemical products. Both would be classified as NNVA since it is impossible to eliminate them completely due to a system requirement to change batches. However, these wastes could be minimized.
- The polishing process, strictly speaking, does not add value since it involves reworking the parts and could be executed as part of the painting process. Therefore, an avoidable waste of transport and energy has been identified (i.e. NNVA).
- The post-polishing warehouse is defined to fulfill client's requirements, to protect against errors.
- In the assembly department, waste is observed due to over-processing.
- Transportation is set by the sequence of the product and entails high energy consumption. To a certain extent, transportation can be assigned to NNVA, but sometimes it can be considered as NVA.

4.3 Lean State Map

Following the three principles explained in sub-Section 3.3 (i.e. takt time, one-piece flow and Kanban) and the methodology developed by Rother and Shook (1998), we obtain the Lean State Map (see Figure 8), in which the main improvements are:

1. The painting and polishing processes are merged and transportation between these two is eliminated.
2. Kanban leads to a pull flow implementation for the final three processes. This results in a significant reduction of stock.
3. Because of the bumper manufacturer's proximity to the OEM and the OEM's infrastructure, it would be possible to deliver just-in-sequence parts via conveyor.

4.4 Green analysis

This phase uses the Lean State Map to analyze whether the previously identified environmental wastes have been solved or increased or whether new wastes have been created. First, it was observed that decreasing the size of the stock by increasing the frequency of the truck arrivals

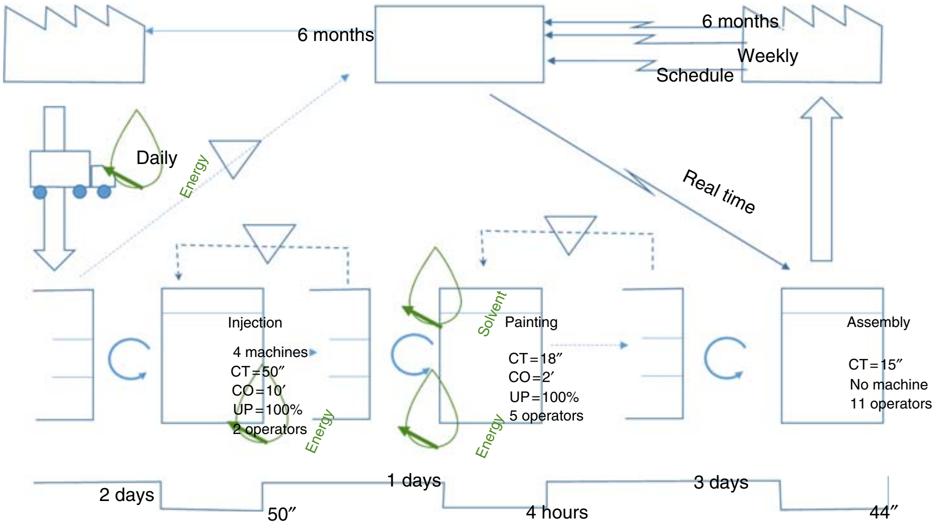


Figure 8.
Lean State Map

led to an increase in transport energy consumption, without clear evidence of an improvement in productivity. Theoretically speaking, reducing stock helps to identify problems earlier than large batches. It would be necessary to maintain this "improvement" of small batches, if it also entailed a significant reduction in costs and improvement in the sustainability of the system. However, this is not the case since a Full Truckload Shipping policy is clearly more efficient in terms of sustainability. In addition, the increase in the raw material stock level does not have to influence the rest of the plant since the output of material could be regulated.

In terms of batch size, an excessive reduction would lead to an increase in the energy consumed during the batch changes in the injection and painting machines. In the injection process, the increase in batch changes would increase the energy needed to keep molds heated while they are not being used. In the painting process, it would cause an excessive increase in solvent consumption.

4.5 Lean-green state map

In the previous section, some environmental wastes were not solved, and they even increased. The objective of the OGP-SVM approach is to achieve a significant improvement in factory flexibility, while defining a batch size that is able to optimize energy consumption. Thus, in order to avoid overproduction and maintain the improvements linked to a tense flow, production will be regulated with a Kanban system, where batch sizes will be calculated by taking into account environmentally sustainable criteria.

The case of the paint carousel is different from the injection process. It is possible to regulate the carousel with Kanban, but it is clearly inefficient in terms of environmental impact. Kanbans work with batch sizes defined by product types: when a product reaches a certain batch size, the production order is placed. In this case study, the Kanban operation would be: when a bumper model of a certain color is consumed, the cards are accumulated, once a certain number of Kanbans has accumulated, the production order is placed. This alternative is feasible but has a drawback. The use of solvents depends on the sequence of colors, and going from a dark to a light color consumes many more solvents than moving gradually by color type from light to dark. That is, the excessively small size of the batch (necessary for the Kanban to function correctly) entails excessive color change. Thus, it is necessary to guarantee optimization in the change of colors in order to avoid the excessive use of solvents.

The final Lean-Green State Map is presented in Figure 9, where the improvements to be made are the following (starting from the customer side):

- Connect a conveyor from the plant to the customer, which keeps a high number of trucks from coming to the plant. Although this is a long-term investment, it is profitable both economically and sustainably speaking.
- Improve the productivity of the assembly section. It is estimated that a productivity increase of more than 10 percent can be achieved.
- Design a working cell that combines painting and polishing, thus eliminating the need for transport and improving productivity.
- Recalculate the batch size for the painting carousel.
- Construct Kanban and supermarket panels for the injection loop and the subsequent study of batch size.

5. Discussion and conclusions

This paper proposed a new methodology that integrates lean management tool concepts in order to improve environmental effectiveness in companies. This approach provides insights and highlights whose characteristics are to be considered in order to shift toward environmentally friendly (green) manufacturing. For example, it is important to note that some activities that are instituted for lean benefits have the opposite effect on the environmental performance of companies. In this context, the final applied alternatives should seek a balance between improving productivity and improving environmental performance.

One of the conclusions of our research is the lack of practical integration between productive and environmental performance. Given the similarities between lean and environmental management, OGP-VSM approach can serve as a bridge to productivity and environmental efficiency. In this methodology, an environmental assessment metric (i.e. OGP), which aims to integrate productivity and environmental performance using the value-added concept, was incorporated into VSM. The methodology has been validated in a practical case, demonstrating

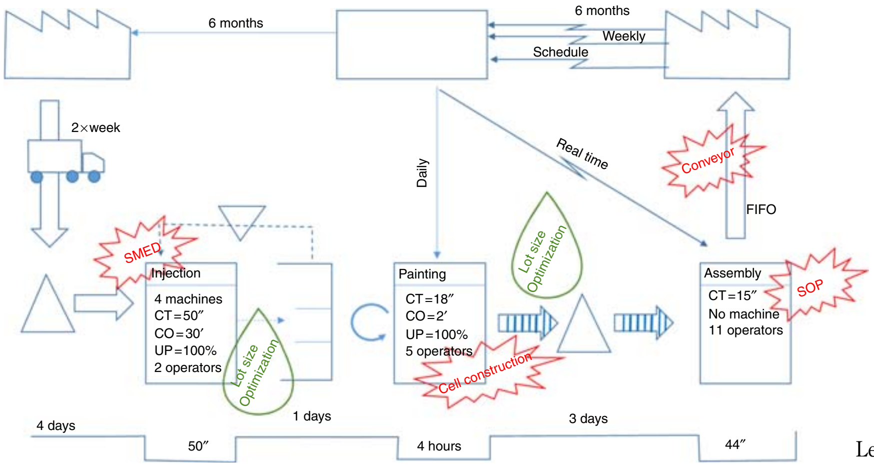


Figure 9.
Lean-green state map

its potential for finding a balance between lean and green practices in order to achieve the simultaneous improvement of productivity and environmental performance.

In addition, the paper offers interesting results for managers. Managers concerned about productivity and environmental issues have the chance to rapidly determine the link between the consumption/emissions of a company's processes and productivity, using different categories (i.e. company context, supply chain and NVA, NNVA and VA). Another important practical implication for managers is that a methodological improvement of these dimensions may result in a positive influence on financial performance through productivity and environmental performance. Future work should extend the proposed methodology to other contexts and explore specific supporting tools and techniques (e.g. monitoring). Additionally, different environmental metrics could be tested according to the interest of decision makers.

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