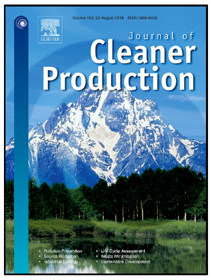

Creating value with less impact: lean, green and eco-efficiency in a metalworking industry towards a cleaner production

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Creating value with less impact: lean, green and eco-efficiency in a metalworking industry towards a cleaner production

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Abstract

It is possible to create value with less environmental impact through the adoption of Lean and Green manufacturing concepts and tools. This paper proposes a Lean-Green model based on the application of the Single Minute Exchange of Die (SMED) combined with Carbon Footprint (CF) to analyze eco-efficiency of a machining center in a case study in Brazil. The novelty of this paper was the proposal of a Lean-Green model based on ecoefficiency indicators to measure performance of production systems toward a cleaner production. The developed Lean-Green model should be used by companies with low-capacity of production due to restrictions of machine availability. The case study was organized in five different scenarios by varying machine tools, workers and workpieces. First, the SMED tool was applied in the setup activities and gains of reduced idle times were up to 88%. CF results were reduced up to 81% after applying the SMED tool on each scenario. Lastly, an eco-efficiency set of indicators were used to combine results of SMED and CF, and results of eco-efficiency were 3% higher even with higher CF values after converting setup saved time into productive time. To achieve such results simple improvements were performed in the machining center, through the standardization of work and the study of time and methods for setup activities, showing that the proposed Lean-Green model could be also adopted by other companies to create value with less impact.

Keywords

Eco-efficiency; Carbon Footprint; Quick Changeover Tool; SMED; Lean Manufacturing; Green Manufacturing.

1. Introduction

There is a constant search for tools and techniques to improve quality of products and processes, once competitiveness is getting fiercer (Parry et al., 2010). Nowadays, customers' demands are not restricted to traditional factors of competitiveness such as quality and fast delivery of products, customers are also demanding sustainability issues (Dornfeld et al., 2013).

According to Wang et al. (2015), sustainability is increasingly becoming the main goal of most forward-looking organizations. Social and environmental management issues need to be considered as a competitive differential for organizations in view of creating value with less socio-environmental impact (Allwood and Cullen, 2009). An increasing number of manufacturing companies are concerned about their Carbon Footprinting, i.e, measuring greenhouse gases emissions (GHGs) releases from their industrial processes, as well as being able to create alternatives to reduce such emissions towards a cleaner production (Allwood and Cullen, 2009; Jeswiet and Kara, 2008).

In this context, companies can adopt and combine Lean with Green manufacturing strategies (Fercoq, Lamouri and Carbone, 2016) to evaluate and improve their economic and socio-environmental performance. The Lean strategy has emerged from the need faced by Japanese industries after World War II, in which the market required the production of large quantities of many varieties of products (Ohno, 1997). The Green paradigm has arisen in the 1990's as a philosophy and operational approach to reduce the negative ecological impact of products and processes as well as improving environmental performance of production systems, while still achieving their financial objectives (Garza-Reyes, 2015).

Lean manufacturing is defined as a production of products (goods or services) with minimal buffering that can help companies to improve operational performance to reduce wastes in human effort, inventory levels, time to market and manufacturing space, to become highly responsive to customers' demands (Hopp and Spearman, 2004; Jasti and Kodali, 2015; Singh et al., 2010). Lean improves quality and productivity by increasing output per unit of input, reducing wastes, time and minimizing costs, while green manufacturing reduces environmental risks and impacts, while improving ecological efficiency and eliminating environmental waste.

The concept of Green manufacturing has garnered considerable attention globally, with many countries and organizations spending time and money to enhance the efforts of an environmentally benign manufacturing of products (Chuang and Yang, 2014). Green manufacturing protects the environment through reduction or elimination of toxic materials, the use of environmentally friendlier raw materials and manufacturing processes, and designing eco-products, designing for the environment, for re-use, for remanufacture and for recyclability (Dhingra, Kress and Upreti, 2014; Duarte and Cruz-Machado, 2013; Silva, Silva and Ometto, 2016). A green company can apply different types of environmental practices, such as cleaner production, eco-efficiency and life cycle management, being them the most well-known related initiatives (Pampanelli et al., 2014; Silva, Silva and Ometto, 2016).

According to Leon and Calvo-Amodio (2017), lean tends to facilitate the adoption of environmental practices mainly by involving people and enhancing their problem-solving skill sets, and its practices may facilitate the focus on sustainability issues. Therefore, the integrated approach "Lean-Green" is a targeted intervention for organizations to implement more sustainable business models to reduce waste and improve material efficiency, and subsequently minimizing operational costs (Caldera and Dawes, 2017). The Lean-Green concept associates value aggregation with high efficiency in operational and environmental terms, and it adds more value while contributing to prevent environmental impacts (Abreu, Alves and Moreira, 2017).

The delivery of competitive products that meet human needs and progressively reduces environmental impacts and resources consumption over the life cycle of a product is defined as Eco-efficiency (WBCSD, 1995). Thus, working with Lean-Green seems to be a desired way to achieve eco-efficiency, and this concept is used on this paper to integrate Lean with Green manufacturing initiatives.

For Johansson and Sundin (2014), Lean and Green belong to the same "currency", i.e., they share a number of similarities that indicate a synergistic relationship. The interest on this integrated approach has grown in both academic and industry fields (Johansson and Sundin, 2014; Cherrafi et al., 2017; Verrier et al., 2016). However, it is relatively new, and it remains unclear for many, how exactly Lean-Green can be put in practice to transform organizations in more sustainable businesses models (Caldera and Dawes, 2017).

Within this context, the present paper proposes a theoretical Lean-Green model and shows its application in a Brazilian case study. It was selected a metalworking company that produces automotive components used by Brazilian and international manufacturers of automotive products.

The Lean-Green model integrates the use of Lean manufacturing through the SMED (Single Minute Exchange of Die) tool and performs the calculation of the Carbon Footprinting (CF) in the machining center from the metalworking company.

SMED is a tool developed by Shigeo Shingo in 1985 to reduce setup time to a single digit (less than 10 minutes) by transforming internal activities performed only when a machine is shut down, into external activities that can be done while the machine is running (Shingo, 1985). On the other hand, CF is related with the measurement of direct and indirect GHG emissions of a manufacturing process or in a product life cycle approach (Cerutti et al., 2016). Further explanation about SMED and CF are presented in section 2.2.

In this paper, the combined results of SMED and CF are used to calculate eco-efficiency indicators in order to reduce wastes, such as idle time, resources consumption, as well as environmental impacts due to GHG emissions. It is important to note that there are no published papers focusing on SMED and CF to measure eco-efficiency of production systems, and the theoretical proposal from this paper aims to fill this gap and to contribute to enhance knowledge on that aspect.

2. Methodology

2.1. Description of the metalworking company

The studied company is a tooling company from the metalworking sector, which in Brazil represents around 78.3 thousand establishments (25% of the national manufacturing industry market share), with more than 80% of the companies concentrated in Southeast and South regions. In addition, this sector employs 2.27 million formal workers and it is predominantly composed by micro and small companies, which correspond to 95% of the country's companies (MTE/RAIS, 2010; FIERGS, 2014).

The selected company is located in the southeast region of Brazil, Campinas city, São Paulo state, and its identity was preserved due to privacy issues. It belongs to the segment of high precision molds production and supplies the needs of other companies downstreaming the production chain, with emphasis on the automotive product's chain. In Brazil, Santos (1997) pointed out that tooling companies are mostly small companies that produce injection molds, extrusion molds and other tools and devices used by larger companies from different sectors, such as household appliances, automotive and consumer goods.

The production system is classified as assembly-to-order, and the company produces molds composed of metallic or polymeric materials designed and made according to a specific mix of parts that will be formed in the injection process. The company can be classified in the category of second tier level, which provides parts to supply a first tier level of companies (large automotive manufactures).

The machining sector of the evaluated company shows low-capacity machines due to restrictions of machine availability. It operates 09 hours shift and the machine sector has two types of machine tools, as follows: 04 machines of ROMI FV-1300 Feeler model and 04 machines of ROMI Discovery 1250 model. To operate both types of machine tools there are 03 employees (A, B and C) per shift. Employee A is responsible for operating 03 ROMI FV-1300 Feeler machine models; employee B operates 02 ROMI Discovery 1250 machines and 01 ROMI FV-1300 Feeler machine; and employee C is responsible for 02 ROMI Discovery 1250 machines.

2.2. The Lean-Green model for eco-efficiency

The theoretical Lean-Green model proposed is given in Figure 1. It is divided in three phases: phase one focus on the SMED application, phase 2 on CF calculation and phase 3 performs the estimation of eco-efficiency indicators.

The model in Figure 1 should be used by companies with restrictions of time availability for scheduling of industrial machines and equipment. Under such situations, it is important to reduce idle times from the setup activities running (Ohno, 1997). Most part of the manufacturing activities of the evaluated metalworking company are due to machining operations with capacity constraints.

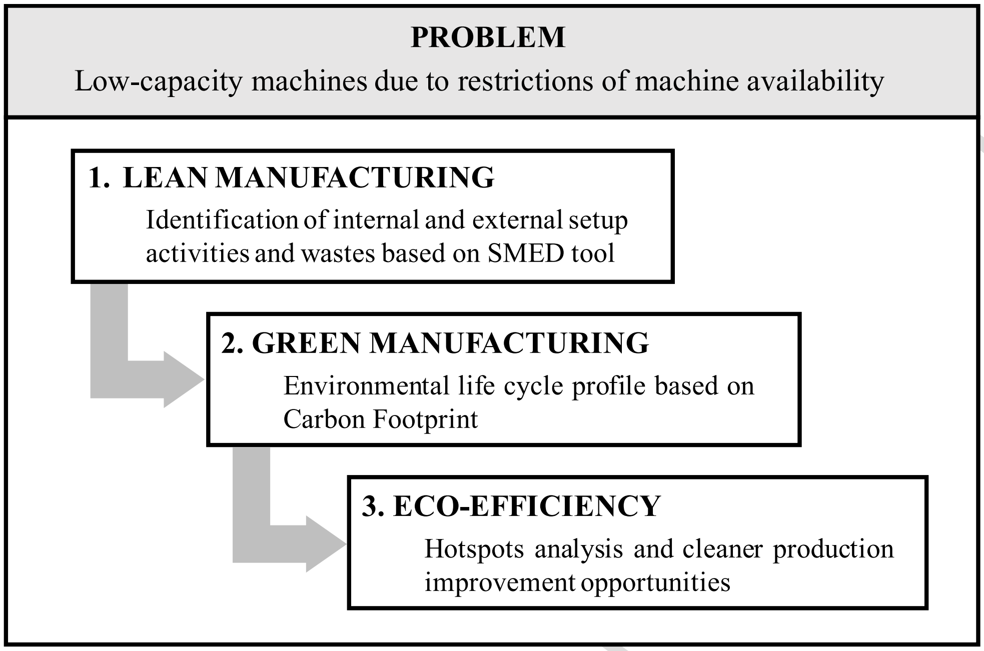


Figure 1. The Lean-Green model proposed for this research.

The first phase in Figure 1 consists of the data collection through observations and timing of setup activities. Setup activities should be filmed for further analysis according to the SMED methodology. In the second phase, it is calculated Carbon Footprint of the machining operations during the setup activities in a cradle-to-gate perspective. Finally, results of the Lean-Green model application are combined by using eco-efficiency indicators in order to analyze hotspots and suggesting improvement opportunities towards cleaner production.

It is important to note that the Lean model was based only on the SMED application, because of the interest of this paper to minimize idle times wasted during setup activities. However, other studies (e.g. Bergmilller, 2006; Faulkner and Badurdeen, 2014) have been adopted other different Lean tools and methods, such as Value Stream Mapping.

Regarding the Green model, this paper is focused on Carbon Footprint (CF) based on the calculation method proposed by Jeswiet and Kara (2008). CF was chosen because of its relevance for evaluation of manufacturing processes, further discussed.

The SMED is a Lean tool that contribute for the minimization of setup time by converting internal activities into external activities. Internal setup activities can be performed only when a machine is stopped, such as mounting or removing dies. External activities, such as transporting old dies to storage or conveying new dies to the machine, can be conducted while a machine is in operation. Therefore, by reducing idle times it can create more value for the manufacture of products (Shingo, 1985; Braglia, Frosolini and Gallo, 2016).

Application of SMED can also contribute to minimize inventory, transport, motion and waiting during setup activities, since its adoption contributes to save time, of both operator and machine levels (Santos, Wysk and Torres, 2014). The economic benefits derived from its implementation may vary depending on the purpose of each company. For example, a machine may be overloaded, and the purpose should be to increase its availability leaving more time available for production, and therefore, for more sales (Santos, Wysk and Torres, 2014).

Shingo (1996) has suggested four stages to apply SMED: preliminary stage, first stage, second stage and third stage (Figure 2). In the preliminary stage, internal and external setup activities are not distinguished, and they are represented by a single bar (red bar). Each activity that compose the total setup operation is timed and filmed and thoroughly analyzed, so in the first stage of SMED they are separated into internal setup (blue bar) and external setup (yellow bar).

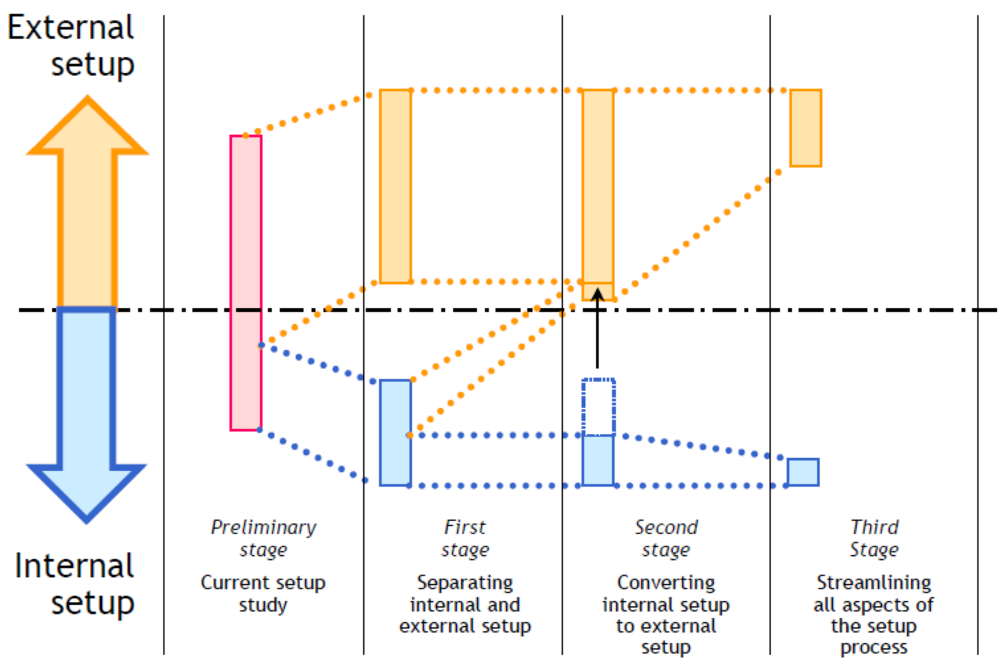


Figure 2. The four stages to apply SMED. (Shingo, 1996; Santos, Whisky and Torres, 2014).

In the second stage, internal setup activities are converted into external ones by re-examining operations to check whether any steps were wrongly assumed to be internal, and also to find ways to convert them into external activities. Lastly, the third stage is executed if the target setup time has been not reached yet. A standardization of activities should be performed to reduce time of the remaining internal and external setup activities (Shingo, 1996; Whisky and Torres, 2014).

Beyond a setup analysis, manufacturing systems also generate environmental impacts, for example, due to consumption of resources in manufacturing of products. Energy consumption is prominent in Green Manufacturing studies (Silva, Silva and Ometto, 2016), because it is essential for the manufacturing activities (e.g., robots use, machining, assembling, transport systems, activating peripherical for communication). Energy consumption is closely linked with CF because of GHG emissions to convert primary energy sources (fossil fuels, hydropower, biomass, etc.) into electricity and/or heat. There are many papers focusing on monitoring energy consumption (Abele et al. 2015; Filleti et al., 2014; Narita et al. 2006) or on simulating energy use in manufacturing (Zhao et al. 2015; Yan et al. 2010), as well as, on calculating CF in manufacture.

According to Cerutti et al. (2016), the Carbon Footprint allows a company to infer about the energetic efficiency associated with its manufacturing activity. The term Carbon Footprint is associated with the measurement of an amount of GHG emissions expressed in equivalent carbon dioxide ($CO_{2\text{-eq.}}$) that are generated directly or indirectly by a particular activity or product in a life cycle perspective. Carbon Footprint is one of the main tools currently adopted by companies towards a cleaner production, and CF results can be used to improve manufacturing processes to reduce GHG emissions not only in the production phase, but also in a life cycle perspective (e.g., in the use or post-use phases of a product) (Silva, Silva and Ometto, 2016).

Jeswiet and Kara (2008) proposed a Carbon Footprint procedure to be used in manufacturing level based on inventory data of electricity mix and consumption in production activities. This research is based on the methodology proposed by Jeswiet and Kara (2008) to calculate CF during the setup activities in the machining center. The CF step-by-step is detailed below:

- **Energy matrix**: it was used the energy mix in Table 1 based on information from the Statistical Yearbook of Electricity for 2016 baseline year. This report was developed and published by the Brazilian Ministry of Mines and Energy.
- **Carbon emissions calculation:** Jeswiet and Kara (2008) identify CES as the Carbon Emission Signature to measure the quantity of carbon generated by a fraction of fuel used in energy production, and whose measurement is expressed in kg CO_2/GJ. Carbon emissions (CE) can be found by multiplying the energy used (EC) by the carbon emission signature (CES), as shown in Equation 1.
- **Carbon emission signature:** to calculate CES it is necessary to know the percentages of primary energy (%) that compose the electrical mix that feeds the industrial machines and equipment in the company under study. The energy sources were hydroelectric power plants (H), biomass (B), petroleum products (P), natural gas (G), mineral coal (C), nuclear plants (N), wind plants (W) and others (O), meanly solar plants. In addition, it is necessary to know the respective values of enthalpy of formation for the CO_2 (ΔCO_2) coming from each of the energy sources represented by kilograms of carbon emitted by one giga joule of released heat. The yield (η) is also used in the CES calculation in Equation 2, following Jeswiet and Kara (2008) recommendation, $\eta = 0.34$.

Table 1: Brazilian electric mix in 2016

Type of fuel	(%)
Hydraulics	65.8
Natural Gas	9.8
Petroleum Products	2.1
Mineral Coal	2.9
Nuclear	2.7
Biomass	8.5
Wind	5.8
Other	2.4

Source: Ministry of Mines and Energy

$$\text{CF}\ (\text{kgCO}_2) = \text{EC}\ (\text{GJ}) \times \text{CES}\ \left(\frac{\text{kgCO}_2}{\text{GJ}}\right) \qquad (1)$$

$$\text{CES} = \eta \times \left[\left(\Delta\text{CO}_{2_H} \times x\%\text{H}\right) + \left(\Delta\text{CO}_{2_B} \times x\%\text{B}\right) + \left(\Delta\text{CO}_{2_P} \times x\%\text{P}\right) + \left(\Delta\text{CO}_{2_G} \times x\%\text{G}\right) + \left(\Delta\text{CO}_{2_C} \times x\%\text{C}\right) + \left(\Delta\text{CO}_{2_N} \times\right.\right.$$
(2)

To calculate ΔCO_2 for petroleum products, mineral coal and natural gas it was collected data found in the "Guidelines for National Greenhouse Gas Inventories (2006)" published by the Intergovernmental Panel on Climate Change (IPCC, 2006). For the hydraulics, nuclear, biomass, wind and other kinds of energy (solar), it was followed the values available in "Emissions from tropical hydropower and the IPCC" by Fearnside (2015). All this information can be found in Table 2.

Table 2: Kilograms of carbon emitted by one giga joule of released heat for each type of fuel.

Type of fuel	(Kg/GJ)
Hydraulics	1.4
Natural Gas	15.3
Petroleum Products	20.2
Mineral Coal	25.8
Nuclear	4.4
Biomass	5.0
Wind	3.3
Other	12.8

Source: IPCC (2006) and Fearnside (2015).

Finally, the last part of the Lean-Green model described on Figure 1 is the estimation of eco-efficiency indicators. According to Verfaille and Bidwell (2000), there are several ways in which eco-efficiency can be calculated, however, Equation 3 was used on this paper to calculate eco-efficiency (EE), because it is the most widely used form.

$$EE = \frac{Product\ value}{Environmental\ impact} \tag{3}$$

EE is used to analyze the data resulting from the SMED and CF applications for a set of setup activities of the company studied on this paper. The "Product value" is the quantity of manufactured goods or the number of services offered to clients and expressed in terms of mass, volumes, numbers, net sales, etc. The "Environmental impact" represents impacts that may influence the environment, such as GHG emissions.

Equation 3 was used in three different forms to combine the SMED with CF results, as described by Equations 3.1 to 3.3.

Equation 3.1 shows the product value represented by the total setup time in one trimester divided by the respective CF calculated during the setup activities for each scenario before and after SMED application. The purpose of this indicator is to measure the eco-efficiency involved only into the setup activities.

$$EE = \frac{Total\ setup\ \ hours\ in\ one\ semester}{Carbon\ emission\ during\ setup}\left(\frac{Hours}{gCO_2}\right) \tag{3.1}$$

Equation 3.2 is the second form for EE calculation used to compare eco-efficiency of both types of machines available in the machining sector of the evaluated company. For this, it was taken into consideration only the production times of all machines types and working at maximum capacity of production. EE was calculated by the total time of production in one trimester divided by the CF values for each machine tool in the same period.

$$EE = \frac{Total\ production\ hours\ in\ one\ trimester\ (for\ each\ type\ of\ machine)}{Carbon\ Emission\ during\ production\ (for\ each\ type\ of\ machine)}\left(\frac{Hours}{gCO_2}\right) \tag{3.2}$$

The values of power for each type of machine operating at maximum production capacity were obtained from their respective manuals, as nominal power. Data of nominal power was used to calculate energy consumption and CF, further described.

The last EE indicator is given by Equation 3.3 and it considers the total time gained with the reduction of setup activities after the SMED application in one trimester. All the setup time reduced will be converted into productive time for the machining sector. Further, CF was the total carbon emissions during setup and production at maximum production capacity for the machining sector in one trimester.

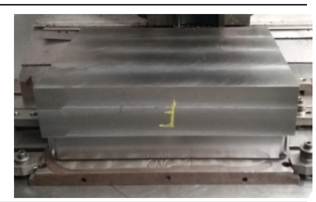
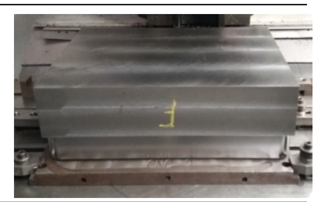
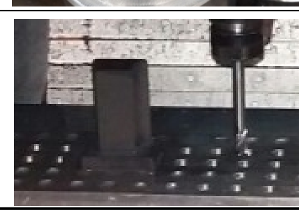
$$EE = \frac{Total\ production\ hours\ in\ one\ trimester\ (setup + production)}{Carbon\ Emission\ (setup + production)} \left(\frac{Hours}{gCO_2}\right) \qquad (3.3)$$

3. Results and discussion

3.1. Lean manufacturing: SMED application

The developed Lean-Green model was applied for five setup scenarios described on Table 3. Each scenario represents the use of different workpieces and/or different machines and operators (workers).

Table 3: Scenarios for application of the Lean-Green model.

Scenario	Operator	Machine	Workpiece	
1	**A**	FV-1300 Feeler	Steel block in rectangular format. **Dimensions:** 31,5 x 10,2 x 11,4 (in)	
2	**B**	Discovery 1250	Steel block in rectangular format. **Dimensions:** 31,5 x 10,2 x 11,4 (in)	
3	**C**	Discovery 1250	Steel block in rectangular format. **Dimensions:** 31,5 x 10,2 x 11,4 (in)	
4	**A**	FV-1300 Feeler	Cylindrical part. **Dimensions:** Ø9,8 x 19,7 (in)	
5	**C**	Discovery 1250	Small size graphite block. **Dimensions:** 3,1 x 1,8 x 5,0 (in)	

In the preliminary stage of SMED the setup activities were mapped as described in Table 4 for Scenario 1. All the remaining results for scenarios 2 to 5 were similar and they are available as electronic supplementary material in Appendix A.

After the preliminary stage of SMED, the mapped setup activities were classified as internal and external (step 1), and after that, some internal setup activities were converted into external setup activities (step 2). Results of steps 1 and 2 of SMED are given in Table 4 for scenario 1, while the remaining analyses for scenarios 2 to 5 can be found in Appendix B in the supplementary material.

Table 4: Application of Preliminary Step and Steps 1 and 2 of SMED – Scenario 1.

Workpiece:	Steel block in rectangular format	**Setup classification**
Machine:	ROMI FV-1300 Feeler model	**Internal Setup**
Operator:	A	**External setup**
Nº	**Activity**	**Timed intervals**
1	Opening Machine	00:00:12
2	Catching a broom and dustpan	00:01:46
3	Backing to the Machine	00:00:28
4	Clearing Machine	00:04:13
5	Picking up garbage cart	00:00:56
6	Putting garbage in cart	00:02:12
7	Taking cart to the bucket	00:01:08
8	Depositing trash in the bucket	00:01:23
9	Saving cart	00:00:36
10	Searching Cart to pick up parts and rolling bridge	00:00:34
11	Searching rolling bridge	00:00:26
12	Bringing rolling bridge and cart to place a workpiece	00:00:40
13	Removing machine table	00:01:05
14	Putting the workpiece in cart	00:00:40
15	Unpinning the workpiece of the bridge	00:00:19
16	Taking the workpiece to the preparation stand	00:00:17
17	Removing the magnet from the workpiece	00:00:02
18	Attaching hand hoist to the workpiece	00:00:27
19	Positioning the workpiece for air-cleaning	00:00:32
20	Clearing the workpiece	00:01:15
21	Putting workpiece on the bench	00:00:27
22	Removing the hook from the workpiece and attaching the bracket	00:00:03
23	Positioning stand on top of workpiece	00:00:09
24	Clearing workpiece and support	00:00:08
25	Coming down workpiece in support	00:00:06
26	Searching screws for securing the holder to the workpiece	00:00:25
27	Attaching the holder to the workpiece	00:02:40
28	Sanding holder	00:00:13
29	Attaching hand hoist to workpiece	00:00:53
30	Bringing workpiece to the machine	00:00:58
31	Saving hand hoist	00:00:30
32	Catching tools in the drawer	00:00:11
33	Putting clock	00:00:10
34	Positioning the workpiece	00:00:20
35	Removing part hook	00:00:13

36	Holding support	00:00:29
37	Aligning tool	00:01:21
38	Tightening screws	00:00:50
39	Aligning workpiece	00:04:26
40	Saving used tools	00:00:05
41	Removing clock	00:00:17
42	Positioning cutting tool	00:00:25
43	Putting cutting tool	00:00:08
44	Aligning cutting tool on the workpiece	00:00:55
Total Setup Time		00:35:33
Total Internal Setup Time		00:12:56
Total External Setup Time		00:22:37

In the first stage the total setup time was 35 minutes and 33 seconds, however, internal setup was reduced to 12 minutes and 56 seconds after converting some internal setup activities into external ones (step 2), representing a reduction of approximately 64%.

The remaining setup activities were examined aiming to find opportunities to reduce the setup time (step 3). Table 5 presents some suggestions of improvement for activity 4 (cleaning the machine) and activities 37, 39 and 44 (related to resetting and standardizing the workpiece to be machined) and an expectation of reduced setup time that would be gained after their implementation.

Table 5: Application of Step 3 of SMED – Scenario 1.

<table>
<tr><th>Nº</th><th>Activity</th><th>Improvement</th><th>Current time</th><th>Time after improvement</th><th>Reduced time</th></tr>
<tr><td>4</td><td>Cleaning</td><td>Allocate another operator to help with this activity. Investment: Zero. Idle operators in the same sector can be allocated on this process.</td><td>00:04:13</td><td>00:02:07</td><td>50%</td></tr>
<tr><td>37</td><td>Aligning tool</td><td rowspan="3">Changing work procedure: Current: Alignment is realized with feeler clock and shim. Propose: Use of a pre-set tool with clock and magnetic base. Investment: $255.00</td><td>00:01:21</td><td rowspan="3">00:00:20</td><td>75%</td></tr>
<tr><td>39</td><td>Aligning workpiece</td><td>00:04:26</td><td>92%</td></tr>
<tr><td>44</td><td>Aligning cutting tool on the workpiece</td><td>00:00:55</td><td>64%</td></tr>
</table>

After improving setup activities according to the list of suggestions from Table 5, it should be achieved a total reduction of around 86% in the total setup time, i.e., from 35 minutes and 33 seconds to 5 minutes and 8 seconds. The same suggestions described on Table 5 were also adopted for scenarios 2 to 5. On this sense, Figure 3 shows the SMED results for scenarios 1 to 5 in terms of avoided time (in minutes) with setup activities.

Figure 3 shows that after SMED application all setup activities were drastically reduced to around 5 minutes for scenarios 1 and 2, about 10 minutes for scenarios 3 and 4, and 8 minutes for scenario 5. Scenario 1 showed a total setup time reduction of 86%, while scenarios 2 and 3 showed, respectively, 88% and 77% of setup time minimization. For scenarios 4 and 5, the time decrease in 76% and 71%, respectively. Therefore, more than 70% of setup time was reduced during the SMED application for all types of machines, workpieces and operators.

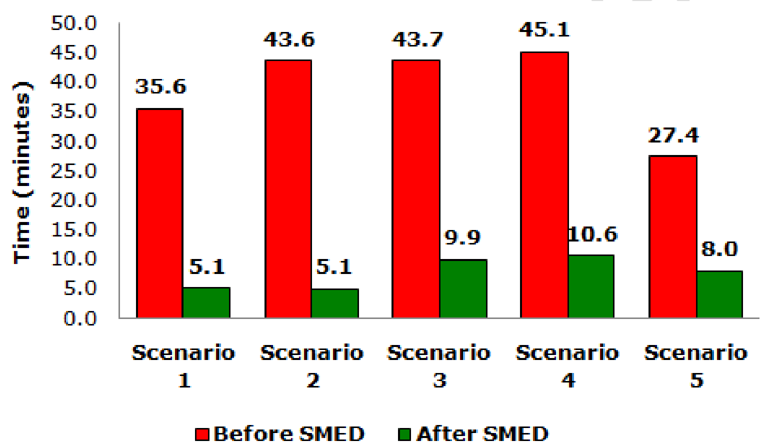


Figure 3. Comparison of the SMED results for each scenario.

It was also analyzed the total time spent with setup activities in the last trimester of 2016 for the machining sector under investigation. Results are expressed in Figure 4 in terms of an aggregated comparison before and after the SMED application. It is important to note that 71% of the total number of setups were performed for rectangular workpieces, while 18% were for cylindrical parts, and 11% for small-sized parts.

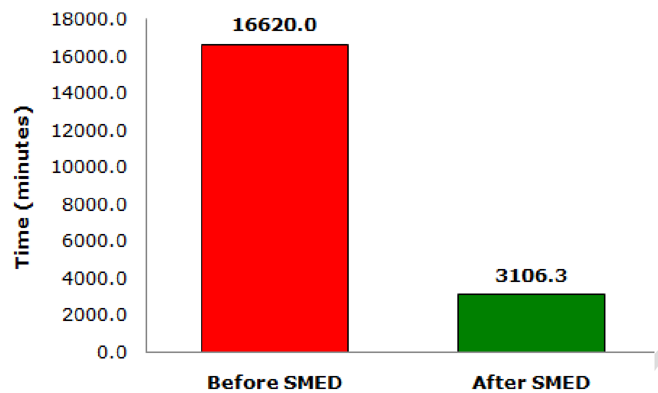


Figure 4. Comparison of the SMED results for the last quarter of 2016.

Figure 4 shows that 13513.7 minutes (225.3 hours) of setup activities were avoided in the machining sector after the SMED application. Such number is equivalent to approximately 25 days of production for the machining center considering that a day of work is a 9 hour shift. Such waste of time with setup activities also contributes to the generation of environmental impacts in the production system, further discussed on section 3.2. Finally, it is also important to note that a better work environment was created for workers after SMED, by reducing stress and discontent, as well as avoiding wasting of resources and creating more value with less environmental impact in the shop-floor.

3.2. Green manufacturing: Carbon footprint

To measure CF related to the setup activities, it was necessary to find the CES, following Equation 2. The CES was 1.58 kg CO_2/GJ, as detailed bellow:

$$\begin{aligned} \mathrm{CES} &= 0.34 \text{ x } [(1.4 \text{ x } 0.658) + (15.3 \text{ x } 0.098) + (20.2 \text{ x } 0.021) + (25.8 \text{ x } 0.029) \\ &+ (4.4 \text{ x } 0.027) + (5.0 \text{ x } 0.085) + (3.3 \text{ x } 0.058) + (12.8 \text{ x } 0.024)] \\ &= 1.58 \frac{\mathrm{kgCO_2}}{\mathrm{GJ}} \end{aligned}$$

With the CES value, it was necessary to find the energy consumed by the machines during the setup activities for scenarios 1 to 5. So, it was measured the electrical current consumed by each machine for each scenario under evaluation. The reference situation for the setup was the measurement of energy when each machine was only activated, i.e., running in standby mode, which represents what happens during the internal setup activities. All the two types of machine tools were analyzed by using an ammeter to measure the electrical current, and the result was around 1.5A, with no representative differences according to the machine tool model under investigation.

After measuring the electrical current (I) for the standby mode, it was calculated the power consumed by each machine by using Equation 4, where P represents power demand (in watts), and V is the nominal voltage (220 V).

$$P = V \times I \tag{4}$$

The result was P = 330 watts for both machines in idle mode, since they both show the same current when in standby, and 1 watt is equal to 1 Joule per second (J/s), the power was equals to 330 J/s or 3.3×10^{-7} GJ/s. Finally, it was calculated the CF by using Equation 1, as follows:

$$CF = 3.3 \times 10^{-7} GJ \times 1.58 \; kgCO_2/GJ = 5.2 \times 10^{-7} \; kgCO_2/s$$

Figure 5 shows results of the total CF before and after the SMED application for the machining sector during one trimester, including all the five scenarios under analysis.

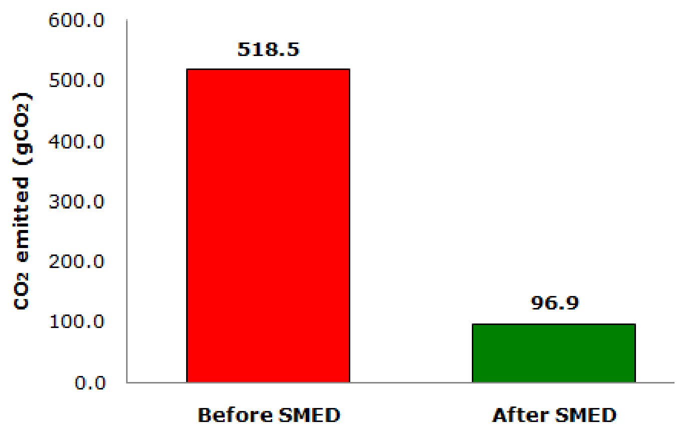


Figure 5. Carbon footprint before and after the SMED application in the last quarter of 2016.

It can be seen in Figure 5 that the company has generated 518.5 g of CO_2 before the SMED application, and only 96.9 g of CO_2 after applying the SMED, reducing around 81% of the carbon footprint.

For comparison purposes between the two machine models, which use the same electrical current during setup activities (i.e., 1.5 A), it was measured the carbon footprint for both machines also during the machining process itself for each of the five scenarios under investigation. To this end, it was assumed the maximum current available consumed by the machine's motors according to the manufacturer's manuals. According to the data supplied by the machines manufacturers, the FV-1300 Feeler model can achieve up to 50 A of electrical current, and the Discovery 1250 model can reach up to 23 A.

Consequently, the Discovery 1250 model would emit 0.008 g of CO_2 for each second of operation, while the FV-1300 Feeler model would emit 0.017 g of CO_2/s. Thus, the FV-1300 Feeler model would generate more than two times more carbon emissions than the Discovery 1250 model, and this also brings some implications in terms of eco-efficiency results, described on section 3.3.

3.3. Eco-efficiency

Eco-efficiency (EE) results are showed in Figure 6 based on application of Equation 3.1. For this, it was combined results of setup time before and after SMED application and CF calculation. All the EE results are expressed in hours/gCO_2 for one trimester of the machining center operation during setup activities.

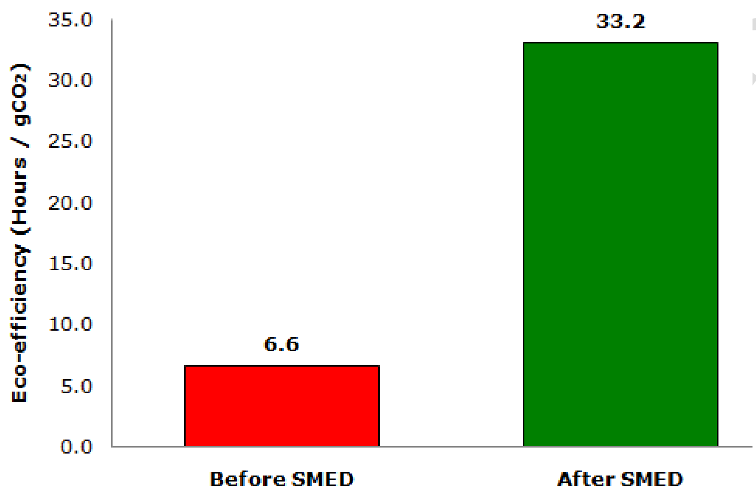


Figure 6. Eco-efficiency results before and after SMED for the last quarter of 2016 – an overview.

The EE indicator shows an expressive eco-efficiency improvement after SMED application, approximately five times higher than before SMED. However, the total setup time must be converted into productive time, otherwise the EE result after SMED in Figure 3 will be just a mirage.

Thus, Figure 7 shows EE results for one trimester by using Equation 3.3, considering the saved time after SMED application converted into productive time to generate an increase in production capacity for the machining center. Furthermore, it was assumed results of CF for both machine tools when they are working on and are not in standby mode, i.e., 0.008 g of CO_2/s for the Discovery 1250 model, and 0.017 g of CO_2/s for the FV-1300 Feeler model.

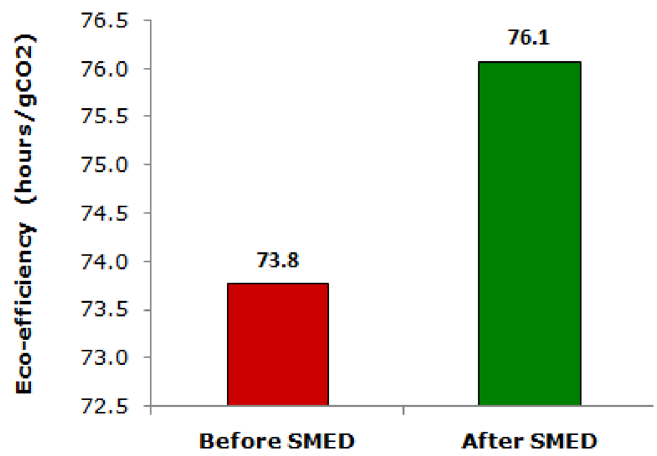


Figure 7. Eco-efficiency results before and after SMED application for the last quarter of 2016 – setup time converted into productive time

CF results if the machine tools are in standby mode will be $0.52 x 10^{-7}$ $kgCO_2/s$ (see section 3.2 again), while if the machine tools are working on, the CF results would increase to $1.73 x 10^{-6}$ $kgCO_2/s$ for Discovery 1250 model and $0.79 x 10^{-5}$ $kgCO_2/s$ for FV-1300 Feeler model. Results on Figure 7 shows higher values of EE than compared to Figure 6, because all setup time were converted into productive time. However, percentage differences were only around 3% before and after SMED application due to the higher values of carbon emissions when the machine tools are working on.

In order to investigate effects of each machine tool into EE results from Figure 7, a final comparison is given for the two machine tools in relation to their eco-efficiency based on Equation 3.2. On this case, results are given for one trimester and with both machines operating at maximum capacity of production.

Results in Figure 8 show Discovery 1250 model with higher EE results, therefore, it was the most eco-efficient machine tool to be used in the machining center under investigation, with an EE result more than twice higher than the FV-1300 Feeler model. The EE indicator can serve as a parameter for the evaluated company to invest in a future acquisition of new machinery, for example, towards a cleaner production.

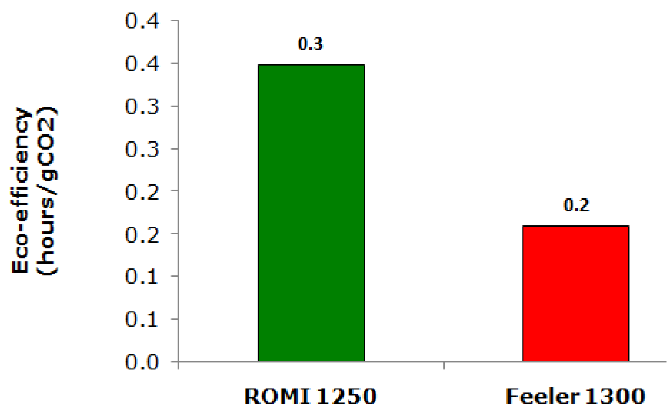


Figure 8. Eco-efficiency results between the two types of machine tools.

Eco-efficiency indicators are being used more and more by global organizations with the concept of "doing more with less". The EE studies, in a holistic way, were not very often in literature, but they have become more popular in the last few years. Some of them highlight data for managers' decision-making, for example, Davé et al. (2016) applied EE to the creation of a new furniture factory based on the production divided by the resources consumption. Another recent study of Davé, Ball and Salonitis (2017) point out a simulation model that represents all the production cells of a company by calculating EE indicators to improve energy consumption at factory level.

These are some examples of EE indicators created to guide decision making in production systems toward a cleaner production, and the current research also contributes on that aspect by the combination of SMED and CF results in a Lean-Green model.

4. Conclusion

This paper shows the importance of lean and green manufacturing practices combined in a Lean-Green model for optimization of processes and reduction of wastes through a case study research in Brazil. The aim was to reduce time and resources wastes, and to reduce the emission of GHG releases, improving the company's eco-efficiency and showing the contributions of the Lean-Green in an integrated approach.

Additionally, this paper highlighted how simple can be the implementation of SMED integrated with CF to calculate eco-efficiency into setup activities from the manufacture of products. The proposed Lean-Green model is still not widely explored in literature, and this paper can contribute to fill this gap and enhance knowledge on that aspect.

The results of this study show that the use of SMED, a lean tool, integrated with CF calculation were satisfactory, as there was a significant reduction into setup times, carbon footprint and improvements in eco-efficiency for all the five scenarios under investigation. More than 70% of setup time was reduced during the SMED application for all types of machines, workpieces and operators, and 81% of carbon footprint was reduced after SMED application.

By increasing production time, the machines will demand higher power levels because they are not in standby mode anymore. Thus, it was noticed a trade-off between carbon footprint and SMED application related to the increase of productive time when setup time is converted into productive time. In this case, machines will be not in standby mode, therefore, increasing the factory's carbon footprint due to the higher energy consumption to produce more products than before the SMED. However, the production for the last trimester of 2016 was analyzed in the case study, and eco-efficiency results were still 3% higher than before the SMED application.

The developed Lean-Green model should be used by companies with low-capacity of production due to restrictions of machine availability. Thus, more case studies are desired to test its application in a wider variety of companies and production systems. Further, the Lean-Green model could be improved by integrating more Lean and Green tools and techniques to become a model with a broader use by cleaner production researchers. Also, the CF calculation was focused on the proposal of Jeswiet and Kara (2008), however, it could be explored to include also carbon emissions due to materials consumption in manufacturing, and also in a complete life cycle perspective (cradle-to-grave).

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Appendix A

Table A.1: Preliminary Step of SMED – Scenario 2.

Workpiece:	Steel block in rectangular format	
Machine:	ROMI Discovery 1250 machine	
Nº	**Activity**	**Timed intervals**
1	Opening Drawer	00:00:02
2	Catching Cleaner	00:00:05
3	Going to the machine	00:00:03
4	Cleaning the machine table	00:02:23
5	Picking up garbage cart	00:00:43
6	Putting garbage in cart	00:01:57
7	Taking cart to the bucket	00:00:53
8	Depositing trash in the bucket	00:00:23
9	Saving Cart	00:00:45
10	Going to theDrawer	00:00:03
11	Saving Cleaner	00:00:02
12	Going to the cart	00:00:12
13	Taking cart to the workpiece	00:00:21
14	Picking up workpiece in cart	00:00:16
15	Taking cart to the preparation table	00:00:26
16	Going to the Manual Hoist	00:00:13
17	Disconnecting Hand Hoist	00:00:03
18	Carring Hand Hoist to the preparation table	00:00:21
19	Catching chain	00:00:04
20	Putting chain in hoist	00:00:06
21	Picking up the magnet on the preparation table	00:00:03
22	Putting magnet on workpiece	00:00:05
23	Putting chain on piece	00:00:07
24	Moving the workpiece up to the table	00:00:12
25	Removing Chain and Magnet from Workpiece	00:00:08
26	Turning the workpiece	00:00:11
27	Catching holder	00:00:43
28	Inserting magnet into holder	00:00:05
29	Putting the holder on top of the workpiece	00:00:25
30	Taking out chain and magnet from holder	00:00:11
31	Searching Screws in Drawer	00:01:14
32	Screwing the bracket on the workpiece	00:02:38
33	Attaching magnet to workpiece	00:00:07
34	Attachingchain to workpiece	00:00:03
35	Taking piece to machine	00:00:57
36	Backing to top workpiece	00:00:23
37	Catching cloth	00:00:14
38	Cleaning workpiece	00:00:34
39	Calling another operator	00:00:26
40	Coming down workpiece on the machine table	00:00:17
41	Fiting workpiece in machining position	00:00:16
42	Remove magnet and chain from workpiece	00:00:09
43	Bringing magnet and chain to the preparation table	00:00:32
44	Saving hoist	00:00:47
45	Positioning screws to secure the workpiece to the holder	00:00:16
46	Catching the key to tighten screws	00:00:13

47	Tightening screws	00:02:11
48	Searching Clock with another operator	00:00:34
49	Putting Clock in the machine	00:00:09
50	Aligning Workpiece	00:05:12
51	Removing Clock	00:00:08
52	Saving Clock	00:00:14
53	Picking up cutting tool in the sharpening sector	00:00:54
54	Putting Tool on Machine	00:00:13
55	Catching cloth	00:00:03
56	Cleaning workpiece	00:00:10
57	Machining Clean and Lubricate Workpiece	00:09:32
58	Aligning Workpiece	00:03:41
Total Setup Time		00:43:38

Table A.2: Preliminary Step of SMED – Scenario 3.

Workpieace:	Steel block in rectangular format	
Machine:	ROMI Discovery 1250 machine	
Nº	**Activity**	**Timed intervals**
1	Catching a broom	00:00:12
2	Cleaning Machine	00:02:12
3	Picking up garbage cart	00:00:41
4	Putting garbage in cart	00:03:02
5	Taking cart to the bucket	00:00:42
6	Depositing trash in the bucket	00:00:56
7	Saving Cart	00:00:27
8	Picking up workpiece cart	00:00:14
9	Taking cart to the workpiece location	00:00:27
10	Searching Rolling Bridge	00:00:16
11	Taking Rolling Bridge to the workpiece location	00:00:21
12	Attaching the bridge to the workpiece	00:00:11
13	Removing Pallet workpiece	00:00:18
14	Putting workpiece on pallet next to	00:00:12
15	Taking pallet with the workpiece to be used with the cart	00:00:08
16	Taking cart with the workpiece to the preparation table	00:00:24
17	Picking up manual hoist	00:00:16
18	Putting chain in hoist	00:00:09
19	Taking manual hoist to the preparation table	00:00:23
20	Putting magnet and chain in the workpiece	00:00:04
21	Moving up workpiece	00:00:08
22	Cleaning workpiece	00:00:06
23	Putting Workpiece on the table	00:00:05
24	Removing magnet and chain from workpiece	00:00:11
25	Putting magnet and chain into the holder	00:00:18
26	Raising the holder above the workpiece	00:00:10
27	Putting holder on top of workpiece	00:00:06
28	Removing magnet and chain from holder	00:00:08
29	Going to the workbench	00:00:12
30	Choosing screws	00:00:26
31	Backing to the preparation table	00:00:11
32	Attaching bracket to the workpiece with screws	00:02:30
33	Putting magnet and chain in the workpiece	00:00:13
34	Moving up workpiece with holder	00:00:05
35	Turning workpiece with holder	00:00:21

36	Coming down workpiece on the table machine	00:00:05
37	Removing the magnet and chain from the side of the workpiece	00:00:08
38	Attaching magnet and chain over the workpiece	00:00:11
39	Moving up workpiece	00:00:06
40	Taking workpiece to machine	00:00:23
41	Calling another operator	00:00:14
42	Catching cloth	00:00:05
43	Cleaning underneath workpiece and table	00:00:12
44	Positioning workpiece above the machine table	00:00:16
45	Coming down workpiece to the machine	00:00:07
46	Removing Magnet and Drive Chain	00:00:05
47	Saving Hand Hoist	00:00:19
48	Catching air	00:00:04
49	Cleaning workpiece with air	00:00:09
50	Saving air	00:00:03
51	Positioning fastening screws on the workpiece	00:00:17
52	Hand tightening of fastening screws	00:00:34
53	Picking up key from stand	00:00:03
54	Tightening bolts with wrench	00:00:48
55	Saving key to workbench	00:00:04
56	Picking up clock in the drawer	00:00:02
57	Taking clock to machine	00:00:02
58	Setting Clock on the Machine	00:00:14
59	Aligning Workpiece	00:07:47
60	Taking the Machine Clock	00:00:08
61	Reading process to set cutting tool	00:00:06
62	Taking specified cutting tool	00:00:14
63	Aligning Toolhead	00:00:19
64	Removing Previous Tool	00:00:07
65	Putting new Tool	00:00:09
66	Aligning program and position tool	00:00:32
67	Adjusting grease jet	00:00:08
68	Switching on lubrication	00:00:03
69	Machining Workpiece to Clean	00:07:18
70	Aligning Workpiece	00:05:34
Total Setup Time		00:43:41

Table A.3: Preliminary Step of SMED – Scenario 4.

Workpiece:	Cylindrical format workpiece	
Machine:	ROMI FV-1300 Feeler model	
Nº	**Activity**	**Timed intervals**
1	Opening bench vise	00:00:18
2	Searching Screwdriver	00:00:07
3	Loosening Screws	00:00:11
4	Saving Screwdriver	00:00:06
5	Cleaningyour Hand	00:00:03
6	Going to the fork-lift	00:00:09
7	Positioning the forklift on top of the machine	00:00:25
8	Coming down forklift	00:00:01
9	Catching the Chain	00:00:05
10	Attaching the Chain to the Workpiece	00:00:07

11	Backing to the forklift	00:00:04
12	Moving up workpiece	00:00:12
13	Going to the machine	00:00:02
14	Packing the chain in the Workpiece	00:00:04
15	Returning to the forklift	00:00:03
16	Moving up workpiece	00:00:18
17	Going to the machine	00:00:02
18	Taking Air Hose	00:00:02
19	Cleaning workpiece with air	00:00:07
20	Saving Air Hose	00:00:01
21	Catching the Cleaner	00:00:01
22	Cleaning the Workbench to put Another Workpiece	00:00:14
23	Saving the Cleaner	00:00:01
24	Catching cloth	00:00:01
25	Cleaning the Workbench to put Another Workpiece	00:00:05
26	Saving cloth	00:00:01
27	Going to the forklift	00:00:05
28	Calling other operator	00:00:08
29	Giving instructions to the other operator	00:00:11
30	Moving up workpiece	00:00:04
31	Taking Workpiece to Bench	00:00:34
32	Removing Workpiece Chain	00:00:03
33	Positioning the forklift to pick up another workpiece	00:00:09
34	Putting Chain in the workpiece	00:00:04
35	Taking workpiece to machine	00:00:44
36	Catching the Air Hose	00:00:02
37	Cleaning workpiece with air	00:00:12
38	Saving Air Hose	00:00:02
39	Moving up workpiece	00:00:21
40	Removing Workpiece Chain	00:00:04
41	Moving upforklift	00:00:12
42	Saving forklift	00:00:36
43	Returning to the machine	00:00:16
44	Removing Workpiece Holder	00:00:04
45	Saving Holder	00:00:05
46	Searching Screwdriver	00:00:04
47	Putting Screwdriver in the bench vise	00:00:02
48	Positioning workpiece on bench vise	00:00:14
49	Tightening bench vise	00:00:07
50	Catching chock	00:00:09
51	Supporiting workpiece with chock	00:00:12
52	Tightening bench vise	00:11:00
53	Saving Chock and Screwdriver	00:00:05
54	Catching other Screwdriver	00:00:02
55	Tightening screws	00:00:15
56	Searching clock	00:00:34
57	Putting clock in the machine	00:00:06
58	Aligning Workpiece	00:02:59
59	Re,moving clock	00:00:03
60	Saving clock	00:00:04
61	Adjusting Toolhead	00:00:17
62	Removing Tool	00:00:07
63	Catching other Tool	00:00:04
64	Putting Tool	00:00:15

65	Aligning Tool	00:00:12
66	Switching on lubrication and Aligning Workpiece	00:13:54
67	Machining Workpiece to Clean	00:06:21
68	Aligning Workpiece	00:01:13
Total Setup Time		00:45:05

Table A.4: Preliminary Step of SMED – Scenario 5.

Workpiece:	Small size graphite block	
Machine:	ROMI Discovery 1250 machine	
Nº	**Activity**	**Timed intervals**
1	Cleaning machine table	00:00:24
2	Searching for graphite in stock	00:02:56
3	Bringing graphite to the preparation table	00:00:18
4	Going to the manual hoist	00:00:06
5	Turning off manual hoist	00:00:02
6	Bringing manual hoist to the preparation table	00:00:26
7	Going to the preparation table	00:00:09
8	Catching chain and magnet	00:00:04
9	Bringing chain and magnet to the machine	00:00:08
10	Attaching magnet to workpiece	00:00:05
11	Attachingchain to magnet	00:00:04
12	Moving up manual hoist	00:00:14
13	Attaching chain to manual hoist	00:00:02
14	Removingholder from machine	00:00:06
15	Bringing hoist to the preparation table	00:00:19
16	Moving up holder in the table	00:00:06
17	Putting graphite on the holder	00:00:02
18	Catching screw	00:00:25
19	Screwing graphite into the holder	00:01:28
20	Putting magnetoon the holder	00:00:03
21	Putting chain on the magnet	00:00:02
22	Bringing workpiece to the machine	00:00:24
23	Moving up workpiece	00:00:12
24	Positioning workpiece on the machine table	00:00:16
25	Catching airflow	00:00:04
26	Cleaning holder and table machine with air	00:00:23
27	Coming down on the machine table	00:00:08
28	Saving Manual hoist	00:00:36
29	Positioning the mounting bracket screws	00:00:17
30	Catching Screwdriver	00:00:08
31	Tightening screws	00:00:46
32	Saving Screwdriver	00:00:05
33	Searching clock	00:00:13
34	Putting clock in the machine	00:00:09
35	Aligning Workpiece	00:06:58
36	Removing clock	00:00:07
37	atching Tool	00:00:16
38	Putting Tool	00:00:10
39	Adjusting airflow	00:00:12
40	Machining Workpiece to Clean	00:03:14
41	Aligning Workpiece	00:05:18
Total Setup Time		00:27:25

Appendix B

Table B.1: Application of Steps 1 and 2 of SMED – Scenario 2.

Workpiece:	Steel block in rectangular format	**Setup classification**
Machine:	ROMI Discovery 1250 machine	**Internal Setup**
Operator:	B	**External setup**
Nº	**Activity**	**Timed intervals**
1	Opening Drawer	00:00:02
2	Catching Cleaner	00:00:05
3	Going to the machine	00:00:03
4	Cleaning the machine table	00:02:23
5	Picking up garbage cart	00:00:43
6	Putting garbage in cart	00:01:57
7	Taking cart to the bucket	00:00:53
8	Depositing trash in the bucket	00:00:23
9	Saving Cart	00:00:45
10	Going to theDrawer	00:00:03
11	Saving Cleaner	00:00:02
12	Going to the cart	00:00:12
13	Taking cart to the workpiece	00:00:21
14	Picking up workpiece in cart	00:00:16
15	Taking cart to the preparation table	00:00:26
16	Going to the Manual Hoist	00:00:13
17	Disconnecting Hand Hoist	00:00:03
18	Carring Hand Hoist to the preparation table	00:00:21
19	Catching chain	00:00:04
20	Putting chain in hoist	00:00:06
21	Picking up the magnet on the preparation table	00:00:03
22	Putting magnet on workpiece	00:00:05
23	Putting chain on piece	00:00:07
24	Moving the workpiece up to the table	00:00:12
25	Removing Chain and Magnet from Workpiece	00:00:08
26	Turning the workpiece	00:00:11
27	Catching holder	00:00:43
28	Inserting magnet into holder	00:00:05
29	Putting the holder on top of the workpiece	00:00:25
30	Taking out chain and magnet from holder	00:00:11
31	Searching Screws in Drawer	00:01:14
32	Screwing the bracket on the workpiece	00:02:38
33	Attaching magnet to workpiece	00:00:07
34	Attachingchain to workpiece	00:00:03
35	Taking piece to machine	00:00:57
36	Backing to top workpiece	00:00:23
37	Catching cloth	00:00:14
38	Cleaning workpiece	00:00:34
39	Calling another operator	00:00:26
40	Coming down workpiece on the machine table	00:00:17
41	Fiting workpiece in machining position	00:00:16
42	Remove magnet and chain from workpiece	00:00:09
43	Bringing magnet and chain to the preparation table	00:00:32
44	Saving hoist	00:00:47

45	Positioning screws to secure the workpiece to the holder	00:00:16
46	Catching the key to tighten screws	00:00:13
47	Tightening screws	00:02:11
48	Searching Clock with another operator	00:00:34
49	Putting Clock in the machine	00:00:09
50	Aligning Workpiece	00:05:12
51	Removing Clock	00:00:08
52	Saving Clock	00:00:14
53	Picking up cutting tool in the sharpening sector	00:00:54
54	Putting Tool on Machine	00:00:13
55	Catching cloth	00:00:03
56	Cleaning workpiece	00:00:10
57	Machining Clean and Lubricate Workpiece	00:09:32
58	Aligning Workpiece	00:03:41
Total Setup Time		00:43:38
Total Internal Setup Time		00:15:28
Total External Setup Time		00:28:10

Table B.2: Application of Steps 1 and 2 of SMED – Scenario 3.

Workpiece:	Steel block in rectangular format	**Setup classification**
Machine:	ROMI Discovery 1250 machine	**Internal Setup**
Operator:	C	**External setup**
Nº	**Activity**	**Timed intervals**
1	Catching a broom	00:00:12
2	Cleaning Machine	00:02:12
3	Picking up garbage cart	00:00:41
4	Putting garbage in cart	00:03:02
5	Taking cart to the bucket	00:00:42
6	Depositing trash in the bucket	00:00:56
7	Saving Cart	00:00:27
8	Picking up workpiece cart	00:00:14
9	Taking cart to the workpiece location	00:00:27
10	Searching Rolling Bridge	00:00:16
11	Taking Rolling Bridge to the workpiece location	00:00:21
12	Attaching the bridge to the workpiece	00:00:11
13	Removing Pallet workpiece	00:00:18
14	Putting workpiece on pallet next to	00:00:12
15	Taking pallet with the workpiece to be used with the cart	00:00:08
16	Taking cart with the workpiece to the preparation table	00:00:24
17	Picking up manual hoist	00:00:16
18	Putting chain in hoist	00:00:09
19	Taking manual hoist to the preparation table	00:00:23
20	Putting magnet and chain in the workpiece	00:00:04
21	Moving up workpiece	00:00:08
22	Cleaning workpiece	00:00:06
23	Putting Workpiece on the table	00:00:05
24	Removing magnet and chain from workpiece	00:00:11
25	Putting magnet and chain into the holder	00:00:18
26	Raising the holder above the workpiece	00:00:10
27	Putting holder on top of workpiece	00:00:06
28	Removing magnet and chain from holder	00:00:08
29	Going to the workbench	00:00:12
30	Choosing screws	00:00:26

31	Backing to the preparation table	00:00:11
32	Attaching bracket to the workpiece with screws	00:02:30
33	Putting magnet and chain in the workpiece	00:00:13
34	Moving up workpiece with holder	00:00:05
35	Turning workpiece with holder	00:00:21
36	Coming down workpiece on the table machine	00:00:05
37	Removing the magnet and chain from the side of the workpiece	00:00:08
38	Attaching magnet and chain over the workpiece	00:00:11
39	Moving up workpiece	00:00:06
40	Taking workpiece to machine	00:00:23
41	Calling another operator	00:00:14
42	Catching cloth	00:00:05
43	Cleaning underneath workpiece and table	00:00:12
44	Positioning workpiece above the machine table	00:00:16
45	Coming down workpiece to the machine	00:00:07
46	Removing Magnet and Drive Chain	00:00:05
47	Saving Hand Hoist	00:00:19
48	Catching air	00:00:04
49	Cleaning workpiece with air	00:00:09
50	Saving air	00:00:03
51	Positioning fastening screws on the workpiece	00:00:17
52	Hand tightening of fastening screws	00:00:34
53	Picking up key from stand	00:00:03
54	Tightening bolts with wrench	00:00:48
55	Saving key to workbench	00:00:04
56	Picking up clock in the drawer	00:00:02
57	Taking clock to machine	00:00:02
58	Setting Clock on the Machine	00:00:14
59	Aligning Workpiece	00:07:47
60	Taking the Machine Clock	00:00:08
61	Reading process to set cutting tool	00:00:06
62	Taking specified cutting tool	00:00:14
63	Aligning Toolhead	00:00:19
64	Removing Previous Tool	00:00:07
65	Putting new Tool	00:00:09
66	Aligning program and position tool	00:00:32
67	Adjusting grease jet	00:00:08
68	Switching on lubrication	00:00:03
69	Machining Workpiece to Clean	00:07:18
70	Aligning Workpiece	00:05:34
Total Setup Time		00:43:41
Total Internal Setup Time		00:26:59
Total External Setup Time		00:16:42

Table B.3: Application of Steps 1 and 2 of SMED – Scenario 4.

Workpiece:	Cylindrical format workpiece	**Setup classification**
Machine:	ROMI FV-1300 Feeler model	**Internal Setup**
Operator:	A	**External setup**
Nº	**Activity**	**Timed intervals**
1	Opening bench vise	00:00:18
2	Searching Screwdriver	00:00:07
3	Loosening Screws	00:00:11
4	Saving Screwdriver	00:00:06

5	Cleaningyour Hand	00:00:03
6	Going to the fork-lift	00:00:09
7	Positioning the forklift on top of the machine	00:00:25
8	Coming down forklift	00:00:01
9	Catching the Chain	00:00:05
10	Attaching the Chain to the Workpiece	00:00:07
11	Backing to the forklift	00:00:04
12	Moving up workpiece	00:00:12
13	Going to the machine	00:00:02
14	Packing the chain in the Workpiece	00:00:04
15	Returning to the forklift	00:00:03
16	Moving up workpiece	00:00:18
17	Going to the machine	00:00:02
18	Taking Air Hose	00:00:02
19	Cleaning workpiece with air	00:00:07
20	Saving Air Hose	00:00:01
21	Catching the Cleaner	00:00:01
22	Cleaning the Workbench to put Another Workpiece	00:00:14
23	Saving the Cleaner	00:00:01
24	Catching cloth	00:00:01
25	Cleaning the Workbench to put Another Workpiece	00:00:05
26	Saving cloth	00:00:01
27	Going to the forklift	00:00:05
28	Calling other operator	00:00:08
29	Giving instructions to the other operator	00:00:11
30	Moving up workpiece	00:00:04
31	Taking Workpiece to Bench	00:00:34
32	Removing Workpiece Chain	00:00:03
33	Positioning the forklift to pick up another workpiece	00:00:09
34	Putting Chain in the workpiece	00:00:04
35	Taking workpiece to machine	00:00:44
36	Catching the Air Hose	00:00:02
37	Cleaning workpiece with air	00:00:12
38	Saving Air Hose	00:00:02
39	Moving up workpiece	00:00:21
40	Removing Workpiece Chain	00:00:04
41	Moving upforklift	00:00:12
42	Saving forklift	00:00:36
43	Returning to the machine	00:00:16
44	Removing Workpiece Holder	00:00:04
45	Saving Holder	00:00:05
46	Searching Screwdriver	00:00:04
47	Putting Screwdriver in the bench vise	00:00:02
48	Positioning workpiece on bench vise	00:00:14
49	Tightening bench vise	00:00:07
50	Catching chock	00:00:09
51	Supporiting workpiece with chock	00:00:12
52	Tightening bench vise	00:11:00
53	Saving Chock and Screwdriver	00:00:05
54	Catching other Screwdriver	00:00:02
55	Tightening screws	00:00:15
56	Searching clock	00:00:34
57	Putting clock in the machine	00:00:06
58	Aligning Workpiece	00:02:59

59	Removing clock	00:00:03
60	Saving clock	00:00:04
61	Adjusting Toolhead	00:00:17
62	Removing Tool	00:00:07
63	Catching other Tool	00:00:04
64	Putting Tool	00:00:15
65	Aligning Tool	00:00:12
66	Switching on lubrication and Aligning Workpiece	00:13:54
67	Machining Workpiece to Clean	00:06:21
68	Aligning Workpiece	00:01:13
Total Setup Time		00:45:05
Total Internal Setup Time		00:32:53
Total External Setup Time		00:12:12

Table B.4: Application Step 1 and 2.Internal and External Setup Separation. Scenario 5.

Workpiece:	Small size graphite block	**Setup classification**
Machine:	ROMI Discovery 1250 machine	**Internal Setup**
Operator:	C	**External setup**
Nº	**Activity**	**Timed intervals**
1	Cleaning machine table	00:00:24
2	Searching for graphite in stock	00:02:56
3	Bringing graphite to the preparation table	00:00:18
4	Going to the manual hoist	00:00:06
5	Turning off manual hoist	00:00:02
6	Bringing manual hoist to the preparation table	00:00:26
7	Going to the preparation table	00:00:09
8	Catching chain and magnet	00:00:04
9	Bringing chain and magnet to the machine	00:00:08
10	Attaching magnet to workpiece	00:00:05
11	Attachingchain to magnet	00:00:04
12	Moving up manual hoist	00:00:14
13	Attaching chain to manual hoist	00:00:02
14	Removingholder from machine	00:00:06
15	Bringing hoist to the preparation table	00:00:19
16	Moving up holder in the table	00:00:06
17	Putting graphite on the holder	00:00:02
18	Catching screw	00:00:25
19	Screwing graphite into the holder	00:01:28
20	Putting magnetoon the holder	00:00:03
21	Putting chain on the magnet	00:00:02
22	Bringing workpiece to the machine	00:00:24
23	Moving up workpiece	00:00:12
24	Positioning workpiece on the machine table	00:00:16
25	Catching airflow	00:00:04
26	Cleaning holder and table machine with air	00:00:23
27	Coming down on the machine table	00:00:08
28	Saving Manual hoist	00:00:36
29	Positioning the mounting bracket screws	00:00:17
30	Catching Screwdriver	00:00:08
31	Tightening screws	00:00:46
32	Saving Screwdriver	00:00:05
33	Searching clock	00:00:13
34	Putting clock in the machine	00:00:09

35	Aligning Workpiece	00:06:58
36	Removing clock	00:00:07
37	atching Tool	00:00:16
38	Putting Tool	00:00:10
39	Adjusting airflow	00:00:12
40	Machining Workpiece to Clean	00:03:14
41	Aligning Workpiece	00:05:18
Total Setup Time		00:27:25
Total Internal Setup Time		00:19:05
Total External Setup Time		00:08:20

Highlights

- Development of a Lean-Green model towards a cleaner production.
- Eco-efficiency indicators based on Lean and Green manufacturing tools.
- SMED application followed by Carbon Footprint for improvement of setup activities.
- Creation of more value with less environmental impact in the shop floor.