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GREEN LEAN METHODOLOGY: ENTERPRISE ENERGY MANAGEMENT FOR INDUSTRIAL COMPANIES

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Rezumat. *Scopul acestui articol este de a prezenta utilitatea tehnicilor Lean Manufacturing în abordarea problemelor de mediu. Prezentarea Lean Green Methodology în șapte pași, împreună cu tehnicile și instrumentele adiacente, oferă un cadru de lucru practic. Lean Green Methodology urmează ciclul Deming (PDCA) și vizează obținerea de îmbunătățire continuă incrementală. Creșterea eficacității utilizării resurselor se obține nu doar prin protejarea resurselor naturale, ci și prin creșterea productivității. Aceste câștiguri pentru mediul înconjurător prin productivitate sunt posibile prin reducerea continua a pierderilor din procesele de transformare, prin proiectarea/reproiectarea produselor și serviciilor care să preîntâmpine efectele nedorite asupra mediului, prin conceperea de proceduri de control în cadrul fluxurilor de transformare, prin creșterea investițiilor de capital în tehnologii mai eficiente, prin îmbunătățirea continuă a performanțelor muncii, prin schimbarea percepțiilor managerilor superiori și printr-o cercetare și inovare mai eficientă și mai eficace.*

Summary: *The purpose of this article is to show the usefulness of Lean Manufacturing techniques when approaching the environmental issues. Green Lean Methodology presentation in seven steps with afferent tools and techniques provides a practical framework. Green Lean Methodology follows the Deming's cycle (PDCA) and it aims to achieve the continuous incremental improvement. Increasing the resource use effectiveness is achieved not only by protecting natural resources, but also by increasing productivity. These environmental gains through productivity are possible by continuously reducing losses in transformation processes, by designing/redesigning products and services in order to prevent undesirable environmental effects, by designing the control procedures in the processing flows, by increasing the capital investment in more efficient technology, by continuously improving work performance, by changing the perceptions of senior managers and by a more efficient and effective research and innovation.*

Keywords: Lean manufacturing, Green Lean methodology, Environment

1. Introduction

Human needs are met by developing products and services that involve the consumption of natural resources in any form of economic activity (agriculture, industry or services). The consumption of natural resources, whether we speak of water, energy, mineral resources and biological resources, is sharply increasing and it is leading to an environmental degradation manifested by emissions, large volumes of waste or degradation of natural systems. In this context, the current

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production models and the actual style of consumption require long-term approach to increase the efficiency and effectiveness of resources. Thus, the environment and world development, especially the economic development, cannot be different purposes. The long-term balancing of the humanity resources and needs, as the primary objective of economic and engineering sciences, the natural resource extraction and the impact of these extractions must be continuously correlated with their natural recovery time.

2. Lean Manufacturing and Green Lean

The Lean Manufacturing concept was introduced to the Western world by Womack et al. [1], which sought to understand the increasing of Toyota competitiveness. The Japanese basics of Lean concepts were established and developed by Eiji Toyoda and Taichii Ohno, in collaboration with Shigeo Shingo at *Toyota Motor Company* during the '50s [2]. Toyota has developed a production system capable of achieving small numbers of many different automobiles with limited resource consumption [3]. This approach was totally different from the Western approach based on achieving a large number of similar cars and large batches, on the principles of mass production [3]. According to Womack et al. [1], Lean Manufacturing comparing with mass production requires: 1/2 the human effort in the factory; 1/2 the manufacturing space; 1/2 the investment tools; 1/2 the engineering hours and 1/2 the time to develop new products. Imai introduces the Kaizen concept in order to understand the application of Lean Manufacturing tools. Imai argues that:*"Kaizen is simply an umbrella concept covering most of the Japanese practices that have recently achieved world-wide fame"* [1]. Lean Manufacturing expands the scope of the Toyota production philosophy by focusing on five perspectives of thinking:*"the product development process, the supplier management process, the customer management process, and the policy focusing process for the whole enterprise"* [2].

The first step of a Lean Manufacturing journey is to identify the added value and the non-added value in processes, using the Value Stream Mapping - VSM [4]. The VSM defines the current state and the desired future state of the system. The VSM future state is used to develop improvement strategies through Lean Manufacturing techniques, committing minimal resources.

At the strategic level, in order to transform organizations, the Lean Manufacturing concept is summarized in a set of five steps [5], [6]: (1) specify value; (2) identify the value stream; (3) make the value-creating steps flow; (4) promote a pull culture; and (5) pursue perfection. At the operational level, three categories of losses are tracked in order to eliminate losses as a main element of Lean Manufacturing [7]: (1) *Muri*, meaning excess, producing more than is required; (2) *Muda*, meaning waste, in all of its forms; (3) *Mura*, unevenness, materials parts and goods should all flow at an even rate and not fluctuate. The main targets of Lean Manufacturing thinking focus on individual product, on identifying value-added activities, but especially non-value-added activities and on eliminating all losses (muda) [4]. The Muda concept was detailed in seven types of waste, as originally defined by Ohno [8]: *(1) over-production; (2) defects; (3) unnecessary inventory; (4) inappropriate processing; (5) excessive transportation; (6) waiting; and (7) unnecessary motion.* Over time, in order to eliminate waste, Lean Manufacturing has been completed with other concepts, including TPM and Six Sigma [4].

Later on, Womack and Jones [6] introduced the concept of customer value to define three categories of activities which aim to facilitate the elimination of waste through process continuous improvement: (1) Value adding (VA): what the customer expects to pay for; (2) Non-value adding (NVA): pure waste, what the customer does not expect to pay for; (3) Necessary but non-value adding (NNVA): inherent waste from existing practices that must happen to complete the process, what the customer does not expect to pay for.

Traditionally, companies have focused on *productivity and quality continuous improvement*. In this traditional context, the productivity improvement focuses on cost efficiency (inputs), due to systematic and systemic cost reduction, and thus, on profitability improving, and the quality level focuses on continuous improvement of customer satisfaction through products and services (outputs). In academia and especially in industrial companies, many efforts are made to design and implement new holistic approaches and programs for productivity and quality continuous improvement. Most popular approaches are: LeanSixSigma, Total Quality Management (TQM), Just-in-Time, Total Productive Maintenance (TPM), 5S, Kaizen. Merging the environmental concerns with the concern for productivity and quality is an objective and a natural necessity. Current practices used by industrial companies in the quality and productivity programs are tangentially addressing environmental concerns. For example, *preventive maintenance* programs for equipment are stipulating the standardization of oil lubrication consumption to reduce unnecessary consumption. Another example, the 5S technique addresses physical areas with environment contamination risk. Another approach at equipment level is the *Overall Equipment Effectiveness* (*OEE*) indicator measuring downtime on equipment such as stopping and idling times of equipment, during which at least the energy is unnecessarily consuming. *Before and after kaizen* projects are used to achieve rapid and clear improvements such as insulation of steam conduits in order to limit losses. The standardization of costs by *management accounting* (at least the overhead costs) is another way to control the environmental impact. However, there are many practical examples of companies where there are many "flaws" which increase the burden on the environment and impose a single consistent vision regarding environmental issues.

3. Green Lean methodology

As generally accepted, the productivity was defined as the relationship between outputs (products/services) and inputs (consumed resources). The outputs of companies, especially the industrial ones, are divided into desired outputs and undesirable outputs. As already stated above, the undesirable outputs are called "waste". Among the undesirable outputs, there are also outputs affecting the environment. In this context, pollution as a company undesirable output is a form of loss and a symptom of inefficient industrial production flows. Current calculations of a company's productivity refer to its desired outputs (products and/ or services).

The total productivity of a company is high if it improves the ratio of desired outputs from total outputs (waste minimization) and if it improves quality in accordance with customer requirements (quality management system). The most important input factors in the process of conversion to products and services that need to identify ways of preventing pollution and waste at source and need to streamline and optimize ongoing consumption are: capital, manpower, machines, materials, methods, utilities, energy and so on.

From the managerial point of view in a company, since the primary aim is to achieve profit from desired outputs, the top management plays a critical role in the success of the *Green Lean Program*. Obtaining a deep and active involvement and an appropriate behavior from managers [9],[10] requires understanding the importance of the environmental impact of corporate activities by moving the focus from the short and medium term management goals, particularly financial, to the long-term goals. To reduce the companies' resistance to change, leaders and managers need to devise ways to continuously assess the environmental impact of their activities, to develop policies and strategies resulting from environmental assessments, objectives, performance indicators and to continuously stimulate new projects and initiatives to substantially reduce the undesirable effects of their economic activities on the environment [11-12].

The methodological approach to losses having an environmental impact needs to be done like any other approach to a problem, using *Deming's PDCA cycle (Plan-Do-Check-Act or Plan-Do-Check-Adjust) and Kaizen.* First of all, identify the problem and try to understand it through systematic and comprehensive analysis. After determining the root causes, consider all possible options to solve the problem. After analyzing the options, determine the best solution and then develop an implementation plan for the chosen option. After implementing the chosen option, monitor and analyze the implementation in order to confirm the deliverables along streams. After obtaining the expected confirmations, go to the next problem, and the cycle repeats until the goal is achieved. This way, the *continuous incremental improvement* will be obtained (see Figure 1).

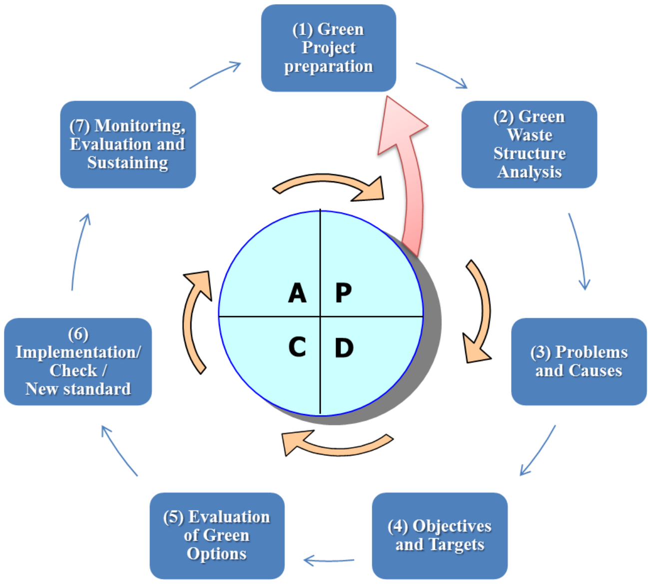

Figure 1: Green Lean methodology - *continuous incremental improvement.*

Each step of **Green Lean methodology** shown in Figure 1 is described in a **number of activities**, as shown in the table below (see Table 1). These steps are guidelines. Some steps can be completed with other steps, removed, combined, simplified or detailed according to Green Lean project. However, the table below shows the **tools** that can be used for each step of Green Lean methodology, *specifically to identify problems and causes, as well as setting objectives and targets.* Setting goals and targets requires prioritization of issues and establishing realistic and feasible goals that can be achieved with the best available technology.

Table 1: Main activities and tools in green lean methodology

	Green Lean methodology steps	*The main activities of the methodology*	*Tools for Green Lean methodology*
1.	**Green Project preparation**	• Forming a Green Lean Team and selecting a team leader • Contacting external consultants if required; • Deciding on responsibilities; • Planning meetings to discuss progress.	✓Benchmarking and Checklists; ✓Plant layout; ✓Value Stream Mapping; ✓Flowcharts and Process flow diagram; ✓Material & Energy balance;
2.	**Green Waste Structure Analysis**	• Walk-through Survey; • Collection of basic information; • Preliminary analysis of information;	✓Flowcharts and Process flow diagram; ✓Benchmarking.

3.	**Problems and Causes**	• The formation of work teams to generate alternatives to fulfil each eco-objective planned. • Defining problems and root cause analysis; • In-depth understanding of the phenomena; • Defining the principles and parameters underlying problems; • Multiple sessions to identify the root cause.	✓Eco-mapping; ✓Concentration Diagram; ✓Control Chart; ✓Brainstorming; ✓5Why; 5W2H & IS/ IS NOT; ✓Pareto charts; ✓Cause and effect analysis; ✓Fault Tree Analysis (FTA); ✓4-6M; Drill Deep & Wide; ✓A3; ✓Critical path analysis; ✓Stratification Analysis.
4.	**Objectives and Targets**	• Setting objectives and targets; • Defining Eco- KPI.	✓Brainstorming; ✓Gantt chart; X matrix.
5.	**Evaluation of Green Options**	• Generating green options for each objective; • Designing options for green protection; • Evaluation of green options • Designing the Master Plan for the implementation of green options; • Establishing responsibilities of work teams.	✓Brainstorming; ✓Cost benefit analysis; ✓Eco-mapping; ✓FMEA; ✓Pareto charts; ✓ABC classification; ✓X matrix; ✓Decision Matrix; ✓Program Evaluation Review Technique (PERT).
6.	**Implementation/ Check/ New standard**	• Implementation of selected options; • Staff training and skills development for the green lean - awareness building; • Monitoring and evaluation of green lean implementation; • Designing eco-standards and establishing plans for continuous improvement over time.	✓Training need analysis; ✓Team briefing ✓Responsibility matrix ✓Critical path analysis ✓Gantt chart ✓Spider web diagrams; ✓SMED; ✓X matrix.
7.	**Monitoring, Evaluation and Sustaining**	• Monitoring all options implemented by KPI; • Reviewing and analyzing the performance of each green lean option; • Reporting of results - post-implementation report; • Corrective actions based on post-implementation report; • Designing a system for continuous identification of new problems and resuming cycle for continuous improvement.	✓Solution effect analysis; ✓Eco-mapping; ✓Failure mode and effect and analysis; ✓Charts (control, tally etc.)/ Spider web diagrams; ✓OPL; ✓Poka Yoke; ✓SixSigma.

Implementing a **green lean methodology** requires integration and application of various **techniques**. The Green Lean methodology is based on the principle of *Waste Prevention*. As with any Lean Manufacturing project, taking into account the implementation effort and its adjacent costs, a timed Green Lean techniques implementation is set as follows: *(1) Housekeeping (5S/6S) and 7 Wastes [16,17]; (2) Improved Operating Procedures, (3) Waste Segregation, (4) Recycle, Reuse and Recovery - Off-site Recycling/On-site Recycling; (5) Resource/Energy Conservation; (6) Process Modification, (7) Input Material Changes, (8) Process and Equipment Change, (9) Air Emission Control, (10) Solid Waste Management and (11) Design for Environment.*

These techniques are interrelated and rarely used independently. Some companies are directly using *Design for Environment (DfE)* to achieve substantial benefits. This is because all environmental and productivity aspects are already included in the product development process. *Design for Environment (DfE)* is the designing process where environmental attributes are treated as a design objective rather than a constraint. *Design for Environment (DfE)* aims at increasing the eco-efficiency and product performance improvement. This is done by increasing the quantity of recycled or recyclable materials used in fabrication process, replacing toxic and hazardous materials through the use of alternative materials. However, this must be done while maintaining an acceptable or improved level for product quality [13-17].

For example, in automotive industry when seeking to move away from *Conventional Product Design*, which aims only to reduce production costs and to achieve planned performance, to *Design for Environment (DfE),* lower production costs through efficient resource utilization, product performance improvement and especially environmental impact reduction at all stages of future product existence *are aimed to use*, through: *(1) selection of low impact materials* (non-hazardous materials – for example: water based lacquers for finishing; recycled materials; recyclable materials); *(2) reduction* (reduction in weight; reduction in transport volume**;** reduced the number of materials used; reducing to minimum the elements that cannot be recycled); *(3) optimization of production techniques* (alternative production techniques; fewer production techniques; low/ clean energy consumption – for example reducing idle time of equipment functioning; low generation of waste; few/ clean production consumables – for example using clean emissions**;** *(4) reduction of the environmental impact in the user stage* (low energy consumption; clean energy source; few consumables needed during use; clean consumables during use; no energy/ auxiliary material wastage; *(5) optimize end-of-life system* (reuse of product; remanufacturing; recycling of materials – for example: plastic parts marked with the symbol of plastic to assist recyclers in identifying the parts; clean incineration) [17, pp. L5 27-29].

5. Case study

Our example on which to develop the methodology presented above is based on the reality of an automotive company – the X Company. The ”X Company” has a continuous improvement culture of successfully using LeanSixSigma principles and techniques: Value Stream Mapping (VSM), 5S, Autonomous Maintenance, Overall Equipment Effectiveness (OEE) monitoring and continuous improvement, PFMEA, Control Plan, Statistical Process Control (SPC), Kaizen Event, Before/After Kaizen, SMED, Makigamy, etc). The LeanSixSigma Department is planning and organizing continuous improvement projects on the basis of a continuously reworked Master Plan.

a) Step 1: Green Project preparation

The company has established a responsible for environmental issues, a responsible for energy issues - from the maintenance department and it has set responsibilities for process engineers. The benchmarking analysis was done for company's emissions having environmental impact (scraps, technological losses, landfilling, carbon emissions, etc.) (see Table 2):

Table 2: **Benchmarking for emissions having environmental impact**

Parameter	*Measure Unit*	*Standard 75/440 CEE*	*Limits required by Romanian norms*	*Actual Values in ”X Company„*
PH	mg/l	6,5-8,5	6,5-8,5	**7,9**
Fe^{3}+	mg/l	–	1	**0,7**
Sulphane	mg/l	–	200	**122,53**
Chloride	°Ge	200	250	**134,83**
Hardness	mg/l	–	20	**12,01**
Oil Products	mg/l	0,05	0,1	**0,06**
Total Slurries	mg/l	25	25	**21,45**

Obs.: the emissions and their limits are within legal parameters.

The factory's plant layout was done (land: 180.000 m^2; covered aria: 77.400 m^2) to identify areas and processes that need improvement from an environmental perspective (simplification at the base production flow level) for electricity, water and gas consumption, whereas the processes emission level is within legal parameters (see Figure 2). If emissions were outside the legal limits, some improvement projects for these deviations would have been scheduled (Kaizen Event, Before/After Kaizen). The major steps of a Kaizen project are: training, current-state analysis, improvement identification, implementation, testing/ evaluation, and results report out. The company does not use steam and compressed air.

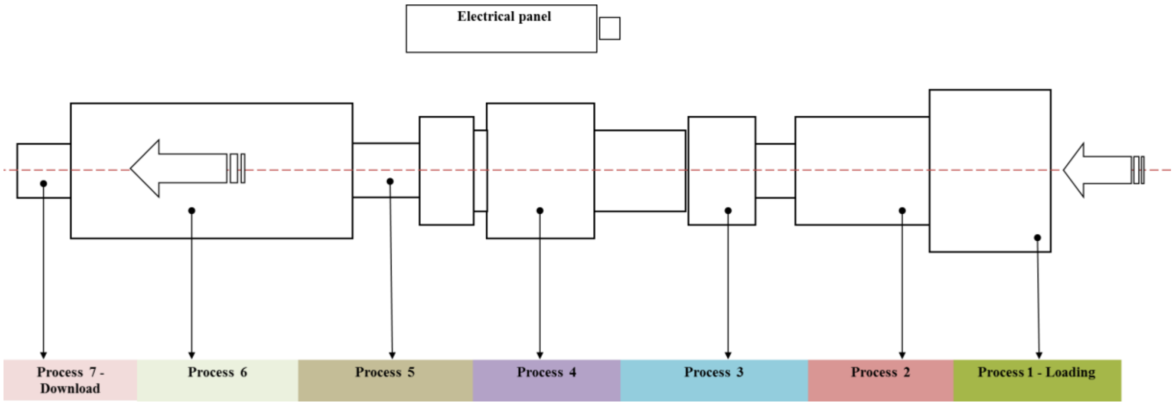

Figure 2: Plant layout simplified.

Taking into account the previous average monthly volumes and the previous average monthly cost of energy, water and natural gas for the 7 production processes and for the administrative areas, it was calculated the average annual consumption for "N-1" year per product unit (see Table 4, column 2).

Flowcharts and process flow diagrams have been made for each of the 7 production processes to identify particular areas and process steps having environmental impact emissions, and utilities consumption that could be saved and/or avoided.

b) Step 2: Green Waste Structure Analysis

The Walk-through Survey was made and the basic data were collected. Since there were no identified problems with the legal limits of emissions, the company has collected the historical reported data regarding the consumption of electricity, water and gas.

c) Step 3: Problems and Causes

The Company has formed work teams (data collection, problem definition and analysis) for the consumption of electricity, water and gas. After the brainstorming sessions and defining the main problems (using 5W2H & IS/IS NOT [18]), 20 opportunities to reduce the consumption of electricity in the 7 productive processes and for administrative office areas were preliminarily identified.
Of the 20 opportunities, 13 aimed at reducing energy consumption. They were located in the processes and some improvement techniques have been established to be used (see Table 3). The priorities on process improvement projects have been set by scaling (5- major impact improvement; 3- mid-level impact improvement; 1- low impact improvement). Likewise it was done for water and gas consumption.

The ”cause and effect analysis” and the ”5Why analysis” for the 20 opportunities have identified the ”root causes” of consumptions that could be avoided or saved.

These analyzes led to the establishment of targets to reduce consumption of electricity, water and gas, for "N Year" and for the next four years, for each process and thus for each product family, including the product unit costs.

Also, Kaizen project planning was done for the following periods. The expenses for the improvement projects to improve utility consumption levels are specified in the annual budget planning [19], [20].

Table 3: Location of projects and techniques to improve energy consumption

			Individual improvement technique								***Systematic improvement***		
The main causes of high energy consumption			*Breakdown analysis*	*Setup time reduction*	*Start up time reduction*	*Short stop analysis*	*Cycle time reduction*	*Operation method*	*Layout improvement*	*Energy saving method*	*Operative maintenance*	*Preventive maintenance*	*Education and training*
Cause 1: Machine	Process	1						3					
		2	5										
		3									3		
		4		5									
		5			3							3	
		6					5			**3**			
		7				1			1				
		Office											3
Cause 2: Man	Process	1											
		2											
		3											
		4											
		5											
		6											5
		7											
		Office						5					

d) Step 4: Objectives and Targets

After the brainstorming sessions to analyze the 20 opportunities, the Eco-KPI was defined [21] for each process where the objectives will be tracked as in Table 4.

Table 4: Objective and targets for electricity, water and natural gas

Objectives	Year "N-1"	"N" Year		Year "N+1"	Year" N+2"	Year "N+3"	Year "N+4"
		Target	Realized				
Electricity (kWh/product)	**34.3**	**32.6**	**33.1**	**30.1**	**28**	**27,5**	**25**
Water (m^3/product)	1.23	0.94	0.73	0.70	0.67	0,55	0,40
Natural Gas (nm^3/product)	5.41	4.81	4.48	4.2	4	3,8	3,3

e) Step 5: Evaluation of Green Options

The 20 opportunities to reduce the consumption of utilities have a total impact on the unit cost of 3% of the total conversion cost for each of the 5 years (it took into account the trend of utilities' price rising) [22]. It is considered that the utility cost reduction of 3% is sufficient for the company to be within the continuous cost reduction strategy. To fit the target price and the target profit, the company has also achieved other initiatives to reduce all the other categories of costs (especially the indirect variables ones).

A Pareto analysis was performed to highlight the impact of improvement projects over the unit cost, taking into account the level of required investment. As an example, the improvement in the process no. 6 will be addressed (mid-level impact improvement - 3) on the equipment's energy consumption – effective energy *(energy saving method especially for start-up, overload, thermal dissipation).* A Before/After Kaizen project was conducted to reduce the energy consumption (*for overload),* as an initiative to achieve the target of reducing electricity consumption for the year "N" (reduction from 33.1 kWh/product to 32.6 kWh/product). The project's contribution to average unit cost reducing taking into account the forecast workload for the 5 years is 2.3% of the 3%. Defining the problem: *reducing electricity consumption in pumping system - steam boiler.* The comparative situation: Table 5.

Table 5: Before/After Kaizen related energy consumption of pumps

Before Kaizen (old system)		*After Kaizen (new system)*	
Number of pumps	2	Number of pumps	2
Installed power	1,1 KW	Installed power	0,5 KW
Tension	220 V	Tension	220 V
Flow	12 mc/h	Flow	6-21 mc/h
Rotation speed	1500 rpm	Rotation speed	1400 rpm

The cost-benefit analysis: the improvement cost is 850 Euro. The payback period is 7.3 months (taking into account the productivity of the new system).

f) Step 6: Implementation/Check/New standard

For the implementation of the 20 improvement projects, an implementation plan (a Gant graphic) was conceived and were settled the activities and persons responsible for the implementation, the necessary cash release and the time limit for implementation.

g) Step 7: Monitoring, Evaluation and Sustaining

The responsible for environmental issues together with the responsible for energy issues and with process engineers will monitor the implementation and the results. In time, 4 new opportunities to reduce utility consumption have been identified.

Conclusions

Energy continues to be a critical issue for many companies. They seek solutions for industrial energy management in order to implement a strategy for continuous cost reduction. This paper presents a practical methodology for implementing a program to reduce unnecessary consumption of utilities (along with the cost of losses), by presenting the logical sequence of activities, methods and tools for Lean approach. The Lean Manufacturing culture should be also used within companies to continuously identify the ongoing opportunities for toxic and hazardous materials reduction and replacement, as well as those that have a long-term regional and global impact [23].

The continuous reconstruction of environmental strategy relating to continuous improvement techniques and to methods that could be used for each methodology step must be a continuous concern of top management at least during *Green Project preparation* phase. The methodology presents an approach to production systems and not only, at product design level and process level by which environmental attributes are treated as primary goals and not mere constraints. Through this methodology, the results of continuous improvement can be measured by Kaizen projects.

It is therefore obvious the need to implement real environmental programs, joining in productivity continuous improvement initiatives, even if there are at the present major concerns for standardization (ISO 9001 - Quality Management System [24]; ISO 14001 - Environmental Management System [24]; ISO 50001 - Energy Management System [24]; OHSAS 18001 - Occupational Health & Safety Management System [25]).

In the future, Green Lean initiatives in accordance with the methodology presented in this paper could be considered by every industry from the product and packaging design phase and taking into account customer needs satisfaction in order to improve economic performance. It would be good that the methodology proposed in this paper would to be a way of life for many companies around the world.

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