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# SIX SIGMA AS A TOOL TO INCREASE ECO-EFICIENCY IN MACHINING PROCESSES: A CASE STUDY

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ABSTRACT

In the competitive market organizations have been reformulating their strategies to offer products and services with improved value by means of better performance, higher quality, reduced delivery and with no hostile effect to the environment. One of the tools employed to reach that objective is the Six Sigma approach, where the reduction of process variability can generate improved product / production performance and reduced costs. In line with that, this paper proposes a procedure where the Six Sigma method is employed to improve the eco-efficiency in machining processes. This is done through a case study where the DMAIC technique was applied to a turning operation aiming to identify, quantify and improve process eco-efficiency measures. The application of the Six Sigma principles on the case under analysis enabled a 20% reduction in the consumption of electric energy, a 13% economy in soluble oil and a 3% decrease in chip generation.

*Keywords:* Eco-efficiency; Machining process; Six Sigma; DMAIC; Brazil.

## 1. Introduction

In highly competitive markets the Six Sigma method has been increasingly applied in the organizations as an effective approach to solve structural problems through the reduction of process variability. According to Calia *et al.*(2009), the Motorola Company created the Six Sigma Methodology around 1986 as an attempt to increase its competitiveness against the Japanese companies in the electronic industry. Santos (2010) informs that this initiative was focused on the total quality where the customer satisfaction and the elimination of product defects and production mistakes were the central objectives. Before adopting the Six Sigma, Motorola spent between 5 and 20% of its revenues to fix quality problems, which represented around US$ 900 million a year in expenses. After the Six Sigma implementation that company saved about US$ 2.2 billion in four years (NAIR *et al.*, 2011). Since then, the Six Sigma has been evolving conceptually to provide wider possibilities of utilization, mainly in relation to the strategic and managerial actions required for its implementation.

It is well established that the industrial growth generates significant contribution to the economic development. However, until recently the manufacturing expansion was to a great extent also responsible for the degradation of the environment (CALIA *et al.*, 2009). Despite the Six Sigma procedure being currently used to cover almost all activities of a company, there are very few studies applying that methodology to minimize the production impact on the environment or to improve the eco-efficiency of the manufacturing processes (ROTONDARO, 2010). Thus this paper aims to answer the following research enquiry: Can the Six Sigma method be fitted to improve the eco-efficiency of manufacturing processes? To respond this question a case study was performed where a modified version of the DMAIC method was applied to a turning operation. Significant economies were obtained as a result.

## 2. Conceptual review

Before moving to the case study it is adequate to review some concepts required to support the developments that will be made herein. Initially it will be presented the fundamentals of the Six Sigma method followed by the concepts required to comprehend the eco-efficiency and its relationship to the environment protection.

### 2.1. Understanding the Six Sigma

Basically the Six Sigma is a structured method to solve problems. It is relevant to mention that a six sigma level represents only 3,4 failures or defects for each million of events or parts made, generating as a result a 99,99966% quality level (Kumar *et al.*, 2006). According to Werkema (2010), the Six Sigma program focus on the strategic objectives of the company and establishes that all the key sectors for survival and future success of the organization should have improvement goals based on quantifiable measures to be reached through a predefined methodology. The resulting projects are then conducted by implementation teams involving Six Sigma specialists (Black Belts or Green Belts) and using the DMAIC (define, measure, analyze, improve, control) and DMADV (define, measure, analyze, design, verify) methods. Table 1 shows in more detail those involved in a Six Sigma project implementation.

According to Eckes (2001) the DMAIC is a methodology applied to exiting processes. It is based on statistical techniques and quality management tools used according to a predetermined method comprising five phases: Define, Measure, Analyze, Improve e Control (PARAST, 2011). In Table 2 there is a summary of each one of those phases.

Table 1. Typical positions involved in a Six Sigma project (WARKEMA, 2010)

| | SPONSORS AND SPECIALISTS | LEVEL | MAIN TASKS |
|---|---|---|---|
| Sponsors | SPONSOR | Managing Director | Promotes and defines strategies for Six Sigma implementation. |
| | SPONSOR FACILITADOR | High Management | Supports the sponsor in the implementation. |
| | CHAMPION | Management | Supports projects and removes barriers to their implementation. |
| Specialists | MASTER BLACK BELT | Staff | Supports the Sponsor and Champion and acts like mentor to the Black Belts and Green Belts. |
| | BLACK BELT | Staff | Leads project implementation multifunctional teams. |
| | GREEN BELT | Staff | Leads project implementation functional teams and supports Black Belts. |
| | YELLOW BELT | Supervision | Supervises the utilization of the Six Sigma tools and implements focused projects normally not conducted by Green Belts. |
| | WHITE BELT | Operational | Executes actions in the company activities to assure the maintenance of results obtained in the Six Sigma projects. |

## 2.2.Eco-efficiency

For the World Business Council for Sustainable Development – WBCSD (1996) eco-efficiency means creating more value with less environmental impact or doing more with less. Vellani and Ribeiro (2009) state that eco-efficiency signifies integrating the ecological and the economic performances, where the prefix eco stands for both economy and ecology. According to Schmidheiny (2000) *"eco-efficiency is achieved by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the earth s estimated carrying capacity"*.

Table 2 . The DMAIC method (WARKEMA, 2010).

| Steps | Process Improvement | Process Design / Redesign |
|---|---|---|
| 1.<br>Define | • Identify opportunity;<br>• Define resources;<br>• Establish measures;<br>• Establish goals; | • Identify specific or wide problems;<br>• Define objective / change vision;<br>• Clarify scope and client requirements; |
| 2.<br>Measure | • Validate opportunities / goals;<br>• Prepare map with input and output variables for each process phase;<br>• Redefine problem/objective;<br>• Measure key steps / inputs; | • Measure performance in relation to requirements;<br>• Collect data about process efficiency; |
| 3.<br>Analyze | • Develop hypothesis;<br>• Identify root causes (few and vital);<br>• Validate hypothesis; | • Identify "best practices";<br>• Evaluate process design;<br>  ◦ With or without added value;;<br>  ◦ Process bottleneck or misconnections;<br>  ◦ Alternative paths;<br>• Redefine requirements; |
| 4.<br>Implement improvement | • Develop ideas to eliminate root cause;<br>• Test solutions;<br>• Standardize solution/measure results; | • Design new process;<br>  ◦ Challenge assumptions;<br>  ◦ Apply creativity;<br>  ◦ Workflow principles;<br>• Implement new process; |
| 5.<br>Control | • Establish standard measures to maintain performance;<br>• Correct problems whenever necessary; | • Establish measures and reviews to maintain performance;<br>• Correct problems whenever necessary; |

Organizations should establish some objectives to improve their eco-efficiency: reduce the intensity of the material they use, reduce the intensity of the energy consumed, reduce the dispersion of toxic substances, increase recyclability, maximize the utilization of renewables, extend durability of products manufactured and increase the intensity service (SCHMIDHEINY, 2000).

## 2.3.Environmental performance indicators

According to Mitchell (1996) performance indicators are tools that support the information gathering regarding a given situation. Their main characteristic is the ability to synthetize data presenting only the key information necessary for decision making. Usually they are used to monitor the processes in a given organization or to measure how successful a strategy implementation was in relation to a planned objective. The environmental performance indicators aim to demonstrate how the organization practices and actions contribute to minimize the adverse environmental impacts resulting from its operations (CAMPOS and MELO, 2008). According to Kaplan and Norton (1997), what cannot be measured cannot be managed. As a result, the organizations that do not monitor their environmental performance could not be adequately managing their environment.

As per Luz *et al.* (2006), in the EMS (Environmental Management Systems) the environmental performance indicators most employed are those easier to measure or readily available in the company. On the other hand, Verfaillie and Bidwell (2000) report that the eco-efficiency measurement should take into consideration the two eco dimensions of economy and ecology by dividing the product or service value by their respective environmental influence. They suggest two sets of eco-efficiency performance indicators: the generally applicable (those that could be used by virtually any organization) and the business specific (individually established from one business to another). The generally applicable indicators consider for product / service value two dimensions:  quantity of goods or services produced or provided to customers and net sales. On the other hand, the environmental influence caused by product / service creation is usually measured in terms of: energy consumption, materials consumption, water consumption, GHG (greenhouse gas) emissions and ODS (ozone depleting substance) emissions. As examples, some generally applicable eco-efficiency performance indicators could be: mass of product sold per energy consumption (expressed in kg per gigajoules) or net sales per material consumption (stated in $ per ton). Regarding the business specific indicators, Verfaillie and Bidwell (2000) also recommend that each organization should appraise its own business to find out which “business specific” indicators are relevant and convenient to management and external stakeholders, in addition to the generally applicable ones. They suggest using ISO 14031 – Environmental Performance Evaluation – to monitor the choice of appropriate business specific indicators, as this standard outlines the general procedures for selecting environmental indicators and designates a management process to provide the organization with dependable and verifiable information. In relation to the environment performance indicators, the ISO 14031 standard recommends that the organization should collect environmental data on a regular basis, following a planned frequency and from appropriate sources to assure the reliability of the information obtained. The data should be properly analyzed and expressed in the form of indicators to describe the environmental performance of the organization (ABNT, 2004). Table 3 shows examples of environmental performance indicators suggested by ISO 14031.

Table 3. Examples of environmental performance indicators (ABNT, 2004).

| ISO 14001:2004 REQUIREMENTS | PERFORMANCE INDICATORS |
|---|---|
| 4.2 - Environmental policy | - Number of objectives and goals reached<br>- Number of preventive and corrective actions on pollution prevention |
| 4.3.1 - Environmental aspects | - Quantity of material used per product unit<br>- Quantity of water reused<br>- Quantity of dangerous materials used in production process<br>- Quantity or type of waste generated by contractors |
| 4.3.2 - Legal requirements and other | - Number of penalties received and their respective costs |
| 4.3.3 - Objectives, goals and programs | - Number of suggestions received from employees<br>- Number of employees participating in environmental programs |
| 4.4.1 -Resources, responsibilities, authority. | - Return on investment for environmental projects<br>- Economy through the red. of resource utiliz., pollution prev. or waste recycling. |
| 4.4.2 - Competence, training and awareness | - Number of local initiatives for cleaning and recycling |
| 4.4.3 - Communication | - Number of comments about questions related to the environment |
| 4.4.6 - Operational control | - Number of equipment parts designed for easy disassembly and reutilization<br>- Average fuel consumption in the vehicle fleet<br>- Number of equipment preventive maintenance hours per year |
| 4.4.7 - Readiness and response to emergencies | - Number of emergency drills developed |
| 4.5.1 - Monitoring and measurement | - Number of products that can be reused or recycled<br>- Duration of product utilization |
| 4.5.2 - Legal requirement evaluation | - Time to respond or to correct environmental incidents<br>- % of compliance to legal requirements |
| 4.5.3 - Preventive and corrective actions | - Number of corrective actions identified |

## 3. Methodology

The basic research method selected by this paper is the case study, following Yin's (1990) recommendation since the investigation presented herein is trying to answer questions mainly related to "how" and "why" and since it is also investigating a contemporaneous phenomenon in a real world context where the boundaries between the phenomenon and the context are not clear.

As stated before, the case study aimed to answer the following research question: Can the Six Sigma methodology be fitted to improve the eco-efficiency of manufacturing processes? To respond this enquiry a modified version of the DMAIC method was applied to a turning operation in a company belonging to the metal-mechanic sector.

The selected company for the case study was chosen following two main criteria: a) it was already employing the Six Sigma approach, even though not considering the related environmental aspects and b) it was willing to allow the researchers to conduct the necessary experiments in the machining area to support the conclusions presented in this paper. The chosen firm has around 500 employees and produces bronze casts and machined parts. Its revenues come mainly from mining, energy and automotive sectors, being 60% for the domestic market and 40% for exports.

## 4. Case study

To verify the possibility of using the DMAIC methodology to generate eco-efficiency improvements, a typical turning operation was selected. Initially, in the "Define" phase some objectives and goals were established: a 15% reduction in the present cycle times being obtained in the selected operations. Then in the "Measure" phase, it was possible to quantify that in the chosen equipment 18,683 machining hours were processed per year, with a typical three machine run stops per shift to change tools due to normal wear or inadequate operation. Also an average of 10 mm chip removal was performed in each blank machined. In the “Analyze” stage data analyses was performed through statistical tools like Ishikawa diagram and Pareto distribution. The probable causes for the machining problems identified were: a) inadequate process – due to lack of standardization there was no pre-defined method to setup the machine; b) excessive blank size – there was no uniform criterion to establish the amount of chip to be removed and c) inadequate tooling – there was no standardized tool tips defined for each operation. Those items were validated in the factory floor and confirmed as root causes of the problems under analysis.

As a result of the “Improvement implementation” step the following upgrading was adopted: a) inadequate process – a new standardized machine setup method was established and the operators were dully trained to repeat the same setup sequence every time; b) excessive blank size – bronze castings were defined to have only 2 to 3 mm of overcut to avoid excessive chip generation and c) inadequate tooling – specific tools were defined for each operation taking into consideration extended tool life at a minimum tool cost. After implementing those changes and after some time required for the process to stabilize, the “Control” phase acknowledged a 20% reduction in a typical turning cycle. As a result projections for the year accounted for a total of 14,956 production hours.

So far, the DMAIC procedure was applied according to its conventional approach of considering only the manufacturing process variables. However, the objective of the investigation reported herein was to evaluate how the Six Sigma concepts could contribute to improve the company eco-efficiency. For that purpose the

DMAIC method was slightly changed to incorporate environmental variables as follows.

In the “Define” phase three environmental performance indicators were selected, following the basic principles already described above and in line with Verfaillie and Bidwell (2000) proposed concepts: a) number of parts machined per MWh of electric energy consumed; b) number of parts machined per liter of soluble oil used and c) parts machined per Kg of chip generated in the machining operations. In the “Measure” stage it was possible to verify that the eco-efficiency indicators presented before the process improvements presented the values shown in Table 4 (“eco-efficiency before” column).

As the environmental analysis was performed after the implementation of the manufacturing process improvements, no “Analyze” or “Improvement implementation” phases were deployed as part of the ecological consideration in the case under analysis. However, in the “Control” phase it was possible to identify a 20% drop in machining cycle time which allowed a 20% economy in the electrical energy consumed since no change affected the power parameters of the machine. Also the reduction of the overcut enabled a 3% decrease in the chip generated by the turning operations. As the soluble oil is concerned, it was possible to confirm a 13% reduction in the water / soluble oil consumption due to the refrigeration time decrease and less evaporation resulting from less chip removal. As a consequence, it was possible to determine the values for the environmental performance indicators after the implementation of the changes proposed by the conventional DMAIC approach. The results can be seen in Table 4 (“eco-efficiency after” column).

As can be seen, even not considering the environmental variables for defining additional improvement actions, the Six Sigma procedure allowed an enhancement in the company eco-efficiency. In fact, the number of machined parts per MWh of electrical energy consumed increased from .51 to .64 representing a 25% expansion. 17% was the increase in parts produced per liter of soluble oil, which grew from 53.2 to 62.5. Finally, with less impact, chip generation also showed a upgrading from 18.2 to 18.8 parts per kg of chip generated in the machining process.

Table 4. Eco-efficiency measurements before and after DMAIC procedure.

| **Eco-efficiency before and after project** | | |
|---|---|---|
| $$Eco-efficiency = \frac{Product\ value}{Environmental\ influence}$$ | | |
| **Environmental influence** | **Eco-efficiency before** | **Eco-efficiency after** |
| **Electric energy** | **0.51 parts / MWh** | **0.64 parts / MWh** |
| **Soluble oil (water)** | **53.2 parts / l of soluble oil** | **62.5 parts / l of soluble oil** |
| **Chip generation** | **18.2 parts / kg of chip gener.** | **18.8 parts / kg of chip gener.** |

However, this paper proposes a procedure where the “Analize” and “Improvement implementation” should be carried out considering not only the manufacturing process variables but also the environmental parameters related to the operations under analysis. By doing so, additional environment related improvement actions could be identified and implemented in such way that eco-efficiency indicators could present a better evolution than those obtained as a result of the DMAIC procedure applied exclusively on the production process parameters.

## 5. Conclusions

The Six Sigma is a powerful methodology structured to solve problems using statistical tools for data analysis aiming to reduce the variability of manufacturing and business processes. It has been extensively used to promote quality improvements, cost reductions, capacity increase etc. Nevertheless its consideration to generate enhancements of the eco-efficiency has been almost inexistent. For this reason, this paper proposes a procedure where the DMAIC method is slightly changed to incorporate environmental variables and the related eco-efficiency measures, as a way to adapt the Six Sigma approach to consider the ecological aspects associated to the manufacturing processes.

Even though the case under study was good enough to support as an example the suggested procedure, its results cannot be generalized for obvious reasons. Further research should consider the application of the suggested Green Sigma technique to other situations, different processes and diverse industries to verify the possibilities of its adoption in a more widespread way.

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