Environmental Gains through the Design for the Environment (DfE) - An Action Research

Elesandro Antonio Baptista (elesandro@uninove.br)

Filipe Marafon de Paoli

Geraldo Cardoso de Oliveira Neto

Wagner Cezar Lucato

UNINOVE, Av. Francisco Matarazzo, 612, Prédio C, 1º andar, São Paulo, Brazil

Abstract:

The objective of this paper is to evaluate and compare the environmental and economic gains resulting from DfE application, through an action-research based on the machining of a very large steel part. To measure the environmental gains, this work used the material intensity analysis as proposed by the Wuppertal Institute.

Keywords: Eco-efficiency, Design for the Environment (DfE), Machining.

Introduction

Currently all types of organizations have adopted more effective and comprehensive environmental actions concerning their product and production process designs to meet growing existing environmental demands (Santos-Reyes and Lawlor-Wright, 2001; Donnelly et al. 2006; Casamayor and Su, 2013). According to Knight and Jenkins (2009) one way companies can reduce the impact of their activities on the environment is by adopting the concept of eco-efficiency. For Gianetti et al. (2003), the Design for the Environment (DfE) is a tool to improve the eco-efficiency of companies that can be used by organizations to generate competitive advantage. The DfE contributes to the development of a sustainable design of a product, minimizing the consumption of energy during its manufacturing and the resulting impact on the environment.

For the World Business Council for Sustainable Development - WBCSD (1996) Eco-efficiency is the production of goods and services that meet the needs and human satisfaction, aiming at reducing the environmental impact generated by them throughout their life cycle. Or, it means creating more value with reduced environmental impact, or even simply doing more with less. According Holliday Jr. et al. (2002) eco-efficiency means producing more goods and services, based on the reduction of energy resources used in order to minimize waste. Sissino and Moreira (2005) define eco-efficient companies as those that achieve economic benefits, obtaining environmental gains through the reduction of waste that is generated during the production process. To Schmidheiny (2000) companies that have implemented the concept of eco-efficiency in their activities are prone to produce products and services with greater added value, as a result of reduced resource consumption and less polluting factors. Thus, to improve their eco-efficiency, companies should establish as goals, actions such as the reduction in the intensity of use of materials, the decrease in the intensity of use of energy consumed, the reduction of the dispersion of toxic substances into the environment, the increased recyclability, the maximization of use of renewable resources, the extension of the durability of the manufactured products and the increase in the intensity of services (Schmidheiny, 2000).

Another important factor for organizations to remain competitive are the strategies used in design, for both product and process. Eco-efficiency employs a series of tools that provide organizations with the optimization of the total materials cycle from virgin material, finished material, components, surplus materials and final disposal (Gianneti et al. 2003; Graedel and Allenby, 1995). Among these instruments, emphasis has been given to the relevant Design for the Environment (DfE), which for Knight and Jenkins (2009) is the systematic integration of environmental considerations into product design and its corresponding manufacturing process. For Giannetti et al. (2003), the DfE is an eco-efficiency tool used to analyze the entire life cycle of a product, in order to propose modifications in its design and production process in order to minimize environmental impacts, from its conception and to its final disposal. Its goal is to prevent pollution and minimize the use of energy resources during the creation and manufacture of a given product. According to the WBCSD (2003) uses the DfE concepts and practices that encourage social responsibility and simultaneously reduce costs, promote competitiveness and foster innovation.

As a contribution to theory and practice related to increasing the eco-efficiency level of organizations, this work aims at assessing and comparing the environmental and economic advantages resulting from the application of DfE. To accomplish that, an action research was developed in which this eco-efficiency instrument was applied to a discrete machining process of a very large part involving substantial consumption of electricity, water and coolant, as well as significant generation chips resulting from the machining process.

Methodology

To achieve the objectives proposed by the present work, it was decided to use as a research method the action research, because in the present study the DfE was applied to a discrete machining process by a small group of persons, motivated, interested, with appropriate knowledge and willing to solve a problem and also to generate scientific knowledge (Zumber-Skerrit and Fletcher, 2007). In addition, the researchers themselves were part of the team that applied the DfE and measured the environmental and economic outcomes resulting from the intervention made in the production process selected for this research (Coughlan and Coghlan, 2002; Thiollent, 2007).

To select the company to be considered in the action research, Patton (1990) recommends the use of samples with content (purposeful sampling), i.e., situations in which the researcher can extract significant amount of relevant information for the study. Among the various strategies suggested by Patton (1990) to choose a sample with content, this paper considers the sampling of typical situations in which the company to be selected should present appropriate conditions to evaluate the economic and environmental effects of the implementation of DfE. In line with this approach three criteria were established for select the company that would provide a basis for the action research that supports this work: a) the company should allow researchers to be part of a project team comprising engineers and technicians to be allocated to apply the DfE for an existing product/process, b) it should have an important manufacturing process in which significant resources were employed, and c) this process should enable the proper implementation of DfE.

Following those criteria, it was selected a large Brazilian industry, with 102 years of existence, belonging to the capital goods sector, with approximately 600 employees and outstanding participation in key market segments such as heavy mechanical manufacturing including power generation, mining and oil and gas equipment. The company has an integrated management system, based on ISO 9001, ISO 14001 and OHSAS 18001 standards. It has ISO 14001 certification since 2000. The part considered by the action research developed was the Hub, used in large wind mills dedicated to power generation. This part is manufactured with manganese steel GG40 and has a gross weight of approximately 12.5 tons. Its machining process is divided into 3 phases, considering 9 faces, 3 of them with a of 5 degree slope I relation to the axis "X". They consist of 33 milling operations (27.5 hours of machine process) and 15 drilling operations (6.2 hours of machine process) generating close to 2.5 tons of chips removed during processing. The equipment used to perform those operations is a plateau CNC boring machine made by the Japanese company Shibaura. It has a machining surface measuring 25' x 12' and a milling power of 20 Kw. Also based on information from the company, it was identified that the process of machining the part in question considers the production of 3 pieces per week or 156 per year.

The action-research developed involved two consecutive cycles according to Zuber-Skerrit and Perry (2002). The DfE project team, under the leadership of the authors performed the cycle 1, which involved: a) planning cycle 1: all the information that could characterize the environmental and economic variables involved in the machining process were obtained, b) acting: the calculation of the intensity of material and machining costs associated with the process under study were developed, c) evaluating: the values obtained in the previous item were critically analyzed by the project team, and d) learning from the results : opportunities for the application of DfE were identified. The next step involved the replication by the project team of a new cycle, number 2, by repeating the same sequence of events: a) planning: based on the results of cycle 1, the project team planned a more appropriate way to adopt the principles of DfE in the process under study, b) acting: the DfE opportunities were actually applied on the manufacturing process chosen, according to the previously planned, c) evaluating: the results obtained were measured with reference to the new intensity of material and production cost compared to those obtained in cycle1 and d) learning from the results : the results obtained in cycles 1 and 2 were compared to verify if there was effective environmental and economic gains resulting from implementation of DfE. Finally, the whole action research process was reported, which was done through this work.

As part of the methodology employed in this work, the method developed by the Wuppertal Institute to analyze the environmental impact of the industrial activities was used. It assesses the environmental changes associated with the extraction of natural resources from their respective ecosystems. The amount of each resource used is defined as material intensity, known by its acronym in English MIF (mass intensity factors) (Oliveira Neto et al. 2010). It serves as a proxy for the quantitative dimension of the potential ecological impact of human activities. The intensity of the material is calculated by considering the total life cycle of the item considered and assumes the total input of materials that humans utilize to generate and delivery products and services (Stiller, 1999). To determine the intensity of material, it is necessary to multiply the amount of mass of a material by its respective factor MIF (WBCSD, 2003). Therefore the MIF is a multiplier, thus lacking a measurement unit. The values for MIF needed by this work are expressed in Table 1 as established by Wuppertal (2013).

Table 1 - Factors intensity of material used in the present work

Mass Intensity Factors (MIF)	*Abiotic Material*	*Biotic Material*	*Water*	*Air*
Water	0,01	0,00	1,30	0,00
Manganese Steel	16,69	0,00	193,76	2,23
Eletric Power	1,55	0,00	66,73	0,54

(Source: Wuppertal, 2013)

The data for the material intensity developed by the Wuppertal Institute are based on the energy mix in Germany, Europe or the world, but that does not prevent this methodological tool to be applied in Brazil (Oliveira Neto et al., 2010). The factors listed in Table 1 mean that, for instance, when using 1 kg of manganese steel, 16.69 kg of abiotic materials are consumed resulting from the process of mining, production, use and disposal of the product. Likewise, 193.76 kg of water and 2.23 kg of air are consumed also during the lifetime of this kg of manganese steel (Stiller, 1999).

The action-research

After the selection of the company, the build-up of the project team, the choice of the process and the part to be considered, an action research was developed in which the environmental and cost data of the machining process were initially collected and analyzed before the implementation of DfE (cycle 1). Then, the principles of DfE were applied and the same environmental variables and costs initially considered were again measured (cycle 2). A comparison of the results obtained in both cycles confirmed the statement made by the literature in which the DfE applied to a production process would provide both environmental and financial gains. The details of the environmental and economic analyses are reported below.

Cycle 1 - Before applying the DfE

As already mentioned, the part chosen for this study comprised 48 machining operations, distributed in 9 sides of the piece. After some random sampling and various analyses, the project team found that the piece presented great variation in the amount of metal to be removed in 14 operations due to its technical complexity. This adversely affected the machining process times as well as it was responsible for a significant increase in power and insert consumption and waste generation. Thus, for the assessment of environmental and economic advantages only those14 operations with excessive allowance were considered because they offered obvious reduction opportunities. Based on the data gathered by the project team in cycle 1, every machined part had a consumption of 21.43 hours of machining (3,343 hours per year) and a chip removal of 1,750 kg per piece which meant an annual generation of 273,000 kg of manganese steel scrap. The water was only used in drilling part in the machining process with an average consumption of

100 liters of for each part (15.6 thousand liters per year). In this volume 5 gallons of cutting fluid were diluted to compose the lubricating fluid / coolant used during the drilling operations The water was not reused due to the conditions of the process and its consumption ocurred by evaporation during drilling operations. The refrigerant used is free of mineral oil. It's synthetic rating and free from nitrites and phenols. As for the electricity, the project team measured the actual consumption for machining one part which reached 543.5 Kwh. On an annual basis this number, which was multiplied by 156 pieces, reached 84,786 Kwh.

Regarding the environmental impact of the evaluated process, the concept developed by the Wuppertal Institute was used. This calculation refers to the material intensity of the metal chips generated and the water and electricity consumed during the 14 selected machining operations. Before applying the DfE and based on the multipliers developed by the Wuppertal Institute, it was possible to calculate the total material intensity which amounted to 63,917,049 kg of material affecting the environment, for the machining of the 14 critical operations. From this total, 4,687,944 kg consists of abiotic materials, 58,574,530 kg of air and 654,574 kg of water.

In relation to the manufacturing cost of the part in question before applying the DfE, the project team made the necessary evaluations. As a result, as the average cost per Kwh was $ 0.3019, the annual consumption of 84,786 Kwh of electric energy would cost the company $ 25,593. Other annual costs included: $ 214,019 of inserts and $ 1,069,786 of machine utilization. Conversely, the 273 tons of steel chip produced in one year were sold which generated a $ 81,900 cost saving. In summary, the total annual cost incurred by the selected company to perform the 14 critical machining operations before the application of the DfE amounted to $ 1.227.498.

4.2 Cycle 2 - Application of DfE

In the evaluation of the process selected for this action research the project team analyzed the information obtained in cycle 1 and identified the possibility of reducing the environmental impact in relation to the use of electricity, water, coolant, inserts and machining chips.

As part of the cycle 2 of the action research, the DfE concepts were applied. To do this the researchers along with with the machining engineers and technicians evaluated the opportunities for change in the product design aiming at obtaining environmental improvements. According to the characteristics and technical complexity of the product, it was decided to adjust only some dimensions in certain significant areas. With some pilot test results and discussions, a consensus was reached that it was important to modify 14 critical dimensions in the part studied. This would be necessary to reduce the cast material to be removed during the machining process. Based on the evaluations made, it was possible to conclude that the ideal machining thicknesses to be provided by the foundry supplier should be between 5 and 10 mm. As a result of this review, a prototype manufactured by the casting supplier was obtained.

After machining this part, the project team was able to verify a consumption of only 7.8 hours of machining (1,217 hour per year against 3,343 hours before) and a chip removal of 649 kg per piece which meant an annual generation of 101,244 kg of manganese steel scrap, against the 273,000 kg before the DfE application. In line with these reductions, the annual consumption of electric energy decreased from 84,786 Kwh to 42,354 Kwh per year generating a US$ 12,808 annual cost saving. Likewise, the consumption of inserts was also reduced producing an annual economy of US$ 107,008. Due to the lower number of machining hours, machine costs were also reduced by US$ 680,410. A smaller amount of scrap to be sold caused a reduction in cost savings of US$ 51,527. In summary the DfE enabled the company under study to obtain a total manufacturing cost reduction of about 60% or US$ 748,699 per year (about US$ 4,800 per Hub) as can be summarized in Table 2.

TABLE 2 – Comparison of the total manufacturing costs before and after DfE

Item	Before DfE (US$)	After DfE (US$)	Savings (US$)	Savings (%)
Consumption Inserts	214.019	107.011	(107.008)	50,0%
Power Consumption	25.593	12.785	(12.808)	50,0%
Cost Time-Machine	1.069.786	389.376	(680.410)	63,6%
Resale Chips	(81.900)	(30.373)	51.527	62,9%
Total	**1.227.498**	**478.799**	**(748.699)**	**61,0%**

The action research developed also showed that the application of DfE caused an annual reduction of 171 tons of machining chips chip and 42.4 MWh of electricity. The consumption of water used in the drilling process did not decrease, because the drilling operation was performed after the milling process and was not changed. As a result, it was possible to reduce the environmental impact by reducing the material intensity by 39,449,236 kilograms, comprising 2,932,377 kg of abiotic materials, 36,110,930 kg of air and 405,929 kg of water, as can be seen in Table 20. These reductions were highly significant because, on average, they accounted for 62% reduction in the material intensity after the application of DfE.

Table 3 - Comparison of the environmental impact before and after DfE

	Material Intensity (Kg)			
	Before *DfE*	**After *DfE***	**Diference**	**%**
Water				
Abiotic Material	156	156	0	0,0%
Biotic Material	0	0	0	0,0%
Air	20.280	20.280	0	0,0%
Water	0	0	0	0,0%
Total	**20.436**	**20.436**	**0**	**0,0%**
Manganese Iron				
Abiotic Material	4.556.370	1.689.762	(2.866.608)	-62,9%
Biotic Material	0	0	0	0,0%
Air	52.896.480	19.617.037	(33.279.443)	-62,9%
Water	608.790	225.774	(383.016)	-62,9%
Total	**58.061.640**	**21.532.574**	**(36.529.066)**	**-62,9%**
Eletric Power				
Abiotic Material	131.418	65.649	(65.770)	-50,0%
Biotic Material	0	0	0	0,0%
Air	5.657.770	2.826.282	(2.831.487)	-50,0%

Water	45.784	22.871	(22.913)	-50,0%
Total	**5.834.973**	**2.914.802**	**(2.920.170)**	**-50,0%**
Total				
Abiotic Material	4.687.944	1.755.567	(2.932.377)	-62,6%
Biotic Material	0	0	0	0,0%
Air	58.574.530	22.463.600	(36.110.930)	-61,6%
Water	654.574	248.645	(405.929)	-62,0%
Total	**63.917.049**	**24.467.812**	**(39.449.236)**	**-61,7%**

In fact, confirming what was suggested by the literature, the implementation of the DfE generated very favorable results in the environmental impact of the industrial operations simultaneously obtaining significant manufacturing cost reductions in the part considered in the action research.

5. Conclusions

Through the development of this work it was possible to confirm what the literature states: the adoption of the eco-efficiency tool called the Design for the Environment (DfE) enables the implementation of changes to already existing designs and related manufacturing processes, aiming to reduce their environmental impact. This was confirmed through an action research where annual reduction in material intensity reached 39,449,236 kg of abiotic materials, air and water that accounted for approximately a 62 % decrease in the environmental impact as compared to the material intensity before applying that tool. But, the study concluded further. The literature also mentions that the implementation of DfE causes, in parallel, a reduction in manufacturing costs. This fact was confirmed by means of the action research developed, because the machining cost experienced a significant 61% reduction resulting from use of the DfE, generating annual savings of US$ 750,000.

Thus, this paper brings contributions to theory as it confirms the fact that the DfE utilization can bring significant contributions to the improvement of environmental conditions in the industry, contributing significantly, in parallel, to the reduction of manufacturing costs. For the practitioners of Industrial Engineering and Operations Management, the conclusions reached here provide them tools to reduce costs meanwhile improving the environment in which they produce, aligning management actions to the expectations of various stakeholders.

However, despite the significant results obtained in this work, it is important to note that, according to the above literature, the DfE is still little known and widespread in Brazilian companies in general. Is also important to emphasize that engineers need to consider in their designs, the environmental impact caused by the corresponding manufacturing processes, without which industrial activities will continue to generate increasingly intense adverse environmental impacts.

Finally it is worth mentioning that this study has some limitations. Firstly, the study developed was based on data from a single part produced in particular kind equipment in one specific company, making it impossible to generalize the findings obtained here. Future research considering other companies, other types of equipment and different parts are suggested as a way to enlarge the results obtained by this study.

Acknowledgment
The authors thank the Fund for Research Support of the Universidade Nove Julho - UNINOVE – for the financial support required to develop this work.

Bibliography

Casamayor, J.L., Su, D. 2013. Integration of eco-design tools into the development of eco-lighting products. *Journal of Cleaner Production* 47: 32-42.

Coughlan, P., Coghlan, D. 2002. Action research: Action research for operations management. *International Journal of Operation & Production Management* 22(2): 220-240.

Donnelly, K., Beckett-Furnell, Z., Traeger, S., Okrasinski, T., Holman, S. 2006. Eco-design implemented through a product-based environmental management system. *Journal of Cleaner Production* 14: 1357-1367.

Gianneti, B. F., Almeida, C.M.V.B., Francisco Jr., M. 2003. Ecologia industrial: projeto para meio ambiente. *Revista de Graduação da Engenharia Química* 11(1): 40-51.

Graedel, T.E., Allemby, B.R. 1995. *Industrial ecology.* Prentice Hall, New York, NY.

Holliday Jr., C.O., Schmidheiny, S., Watts, P. 2002. *Cumprindo o prometido* - casos de sucesso de desenvolvimento sustentável. Campus, Rio de Janeiro.

Knight, P., Jenkins, J.O. 2009. Adopting and applying eco-design techniques: a practitioners perspective. *Journal of Cleaner Production* 17: 549-558.

Lim, S., Kim, Y.R., Woo, S.H., Park, D., Park, J.M. 2013. System optimization for eco-design by using monetization of environmental impacts: a strategy to convert bi-objective to single-objective problems. *Journal of Cleaner Production* 39: 303-311.

Luttropp, C., Lagerstedt, J. 2006. Ecodesign and the ten golden rules: generic advice for merging environmental aspects into product development. *Journal of Cleaner Production* 14: 1396-1408.

Marconi, M.A., Lakatos, E.M. 2010. *Fundamentos de metodologia científica*. Atlas, São Paulo.

Martins, R.A.. *Abordagens quantitativa e qualitativa.* In: Cauchick Miguel, P.A.C. (Coord.). (2012); *Metodologia de pesquisa em Engenharia de Produção e Gestão de Operações*; Elsevier, São Paulo.

Oliveira Neto, G.C., Chaves, L.E.C; Vendrametto, O. 2010. Vantagens econômicas e ambientais na reciclagem de poliuretano em uma empresa de fabricação de borracha. *Exacta* 8(1): 65-80.

Patton, M. Q. 1990. *Qualitative evaluation and research methods*. Sage, Newbury Park.

Pereira, L.F.R. 2005. *Aspectos Conceituais da Ecoeficiência no contexto do desenvolvimento sustentável.* Dissertação (Mestrado Gestão do Meio Ambiente) – Universidade Federal Fluminense, Niterói, RJ.

Santos, J.C.S. 2013. *Proposta de Integração da Técnica Seis Sigma (DMAIC) com métricas ambientais para a busca de melhorias na Ecoeficiência Empresarial.* Dissertação (Mestrado em Engenharia de Produção) – Universidade Nove de Julho, São Paulo.

Schmidheiny, S. 2000. *Eco-efficiency* – creating more value with less impact. WBCSD, Geneva.

Santos-Reyes, D.E., Lawlor-Wright, T. 2001. A design for the environment methodology to support an environmental management system. *Integrated Manufacturing Systems* 12(5): 323-332.

Sissino, C.L.S., Moreira, J.C. 2005. Ecoeficiência: um instrumento para a redução da geração de resíduos e desperdícios em estabelecimentos de saúde. *Caderno de Saúde Pública* 21(6): 1893-1900.

Stiller, H. (1999); *Material Intensity of Advanced Composite Materials* – Paper Nr 90. Wuppertal Institute, Berlin.

Thiollent, M. 2007. *Metodologia da pesquisa-ação*; Cortez, São Paulo.

Vaz, C.R., Fagundes, A.B., Oliveira, I.L. 2009. Proposta de Integração da ISO 14001 e PML: Caso UTFPR-PG. *Revista Eletrônica Produção & Engenharia* 2(1): 96-109.

Vellani, C.L., Ribeiro, M.S. 2009. Sistema contábil para gestão da ecoeficiência empresarial. *Revista Contabilidade & Finanças USP* 20(49): 25-43.

WBCSD - The World Business Council for Sustainable Development. 1996. *Eco-efficiency leadership for improved economic and environmental performance*. WBCSD, Geneva.

WBCSD - The World Business Council for Sustainable Development**.** 2003. *Eco-efficiency toll Box - learning unit C: implementating eco-efficiency***.** WBCSD, Geneva. Availible at: <http://www.wbcsd.org/pages/EDocument/EDocumentDetails.aspx?ID=13593&NoSearchContextKey=true>. Accessed on 04 sep. 2013.

Wuppertal Institute. 2013. *Table of Material intensity, fuels, transport services and food.* Wuppertal Institute, Dusseldorf. Available at: <http://wupperinst.org/uploads/tx_wupperinst/ MIT_2013.pdf > Accessed on 12 oct. 2013.

Zuber-Skerrit, O., Fletcher, M. 2007. The quality of an action research thesis on the social sciences.. *Quality Assurance in Education***,**5(4): 413-436.