



## Implementing cleaner production in an automotive company: an application of material input per unit of service tool to measure environmental and economic advantages

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**ABSTRACT.** Environmental impact reduction has been a growing concern of the automotive industry. One of the main challenges is to implement Cleaner Production as a tool to reduce environmental impacts and provide financial profits. The purpose of this article was to evaluate the environmental impact and economic gains by implementing Cleaner Production, using an unexplored approach, in a company of the automotive sector. The research approach used was a case study, carried out by observation and semi-structured surveys. The production process chosen was updated, so technologies were changed to reduce biotic and abiotic disposal. For the analysis of environmental impacts, the 'Material Input Per Unit of Service' tool (MIPS) was used, in which data was used to calculate: annual net profit; return on investment (%) and return on investment for a period. The results showed that Cleaner Production implementation focusing on changing technology in the production process caused a 75% reduction in environmental impact, and a 62.7% decrease in production costs. Although of this study considers only one case to test the procedure applicability, it can be easily repeated in other more complex systems, by merely making the necessary adjustments due to the complexity of the processes involved.

**Keywords:** environmental impacts reduction, economical profits, automotive industry.

### Implantação de produção mais limpa em uma indústria do setor automotivo: vantagens ambientais e econômicas

**RESUMO.** A redução do impacto ambiental tem sido uma preocupação crescente das indústrias do setor automotivo e uma das dificuldades é implantar Produção Mais Limpa como uma ferramenta para reduzir os impactos ambientais e prover ganhos financeiros. O objetivo desse artigo foi de avaliar os impactos ambientais e ganhos econômicos com a implantação de produção mais limpa, com uma abordagem ainda não explorada, em uma empresa do setor automotivo. O método de pesquisa adotado foi estudo de caso, desenvolvido por meio de observação e entrevista semiestruturada. O processo de produção escolhido foi atualizado com a implantação de novas tecnologias, visando à redução dos descartes no meio biótico e abiótico. Para a análise do impacto ambiental foi utilizada a ferramenta 'Material Input Per Unit of Service' (MIPS), cujos dados foram usados para o cálculo do lucro líquido anual; do retorno sobre o investimento (%) e do período do retorno sobre o investimento. Os resultados indicaram que a implantação de produção mais limpa com foco na mudança de tecnologias no processo de produção gerou redução de 75% do impacto ambiental e ganhos econômicos de 63%. Apesar de o estudo considerar apenas uma aplicação para testar a aplicação do procedimento empregado, ele pode ser facilmente aplicado em sistemas de produção mais complexos, observando-se apenas os ajustes necessários.

**Palavras-chave:** redução de impactos ambientais, ganhos econômicos, indústria automotiva.

### Introduction

The use of natural resources gives cause for concern for public agencies as well as the general public. Therefore, different industries, in particular the automotive sector, are cutting down on the use of these resources by acting heavily on their processes in order to minimize the environmental

impacts on nature. In 1989, Unep (*Programa das Nações Unidas para o Meio Ambiente*) designed and defined the concept of Cleaner Production (CP). CP is the application of a technical, economical, and environmental strategy integrated into processes and products, aiming at increasing efficiency in the use of raw materials, water, and energy by not generating, minimizing, or recycling waste and

emissions with environmental, occupational health, and economical benefits (Organização das Nações Unidas para o Desenvolvimento Industrial & Programa das Nações Unidas para o Meio Ambiente [Unido/Unep], 1995). This in turn leads to eco-efficiency of the productive process. Eco-efficiency has been defined as a general goal to add value and reduce environmental impact. Regardless of the normative part of this concept, the pragmatic part of it refers to the ratio between environmental impact and economic cost or value (Hupples & Ishikawa, 2005).

Automotive sector companies are adopting some low-investment CP practices aimed at reducing greenhouse gas emissions, minimizing losses and waste generation of the production system, mitigating the use of harmful chemical products, and using natural resources efficiently (Telukdarie, Buckley, & Koefoed, 2006). Usually, decision makers in these companies seek to implement CP practices to obtain economic and environmental gains (Orsato & Wells, 2007). Based on the metal-mechanic automotive cluster segment located in the Serra Gaúcha region of Brazil, scientific evidence indicates an opportunity to reduce production costs for economic gains by adopting CP, in addition to generating satisfactory environmental results, contributing to company performance (Severo, Guimarães, Dorion, & Nodari, 2015).

The studies show the concern with rational use of water, implementing a closed cycle process (Sans et al., 1998; Kaenzig, Friot, Saadé, Margni, & Joliet, 2011) to reduce water consumption in applications of thermal treatment and zinc phosphating processes (Alkayaa & Demirerb, 2013). In two of these cases, it was possible to minimize the use of chemical compounds to treat wastewaters from an effluent treatment station (Sans et al., 1998; Alkayaa & Demirerb, 2013), making it possible to manage the station's waste output by converting the sludge for clay manufacturing (Khan, 2008) or simply to pour wastewater without sludge into the sewage system, avoiding contamination (Alkayaa & Demirerb, 2013).

Moreover, automotive industries are reducing greenhouse gas emissions (Taylor, 2006) such as: CO<sub>2</sub>, CFC, particles and dust, carbon monoxide and nitrogen oxide (Kaenzig et al., 2011). To this end, a study measured the ecological costs to study the possibility of mitigating carbon gas emissions via carbon flow mapping, due to governmental pressures to cut down emissions (Lee, 2012), which are fostering the implementation of vehicle power train technology, including manufacturing of hybrid vehicles, bio-fuels, highlighting the Brazilian

scenario of hydrogen energy (Zapata & Nieuwenhuis, 2010).

Another CP practice adopted focuses on controlling and reducing solid waste output (Orth, Baldin, & Zanotelli, 2014) and harmful chemicals (Taylor, 2006; Pandey & Brent, 2008; Kaenzig et al., 2011) such as, corrosive components from the manufacture of cleaning products (Khan, 2008).

In Brazil, following publication of the 2010 Solid Waste Law (*Lei de Resíduos Sólidos*), auto companies acted to cut down the generation of solid waste from molding and finishing processes on reinforced plastic with fiber glass. Yet there is material waste and a lack of worker training on reducing actions and, especially, reuse actions by owners. On average, 74.17 tons of scrap are put out plus a huge quantity of corrugated cardboard and plastic waste output (Orth et al., 2014) – an aspect cited before as an opportunity to minimize package consumption by gauging the packages and reuse (Khan, 2008); besides reducing electric energy use on the production system by mapping the energy flow as well as to put in place recycling practices, reuse and remanufacture of polystyrene (Khan, 2008; Kaenzig et al., 2011; Lee, 2012), therefore increasing economic gains by reducing costs (reusing materials as input) and, environmental awareness, through conserving scarce resources (Xia, Govindan, & Zhu, 2015).

Studies show a higher emphasis on obtaining economic gains by adopting these practices, and environmental measurements are made considering gross mass reduction without establishing the calculation effect of the minimization of environmental impact as a result of the implementation of these practices.

CP implementation in any production system results in lower waste and emissions, and, obviously, lower costs (Giannetti & Almeida, 2006). Any action that results in reduction of natural resources and energy consumption as well as waste output can increase productivity indexes, thus bringing forth added financial profits for the enterprise (Gianetti & Almeida, 2006). Therefore, it is of vital importance that the entrepreneurs bear in mind the gains or financial losses involved in the implementation of a more sustainable process. This becomes a plus when used, because it brings to light important factors for the decision maker (Oliveira Neto, Shibao, Godinho Filho, & Chaves, 2015).

CP economic advantages become more evident in the long run, given that at the start of the project there are investments to adopt new technologies, apart from changes in the existing processes. The advantages of process efficiency increasing are added

to them, creating permanent overall cost reduction as a result by the efficient use of raw materials, water, energy, waste reduction, and also by means of good operational practices (Oliveira Neto et al., 2015).

Within this context, focusing on the automotive sector, there is a scientific gap with regards to the environmental impact evaluation taking into account the abiotic and biotic compartments, water and air whose relation to the ecosystem is direct. Biotic compartment comprises the set of all the living organisms such as plants and decaying organisms, whereas the abiotic compartment is the set of all non-living factors of the ecosystem, but which influence the biotic medium. They are factors such as: temperature, pressure, rain, among others (Odum, 1998).

MIPS is one of the co-efficiency tools which may be used to evaluate environmental impact, considering the abiotic and biotic compartments, water and air, designed at the Wuppertal Institute. MIPS (Material Input Per unit of Service) can be utilized to measure the eco-efficiency of a product or service and, when applied to all scales from a single product for complex systems, so it can measure the environmental impact of a system (Rithoff, Rohn, & Liedtke, 2002).

MIPS tool utilization was evidenced in some papers, as follows: the development of this technology brought about many benefits to people. However, within this global environment is important that companies know how to measure the environmental impacts caused by these advances (Taeko & Takayuki, 2005). Complex systems may have their environmental impacts measured and compared as long as they have appropriate tools (Federici, Ulgiati, & Basosi, 2008). The use of MIPS, along with other environmental evaluation tools can bring significant results for stakeholders, either for immediate and local evaluation or to preview future impacts upon nature (Spinelli, Jez, Pogni, & Basosi, 2013). The use of appropriate tools for environmental evaluation allows the establishment of different scenarios for sustainable solutions within a productive chain (Franzese, Cavalett, Häyhä, & D'Angelo, 2013). In order to have a good evaluation of environmental impacts caused by a manufacturing process, objective measures of simple application should be defined and used in the operation (Jiang, Zhang, & Sutherland, 2012). Thus far, the industry plays an important role on environmental issues controlling, measuring, and cutting down the environmental impacts caused by the manufacturing process (Pirraglia & Saloni, 2012). In addition, MIPS can

indicate the most appropriate solution to reduce environmental impacts. For instance, the results showed that a given technology would not be appropriate for that moment and thereby it was possible to find out at a biodiesel plant that the results collected, in spite of being a likely contribution to reduce CO<sub>2</sub>, soybeans biodiesel was not a viable alternative (Cavalett & Ortega, 2009). The integrated use of environmental measurement tools within a multi-criteria and multi-scale measurement, in which MIPS is one of them, can demonstrate that the use of a fuel-cell new technology is not viable yet (Monaco & Di Matteo, 2011). MIPS was used to measure environmental gain with the implementation of a reverse logistics at a supermarket in Brazil (Oliveira Neto & Sousa, 2014). In the systematic analysis of such articles, which utilized MIPS, no integrated economic gains were seen.

In order to contribute with the theme, specifically focusing on the identified research gap, this study has the following question as its research problem: The implementation of CP practices in an automotive sector company could result in reducing the environmental impact and economic benefit? To carry out the environmental impact calculation, the MIPS tool was used. It contributes to the literature by carrying out environmental impacts measurements in the abiotic-biotic compartments, water and air with the use of MIPS, and the economic gains evaluation on in implementation of CP at a company of the automotive sector, an approach that was not found in literature. In the evaluation of economic benefit the financial gains and investments for the implementation of CP in the researched company were accounted, making it possible to analyze the Return on Investment (ROI). Only two studies were identified that calculated the ROI of adopting CP in automotive industries, reflecting an opportunity of the scientific contribution. The study by Alkayaa and Demirerb (2013) generated considerable capital savings by minimizing the consumption of chemicals in zinc phosphating process, showing ROI in 2.2 years. On the other hand, research by Oliveira Neto, Vendrametto, Naas, Palmeri, and Lucato (2016) showed the results of the implementation of 19 CP practices in the plant of a factory truck, generating cost savings and waste minimization, with ROI in less than a year. This is important because the availability of specific metrics that allow clearly measure the environmental impact of the production system analyzed. These processes were calculated on the production process and showed how a change of determined technologies can

improve the company's results – both environmental and economical. Therefore, the purpose of this work was to measure the economic and environmental impact on the productive system of an automotive sector industry which adopted the CP practice.

In this section, an introduction was presented followed by section 2 of material and methods; section 3, results and discussions; section 4 presents the study itself in which all the interventions that took place in the manufacturing process are outlined; and section 5, Final Comments.

## Material and methods

The literature review of this work was started by a bibliometric research and content analysis with the purpose of identifying published articles in scientific journals; first, which would cite about cleaner production in the automotive industry and, secondly, about the use of MIPS to establish environmental impact calculation. Biometric analysis is to quantify and select the scientific production available to the end of understanding what the authors are addressing regarding the explored subject (Cooper & Lindsay, 1998). Content analysis is to codify the data on an Excel spreadsheet. The content analysis made in this work is of documental origin which via a set of operations (coding, categorization) aimed to represent the content of the present documents to knowledge inference (Bardin, 1986). The data collecting was done and checked by three researchers in an independent way to minimize errors and any prejudice (Hayes & Krippendorff, 2007). For bibliometric research it was, firstly, selected the database to look up (Proquest, Ebsco, Capes, Science Direct, Scopus, and Academic Google). On the second step, the keywords were used to identify the researches on Cleaner Production in the automotive sector. 'Cleaner Production' and 'Automotive' were initially specified for the abstract, title and keywords, which fetched 15 articles. Then, to identify published researches in scientific journals which utilize the keywords: 'MIPS' or 'MIF', identifying 9 studies. On the third step, content analysis of these articles was carried out along with identifying the existing gaps in the literature to contribute to literature. The automotive sector CP articles content analysis focused on identifying the environmental impacts reduction results and the economic aspects, while in the articles that adopt MIPS, to figure out whether these compared the economic gains to the results of the environmental impact minimization.

By doing so, it was verified a lack of researches in the automotive sector as for gains or environmental and economic losses. In order to make up for the lack of related articles on this theme, an explanatory research of qualitative and quantitative nature was carried out (Creswell, 2009) through a unique case study. The case study is a powerful tool and a good research strategy thereby one is able to combine data collecting through the data itself, surveys, questionnaires and observations, turning them into qualitative and/or quantitative results, so that it is possible to create an ideal condition to understand the objective of the expected research (Yin, 2009). In this case study, it was adopted observation and, also, the use of semi-structured surveys which helps to better understand the observation (Seidman, 1991). The observation was done on a data spreadsheet with the quantities used in the processes, as well as the values spent in each operation. The observation also took place in the production process in which were observed all the phases of the manufacture and so it was possible to map all the process by means of a flowchart. All of the information was given by the enterprise and, therefore, it is considered an adequate technique for case study (Bogdan & Biklen, 1992; Westbrook, 1995), to evaluate the gains obtained during the implementation in the industry.

To carry out the case study, we selected a manufacturing process consisting of heat treatment; and machining; packaging and delivery. The company implemented CP procedure of the operations: 10, 30 and 50, focused on technological updating and in the operation 80 (oiling in packing), was eliminated. In operation 10, called heat treatment, was done a technological change, where the salt bath was substituted for H oven. In operations 30 and 50 - in hard turning - the grinding operation was substituted by turning technology. Thus, CP practices were implemented in operations 10, 30, 50 and 80, making it possible to evaluate the minimization of environmental impact by MIPS tool, measuring the economic gain through cost reduction and investment returns. With the economic results at hand it was possible to calculate the ROI (Return on the Investment) based upon Equation 1 and 2 (Gitmann, 1997, Oliveira Neto & Sousa, 2014):

$$\%ReturnOnInvestment (ROI) = \frac{AnnualLiquidProfit}{CPIInvestment} \quad (1)$$

$$\%ReturnOnInvestmentPeriod = \frac{CPIInvestment}{AnnualLiquidProfit} \quad (2)$$

After this phase, it was possible to evaluate the environmental gain obtained through MIPS or MIF

methods, using nine surveys to evaluate the environmental impact: at an electronic industry (Taeko & Takayuki, 2005); at a jewelry industry galvanizing sector (Giannetti, Bonilla, Silva, & Almeida, 2007) comparing sustainable transport options (Federici et al., 2008); on the biodiesel production (Cavalett & Ortega, 2009, Spinelli et al., 2013); on the less aggressive technology in the fuel cell (Monaco & Di Matteo, 2011); on the agriculture sector production (Franzese et al., 2013); on the incremental change of the productive system project (Paoli, Oliveira Neto, & Lucato, 2013) and the reverse logistics implementation in the supermarket segment (Oliveira Neto & Sousa, 2014). MPS or MIP are associated with the Mass Intensity Factors (Material Impact Factor – MIF) in the abiotic-biotic compartments, water and air (Rithoff et al., 2002, Wuppertal Institute, 2013, Oliveira Neto & Sousa, 2014). The quantity of each compartment was processed and, therefore, a total ‘Mass Intensity’ was obtained. To determine the MIF values as presented in Equation 3, just multiply the Mass Flow input (M) by the Intensity Factors (IF), which corresponds to the quantity of material needed to put out a input flow unit (Wuppertal Institute, 2013).

$$MIF = M \times IF \quad (3)$$

The values used in this research are presented in Table 1.

Upon calculating the IF individually, it is possible to calculate the Mass Intensity per Compartment (MIC) in which the environmental impact reduction by compartment is measured (w), biotic (x), water (y) and air (z) like it was presented

in Equation 4. Finally, the total calculation of mass intensity was made (MIT) which consists of, verifying, what is the overall environmental reduction in the system applied, as shown in Equation 5.

$$MIC = IFA(w) + IFB(w) + IFC(w) + \dots + IFn(w) \quad (4)$$

$$MIT = MIC(w) + MIC(x) + MIC(y) + MIC(z) \quad (5)$$

## Results and discussion

The process studied in this work is started at the thermal treatment phase (cementing), which is considered as the most important one, as it consists of the input of the Carbon on the steel surface in such a way that after conveniently tempered, it presents a harder surface than the nucleus. At the next phase, there is the machining process (hard) which is done following the thermal treatment and is made up of 4 operations.

The last phase is comprised of 4 operations, in which the parts are washed, oiled, packed and stored, i.e., they are ready to be delivered to the customer. Figure 1, shows a flowchart with all of the phases of the manufacturing process where the operations 10, 20, and 50, which were object of the CP, are pointed out. These operations went through concept changes and were modified or improved, because a technology upgrade opportunity was identified. As for the operation 80, it was eliminated completely because due to the change of strategy on delivering to the customer, the part started to be delivered in plastic with a Volatile Corrosion Inhibitor (VCI), the process of which will be explained further.

**Table 1.** Mass intensity values used in this article.

Name	Abiotic	Biotic	Water	Air
Aliphatic hydrocarbon [a]	1.69		13.88	0.05
Barium chloride (BaCl) [b]	5.75		13.02	0.43
Barium sulfide [c]	5.75		13.02	0.43
Diethanolamine [d]	1.69		13.88	0.05
Liquid nitrogen [e]	0.81		33.18	1.22
Methanol [f]	1.67		4.46	3.87
Mineral oil [g]	1.69		13.88	0.05
Paper [h]	9.17	2.56	302.99	1.28
Potassium cyanide (KCN) [i]	2.76		90.31	1.06
Sodium cyanide (NaCN) [j]	2.76		90.31	1.06
Sulfuric acid (H <sub>2</sub> SO <sub>4</sub> ) [k]	0.25		4.10	0.70
Triethanolamine [l]	1.69		13.88	0.05
Water [m]	0.01		1.30	0.00

[a] Cheminals, naphtha, Germany data

[b] Basic Materials, borax, synthetic, Germany data

[c] Basic Materials, borax, synthetic, Germany data

[d] Cheminals, naphtha, Germany data

[e] Cheminals, nitrogen, liquid, European data

[f] Cheminals, methanol, European data

[g] Cheminals, naphtha, Germany data

[h] Other, paper and board, bleached, European data

[i] Chemicals, sodium hydroxid, NaOH, European data

[j] Chemicals, sodium hydroxid, NaOH, European data

[k] Cheminals, sulfuric acid, H<sub>2</sub>SO<sub>4</sub>, Germany data

[l] Cheminals, naphtha, Germany data

[m] Water, drinking water, Germany data

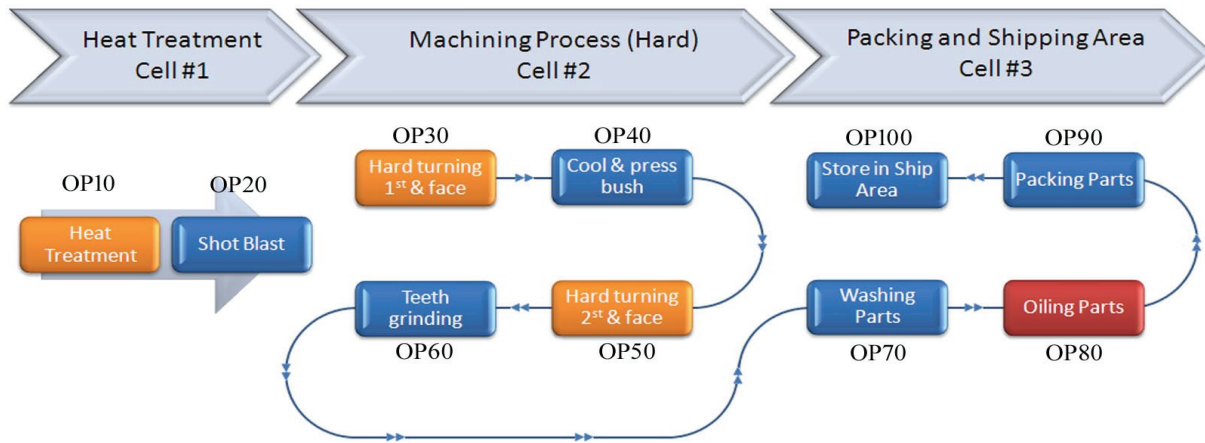


Figure 1. Process Flowchart.

In operation 10 (OP10, in Figure 1), there was a technology change which used thermo-chemical treatment by salt bath and, further, the process started to be carried out with gas oven.

On thermo-chemical treatment it is necessary that the steel, in contact with a substance able of supplying Carbon, is heated up at temperature higher than the critical zone (880 to 980°C), for the iron to be turned into gamma allotropic form. Simply put, thermo-chemical treatment aims at superficially hardening a steel part by partially changing its chemical composition while the material nucleus remains ductile and tenacious.

Salt bath, a process first used in the thermal treatment operation, poses a problem due to the fact of being extremely aggressive to the environment. This occurs because of the use of sodium cyanide (NaCN), potassium cyanide (KCN), as well as barium chloride (BaCl), which is used in the mixtures to prepare the bath. The disposal of such elements in the environment may cause impacts which can be characterized by alteration or degrading of the water quality of these effluent receptor bodies, mainly relating to fish, their habitat, and the use of this water by mankind.

In Figure 2, it was shown the salt bath process used in the industry where the case study was carried. Notice that in Phase#1, the part undergoes 300°C heating to get all of its humidity removed. In phase#2, called 'active bath', there is the steel cementing, i.e., Carbon is released by KCN and NaCN, migrating to the part, so carbonizing its surface. Phase#3, called 'neutral bath', serves to reduce the temperature a little and decrease KCN and NaCN drag to the 'cool down bath', or Phase#4, where the steel tempering occurred at 160 and 200°C. In Phase#5, a wear-out of the part is

done by Sulfuric Acid to remove all and whatever trace of the part's cyanide.

At last, Figure 2, presents a box in which the wastes generated by thermal treatment process through 'salt bath' are pointed out; in this case, 20% of the input products become waste. First, due to the fact of the part going from a bath to another and, part of this bath, ends up falling onto the ground and, after the contamination from one to another until the moment when it is not possible to adjust the bath's concentration, and a general cleanup is mandatory. This 20% disposal is of high toxicity to the environment and the industry must neutralize the same, turning cyanides into cyanates and, only then, the disposal is done.

In the gas oven (cementing oven by gaseous atmosphere), the thermo-chemical treatment is totally controlled by zirconium oxide sensors managed by a supervisory system which allows for maintaining small Carbon concentration and temperature variations. The plus of this process is that into the oven are injected Nitrogen and Methanol only, thereby reducing in a significant way the impacts caused to the environment when compared to the previous process. An investment of US\$ 600K in this process was made as a result of this technology change.

In operations 30 and 50, the process which before used to operate with two over haulers started to use upon implementing use of the CP tool, to work with two lathes equipped with CBN or ceramic pads, which are fit for parts already tempered. Gains of productivity and waste reduction as a result of over hauling reduction which demands a great deal of paper filter were obtained. In these two cases there was no need of investment because there were idle machines which were used again to both processes.

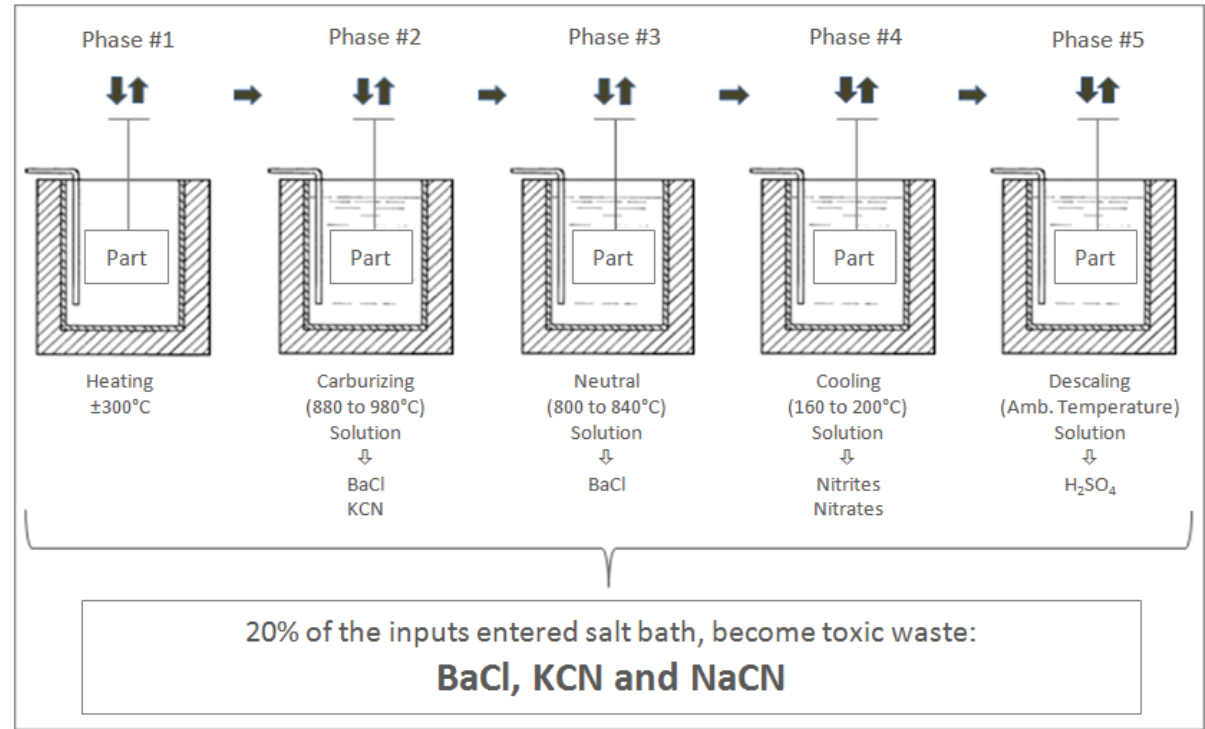


Figure 2. Salt bath Process.

In operation 80, during storing, stocking, and transport, the metals no treated are susceptible to humidity and tend to undergo corrosion if they are not protected. Some anti-corrosion products such as protective oil (Prior to CP application), require an intense labor force and cause huge impact on the environment for both the extraction and the disposal. After various tests as shown in Figure 3, the corrosion inhibitor process was approved and, therefore, the oiling operation was dropped out.

Salt Spray - Test Report  
Engine Intermediate Gear

1. TESTED MATERIAL:  
03 samples of intermediate gears were tested with 20MNCrSE.

2. TEST PERFORMED / METHODOLOGY APPLIED:  
Exposure in chamber of salt spray NBR 8094/94.

3. RESULTS OBTAINED:

SAMPLE (#)	SALT SPRAY TEST (HOURS)	
	RESULTS OBTAINED	SPECIFIED
01	After 2,200 hours in salt spray exposure samples did not show white or red corrosion	Period of 2,160 hours in salt spray exposure without red corrosion.
02		
03		

4. TEST DATE:  
January 15 - April 15, 2013

5. CONCLUSION:  
All samples tested complied with specifications for storage time (3 months)

Figure 3. VCI approval tests.

The process of superficial protection, by an application of a VCI, system begins when the protection vapors are spread within a closed space (by vaporization), thus creating a thin visible layer on the metallic surface and the product will be protected while remaining in the closed space up to

its destination. The VCI layer turns into vapor in the atmosphere when the package is opened and the product is dry and without any corrosion sign. The parts may be kept in stock up to 30 days. Thus, the tests were done with a security coefficient of 3 times, i.e., the protection is guaranteed for 3 months.

One of the greatest concerns when an CP intervention is made on the productive process is to turn it into a more eco-efficient process (Unido/Unep, 1995) and, as a result, turning the industry more competitive (Giannetti et al., 2007). Based on the present case study, it was possible to observe the CP tool aligned with MIPS to measure the environmental impacts exerted in the nature in a complex production process.

The results showed that (1) the industry after a CP implementation obtained a positive and significant relation with regards to reducing environmental impacts, (2) the industry obtained in the relation (before/after) in a very positive way reduction of its production costs (see Table 2 and 3), and (3) the industry was the pioneer to implement CP using MIPS in a complex production process in the automotive sector.

Comparing results of Table 2 to the ones of Table 3, it is observed that the environmental impacts are lower (in Table 3). Regarding the economic aspect, it is possible to notice that the

annual production cost is lower. CP implementation in any production system should have as a result, wastes, emissions and, obviously, costs reductions (Gianneti & Almeida, 2006) and, this, corroborates the results found in this study. The analysis of the data obtained in this study shows that having effective indicators and able of providing the financial and environmental results is fundamental so the industries can be managed adequately (Paoli et al., 2013; Federici et al., 2008) and know how to calculate their environmental impacts (Taeko & Takayuki, 2005) and, also, future (Spinelli et al., 2013). In line with the existing literature it was

possible to observe two distinctive scenarios (Franzese et al., 2013), as noticed in Table 2 and 3, which in a simple and objective way were applied.

In the first scenario (before CP), it was obtained as final result an annual production cost of US\$ 425,586.00 and, an environmental impact of 2,355,720.00 (MIT), which is the mass intensity per unit of input flow, obtained by Equation 4 and 5. Now, in the second scenario, following the same order renders an annual production cost of US\$ 158,586.00 and, an environmental impact of 588,608.40 (MIT), respectively, 62.3 and 75% of reduction, when compared with the first scenario.

**Table 2.** Results obtained prior CP implementation.

OP	Material Used	Qtd (kg) year <sup>-1</sup>	US\$ year <sup>-1</sup>	Ablotic (MIC)	Biotic (MIC)	Water (MIC)	Air (MIC)
#10	Hot Salt Quenching	4800	\$ 121,440.00	16,836.00	0,00	340,740.00	4,332.00
	Potassium cyanide (KCN)	1800		4,968.00		162,558.00	1,908.00
	Sodium cyanide (NaCN)	1800		4,968.00		162,558.00	1,908.00
	Barium chloride (BaCl)	1200		6,900.00		15,624.00	516.00
	Descaling	3600	\$ 63,000.00	900,00	0,00	14,760.00	2,520.00
	Sulfuric acid (H <sub>2</sub> SO <sub>4</sub> )	3600		900,00	0,00	14,760.00	2,520.00
	Partial MIT = 380.088,00		\$ 184,440.00	17,736.00	0,00	355,500.00	6,852.00
#30 & #50	Filter Paper	4800	\$ 15,984.00	44,016.00	12,288.00	1,454,352.00	6,144.00
	Coolant Oil for Grinding	9600	\$ 96,768.00	20,064.00	0,00	238,848.00	960.00
	Water	48000	\$ 13,920.00	3,840.00	0,00	105,600.00	480.00
	Mineral Oil	7200		12,168.00	0,00	99,936.00	360.00
	Triethanolamine	2400		4,056.00	0,00	33,312.00	120.00
	Partial MIT = 1.776.672,00		\$ 112,752.00	64,080.00	12,288.00	1,693,200.00	7,104.00
#80	Protetive Oil	12600	\$ 128,394.00	23,730.00	0,00	174,372.00	858.00
	Mineral Oil	10200		17,238.00	0,00	141,576.00	510.00
	Barium Sulfide	600		3,450.00		7,812.00	258.00
	Aliphatic Hydrocarbon	1800		3,042.00	0,00	24,984.00	90.00
	Partial MIT = 198.960,00		\$ 128,394.00	23,730.00	0,00	174,372.00	858.00
Final Results							
Process Analyzed			US\$ year <sup>-1</sup>	Abiotic (MIC-A)	Biotic (MIC-B)	Water (MIC-C)	Air (MIC-D)
OP 10 .....			\$184,440.00	17,736.00	0,00	355,500.00	6,852.00
OP 30 & 80 .....			\$112,752.00	64,080.00	12,288.00	1,693,200.00	7,104.00
OP 80 .....			\$128,394.00	23,730.00	0,00	174,372.00	858.00
			\$425,586.00	105,54.00	12,288.00	2,223,072.00	14,814.00
Production Cost			A	B	C	D	
			\$425,586.00	Total MIT (A+B+C+D) = 2,355,720.00			

**Table 3.** Results obtained after CP implementation.

OP	Material Used	Qtd (kg) year <sup>-1</sup>	US\$ year <sup>-1</sup>	Abiotic (MIC)	Biotic (MIC)	Water (MIC)	Air (MIC)
#10	Gas Oven Quenching - Controlled Atm	8400	\$22,296.00	8,868.00	0,00	209,784.00	16,608.00
	Liquid Nitrogen	6000	\$15,120.00	4,860.00	0,00	199,080.00	7,320.00
	Methanol	2400	\$7,176.00	4,008.00	0,00	10,704.00	9,288.00
	Cooling Oil	1920	\$24,000.00	3,244.80	0,00	26,649.60	96.00
	Degreaser Oil	1800	\$26,658.00	3,312.00	0,00	60,084.00	90.00
	Water	27000	\$7,830.00	270.00	0,00	35,100.00	0.00
	Mineral Oil	1080		1,825.20	0,00	14,990.40	54.00
	Diethanolamine	720		1,216.80	0,00	9,993.60	36.00
Partial MIT = 328.736,40			\$72,954.00	15,424.80	0,00	296,517.60	16,794.00
#30 & #50	Coolant Oil for Lathe	9600	\$85,632.00	20,064.00	0,00	238,848.00	960.00
	Water	48000	\$13,920.00	3,840.00	0,00	105,600.00	480.00
	Mineral Oil	7200		12,168.00	0,00	99,936.00	360.00
	Triethanolamine	2400		4,056.00	0,00	33,312.00	120.00
			\$85,632.00	20,064.00	0,00	238,848.00	960.00
Final Results							
Process Analyzed			US\$ year <sup>-1</sup>	Abiotic (MIC-A)	Biotic (MIC-B)	Water (MIC-C)	Air (MIC-D)
OP 10 .....			\$72,954.00	15,424.80	0,00	296,517.60	16,794.00
OP 30 & 50 .....			\$85,632.00	20,064.00	0,00	238,848.00	960.00
			\$158,586.00	35,488.80	0,00	535,365.60	17,754.00
Production Cost			A	B	C	D	
			\$158,586.00	Total MIT (A+B+C+D) = 588,608.40			



With the results obtained as a consequence of CP implementation, it was possible to calculate the results of Equation 1 and 2 by means of Equation 6, once the value for the necessary investment required for CP implementation was US\$ 600 K, apart from the gains obtained by its implementation, according to what was presented in Table 3.

$$P = TC_{before} - TC_{after}$$

$$P = \$425,586.00 - \$158,586.00 \rightarrow \$267,000.00 \quad (6)$$

where:

P = annual net Profit;

TC<sub>before</sub> = annual total cost (before);

TC<sub>after</sub> = annual total cost (after).

From this result it was possible to obtain the ROI value presented in Equation 7 and 8:

$$\%ROI = \frac{\$267K}{\$600K} = 44.5\% \quad (7)$$

$$ROI_{Period} = \frac{\$600K}{\$267K} = 2.2 \text{ years} \quad (8)$$

These data shows that (Equation 1) out putting the same quantity of parts (yearly), the environmental impact caused by this process decreased four-fold, whereas in (Equation 2) the production cost decreased 2.6 times, thus demonstrating an economic viability of the project in which is possible to observe this by the ROI calculation, where the investment made is turned over in 2.2 years, consisting of a good turn over time frame. The ROI is therefore, an indicator that allows to analyze clearly the performance of the CP implementation made in this study, primarily reflecting the payback (ROI) period of invested capital. Few Studies analysis of the Return On Investment (ROI) concomitantly with the CP adoption in the automotive industry. Alkayaa and Demirerb (2013) mention the most relevant economic gain occurred through greater efficiency in the consumption of chemicals in the zinc phosphate coating process. It was reduced by 26.1% in the consumption of chemicals, minimizing the costs in order of US\$ 8,442 per year. It is noteworthy that the total annual cost savings was estimated at US\$ 14.760 per year. On the other hand, it was necessary to invest in sustainable measures in the production and procurement of equipment the amount of US\$ 34.233. The payback period on investment (ROI) implementations was achieved in approximately 2.3 years. Oliveira Neto et al. (2016) conducted a survey on a large manufacturer of trucks. It was found investment of US\$ 3.1 million, 2.8 million was spent on equipment and facilities, and US\$ 700,000 was spent

on consulting and training for the adoption of nineteen CP practices in system production. The internal rate of subsequent return on investment reached more than 30% per year and the ROI period was nearly a year. The findings show that the ROI time is associated with the scope of the CP implementation program in automotive companies, higher investment for more CP practices, in the respective companies production system, make a ROI in less time. This result boosts organizational managers of the automotive sector to adopt CP practices in the production system for economic gain.

## Conclusion

The implementation of CP in the automotive sector industry yielded a 75% environmental impact reduction and, a 62.3% economic gain. It was notice during the bibliographic lookup, the lack of material published about this theme in question, in the automotive sector, what shows the contribution of the present study.

The results herein yielded support some theoretical and pragmatic implications in which increases the field of knowledge because they put aside more simple interventions in the production processes and act upon more complex processes, which involved change of technology and operation leave out. As a case study, this paper presents limitations.

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