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# Identifying and Prioritizing Ecodesign Key Factors for the Automotive Industry

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## 1. Introduction

One of the key causes that most contribute to the environmental degradation that threatens the planet is the increasing production and consumption of goods and services. Some of the factors that contribute to that are: (a) the lifestyle of some societies; (b) the development of emerging countries; (c) the ageing of population in developed countries; (d) the inequalities among regions of the planet; and (e) the ever smaller life cycle of products (Maxwell et al., 2006).

The balance between environmental “cost” and functional “income” is essential for sustainable development, resulting that environmental issues must now be merged into “classical” product development processes (Luttropp & Lagerstedt, 2006). Concepts such as ecodesign, cleaner production, design for (the) environment, recycling projects and development of sustainable products promote a re-design at techniques, like conceptualization, design and manufacturing of goods (Byggeth et al., 2007).

Ecodesign is a concept that integrates multifaceted aspects of design and environmental considerations aiming to create sustainable solutions that satisfy human needs and desires. The product is a part of life-style and design, as well as ecodesign, relate to more than the rational function of a product or service (Karlsson & Luttropp, 2006).

There are several motivations for implementing ecodesign besides the environmental aspects, e.g. cost savings, competitive advantage, image of the company, quality improvement, legal requirements. Large companies consider the implementation of ecodesign as a way to preserve the environment as well the competitiveness and the image of the organization. Nevertheless, small and medium enterprises still need to be convinced of the advantages and possibilities of ecodesign (Vercalsteren, 2001). A priori, SMES rarely integrate the analysis of environmental restrictions to their field of knowledge (Pochat et al., 2007).

Another difficulty presented for companies in general, and SMES in particular, refers to the ecodesign tools. Most require application by experts (Pochat et al., 2007; Rao, 2004). Moreover, many tools for ecodesign fail because they do not focus on the design, but seek retrospective analysis based on existing products (Lofthouse, 2006). Indeed, ecodesign, as a process, must be integrated into the design and management processes of the company. Not only appropriated tools for ecodesign are needed, but also tools that can help designers to link them to their conventional tools (Pochat et al., 2007). A lot of different requirements for

ecodesign are proposed in literature. Main of them regards materials, components, processes and products characteristics, use of energy, storage and distribution, packaging and waste (Wimmer et al., 2005; Luttrupp & Lagerstedt, 2006; Fiksel, 1996).

Among others, the automotive electronics industry hosts ecodesign initiatives in response to the regulations and to the innovation's demand verified in this industry (Ferrão & Amaral, 2006; Mathieux et al., 2001).

Aiming to contribute to increase knowledge on ecodesign practices and management, the first part of this chapter highlights some of the key factors that influence the adoption and implementation of ecodesign practices in manufacturing companies. The discussion focuses particularly on a case study which illustrates how ecodesign is being incorporated into the design of products manufactured by a mid-sized automotive electronics supplier in Brazil.

An analysis of the performance of ecodesign is also contributive in this subject. Authors such as Cabezas et al. (2005) and Svensson et al. (2006) have been working on the development of performance indicators associated to ecodesign; they highlight, however, there is no common sense to that matter. Despite of how frequent the environmental performance is present in literature, it has not been found a shape of guide lines or an objective method that might generate an instrument for measuring the application or performance for ecodesign practices. Such instrument would avoid all efforts towards ecodesign to result contradictory and ineffective and could, as well, guide the organizations giving priority to resources where environmental gains are more meaningful.

For the prioritization of resources and actions related to ecodesign, supported by papers that discuss evaluation and performance in environmental aspects, it is understood to be relevant the identification of the degree of importance of each key factor of ecodesign for companies of a particular industry and how much each company fulfils each requirement.

This investigation also aims to prioritize resources and actions of ecodesign. Supported by Hermann et al. (2007), which speak on measurement of performance on environmental aspects, the authors consider relevant to identify the degree of importance of each ecodesign construct for companies in a particular industry and to evaluate the degree of application of ecodesign constructs.

Considering the context presented, the main objective of the second part of this chapter is to assess the performance of ecodesign in a chemical company that supplies the automotive industry. Secondary objectives were: (a) to identify latent constructs and indicators that explain the ecodesign performance of the operation; (b) to assess the relative importance of ecodesign constructs (practices), supported by the Analytic Hierarchy Process (AHP); (c) to assess the degree of application of ecodesign constructs (practices); (d) to evaluate the gaps between importance and application of ecodesign constructs. For doing so, it was developed a method to evaluate the performance in ecodesign. The method was developed taking into account that the application in other industries is feasible.

After this introduction, the chapter presents: theoretical background about ecodesign implementation, practices and discussion about the reasons for adoption; theoretical background about environmental performance measurement; research methodology, findings, discussions and contribution for the first and the second objectives; and conclusions and suggestions for continuity. Limitations of the research are those related to the research method, that is, the results are valid for the case, nor for the entire industry, but the method can be replicated elsewhere, if applicable.

## 2. Ecodesign

### 2.1 Concepts, implementation and practices

Kazazian (2005) focuses on eco-conception, which is the process of applying the concepts of ecodesign. With this approach, the environment is considered to be equal in importance to factors such as technical feasibility, cost control, and market demand. Eco-conception can lead to three different levels of eco-design intervention when designing a product: (a) optimization for environmental impact reduction, (b) more intensive development efforts, such as modifying the product, and (c) “radical” intervention, such as substitution of different products or services (Kazazian, 2005).

Boks (2006) stresses the importance of product designers, emphasizing their unique position and ability to influence environmental strategies. Designers can have a key impact when they enlarge the focus of their efforts, giving the environment a prominent position in defining the parameters of product development.

Karlsson & Luttrupp (2006) note that ecodesign incorporates priorities related to sustainability into the overall business scenario. The “eco” in ecodesign can refer to both economics (reflecting a business orientation) and ecology (reflecting the importance of environmental aspects) (Figure 1).

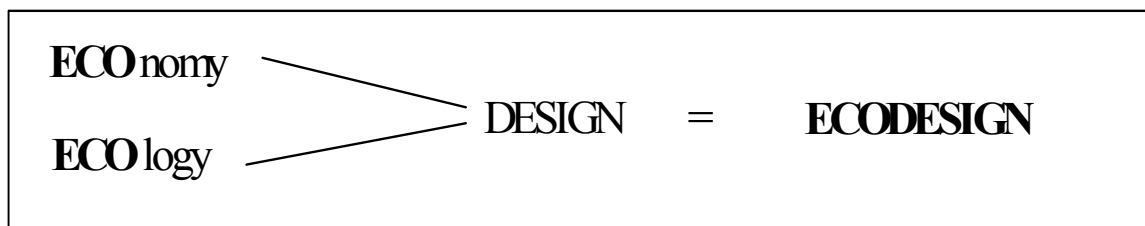


Fig. 1. The linguistic map of the word ecodesign (Karlsson & Luttrupp, 2006).

#### 2.1.1 Potential of a company for the application of ecodesign

Regarding the potential of a company for the application of ecodesign, and consequently its insertion on products development routine, the organization must evaluate internal facts, external facts and the product (Vercalsteren, 2001). Internal factors are: (a) company motivation; (b) innovation, considering the ability of the company into influencing the specifications of the product; (c) competitiveness, once a company that is leader of a specific sector in the market has more chances of re-sketching the products, the smaller companies can consider ecodesign as an opportunity to increase its participation in the market; and, (d) sector, considering that if there already are equivalent initiatives in the sector, the company can learn from these experiences. External factors are: (a) regulation; (b) clients and market, where it is necessary to evaluate whether the market will accept or not the green products; and, (c) suppliers, once it is essential their willing in cooperate. As per the product, it must have the potential for a redesign based under the environmental ponderings (Vercalsteren, 2001).

#### 2.1.2 Practices for ecodesign

Recognized the potential of a company for the application of ecodesign, it is necessary the identification of the key factors that constitute ecodesign. In order to do so, we evaluated propositions from Fiksel (1996), Wimmer et al. (2005) and Luttrupp & Lagersted (2006). The synthesis of the proposed practices is presented on Table 1.

First level (key factors)	Second level (items)
<b>Materials: choice and use</b>	(i) ability to use raw material closer to their natural state, (ii) ability to avoid mixtures of non-compatible materials, (iii) ability to eliminate the use of toxic, hazardous and carcinogenic substances, (iv) ability to not use raw materials that generate hazardous waste (Class I); (v) ability to use recycled and / or renewable materials, and (vi) ability to reduce atmospheric emissions caused by the use of volatile organic compounds.
<b>Product components: selection and choice</b>	(i) ability to recover components or to use components recovered, (ii) ability to facilitate access to components, (iii) ability to identify materials and components, and (iv) ability to determine the degree of recycling of each material and component.
<b>Product/Process characteristics</b>	(i) ability to develop products with simpler forms and that reduce the use or consumption of raw materials, (ii) the ability to design products with longer lifetime (iii) capacity to design multifunctional products, (iv) capacity to perform upgrades to the product, and (v) ability to develop a product with a "design" that complies with the world trends
<b>Use of energy</b>	(i) ability to use energy from renewable resources, (ii) ability to use devices for reduction of power consumption during use of the product, (iii) ability to reduce power consumption during the production of the product, and (iv) ability to reduce power consumption during product storage.
<b>Products distribution</b>	(i) ability to plan the logistics of distribution, (ii) ability to favor suppliers / distributors located closer, (iii) ability to minimize inventory in all the stages of the product lifetime, and (iv) ability to use modes of transport more energy efficient.
<b>Packaging and documentation</b>	(i) ability to reduce weight and complexity of packaging, (ii) ability to use electronic documentation, (iii) ability to use packaging that can be reused, (iv) ability to use packages produced from reused materials, and (v) ability to use refillable products.
<b>Waste</b>	(i) ability to minimize waste generated in the production process, (ii) ability to minimize waste generated during the use of the product, (iii) ability to reuse the waste generated, (iv) ability to ensure acceptable limits of emissions, and (v) ability to eliminate the presence of hazardous waste (Class I).

Source: adapted from Wimmer *et al.* (2005); Luttrupp & Lagerstedt (2006); Fiksel (1996).

Table 1. Syntheses of practices proposed for ecodesign

### 2.1.3 Ecodesign tools

Over the past decade or so, a wide range of ecodesign tools have been developed in order to support the application of the ecodesign practices. In many cases, tools have grown out of pilot projects and partnerships between private companies and academic research centers. Pochat *et al.* (2007) identified more than 150 ecodesign tools. More tools have been created as interest in ecodesign increases.

Despite the plethora of tools available, ecodesign is not always promptly adopted by manufacturing companies. Several authors note that industry designers often find the tools

difficult to use (Lofthouse, 2006; Pochat et al., 2007; Luttrupp & Lagerstedt, 2006; Byggeth & Hochschorner, 2006; Byggeth et al., 2007). According to Lofthouse (2006), tools often fail to be adopted “because they do not focus on design, but instead are aimed at strategic management or retrospective analysis of existing products.” The author notes that what designers actually need is “specific information on areas such as materials and construction techniques to help them become more easily involved in ecodesign projects.” The environmental information associated with ecodesign tools is often very general. In most instances, tools do not provide the detailed and specific information that designers find necessary when working on design projects.

Pochat et al. (2007) note that effective use of ecodesign tools generally requires input from experts. This can create difficulties for many companies, especially small and mid-sized enterprises, in which often lack the resources required to bring in expert assistance.

Moreover, the amount of information available about both materials and product environmental aspects has increased substantially in recent years. This has made ecodesign tools even more difficult and cumbersome to use, and requires them to be updated frequently (Luttrupp & Lagerstedt, 2006).

Several authors mention ecodesign checklists. These checklists typically include lists of questions relating to the potential environmental impacts of products. Pochat et al. (2007) see the ecodesign checklist as a qualitative tool that is useful primarily for identifying key environmental issues associated with the life cycle of products. According to Lofthouse (2006), many designers view ecodesign checklists as too general to be useful. In addition, the checklists often are perceived as including too many requirements. Byggeth & Hochschorner (2006) note that ecodesign checklists often require the user to make trade-offs among a variety of different aspects and issues without sufficient direction on which options are the most preferable from the standpoint of promoting sustainability. The checklist user typically must evaluate whether the solutions offered “are good, indifferent, bad or irrelevant.”

A number of different ecodesign checklists exist, many of which have been developed by designers and engineers. Despite their potential drawbacks, using these checklists can help implementers record their ecodesign activities and work more cooperatively with other teams (Côté et al., 2006).

## **2.2 Environmental practices in the automotive industry**

Regulation clearly can play an important role in promoting ecodesign. Much of the relevant literature that was reviewed concentrated on regulation in the European Union (EU), which has implemented some important environmental regulatory directives affecting the automotive and electronics industries. These studies include the end-of-life vehicles (ELV) directive, the waste electrical and electronic equipment (WEEE) directive, and the restriction of hazardous substances (RoHS) directive. In addition, the EU has finalized a framework directive for reducing the environmental impacts of energy-using products through ecodesign (Park & Tahara, 2008; Pochat et al., 2007).

The automotive industry operates in a highly competitive market, with worldwide sales and distribution of products. The tolerance for product flaws is low, especially in the case of vehicle safety features. These factors can operate as constraints on the adoption of ecodesign practices by companies in the industry.

### **2.2.1 Negative environmental impacts**

In terms of natural resources, the “environmental balance” for vehicles has always been negative. According to Kazazian (2005), production of a vehicle typically requires displacing fifteen tons of raw material (about ten times the weight of the final product). The production phase also uses large amounts of water. For example, about forty thousand liters of water are required to manufacture a car. During their useful life, vehicles consume fuel and lubricating oils, most often in the form of non-renewable fossil-based resources. Some of the fuel and oil products leak into the environment as contaminants. In addition, each vehicle uses several tires, many of which are not recycled. Moreover, vehicles emit significant quantities of air pollutants, including carbon dioxide (a major greenhouse gas) and sulphur dioxide (which contributes to acid rain).

Vehicles can also be difficult to recycle at the end of their life cycle. They typically contain a variety of different materials (including plastics and metals, as well as electrical and electronic components) that may be costly and challenging to separate.

### **2.2.2 Efforts to green the automotive industry**

These negative impacts, related to the environmental balance for vehicles, reinforce the perception that automobiles and other vehicles are not designed with an emphasis on preserving the environment and promoting sustainability. Partly in response to these perceptions and concerns, car makers are working to make the industry more environmentally friendly.

In recent years, the automotive industry has developed high-performance and hybrid engines. Car makers are using more parts manufactured with recycled composite materials. In addition, more vehicles now run on renewable bio-fuels and use high-durability synthetic lubricating oils.

As noted in the following sections, the automotive industry is also seeking to restrict the use of hazardous substances and to increase the quantity of packaging and materials that are recycled and reused. These issues are particularly relevant to automotive manufacturers that sell products in the European Union. The EU’s RoHS directive bans the use of certain hazardous materials as constituents in specified types of electronic equipment (Donnelly et al., 2006).

### **2.2.3 Restrictions on the use of hazardous materials**

Many automotive car assemblers now provide their suppliers with lists identifying hazardous materials that are subject to restriction of use pursuant to applicable laws or standards. Typically, “white lists” identify materials that can be used. “Gray lists” indicate materials that can potentially be used if certain conditions are met or there is sufficient reason to do so. “Black lists” identify materials that are prohibited (Luttrupp & Lagerstedt, 2006; Tingström & Karlsson, 2006).

As part of product development, companies that supply automotive assemblers generally must produce statements confirming that they are in compliance with any applicable restrictions on the use of hazardous substances. If they cannot do so, they may be able to request a temporary waiver from the assembler. In connection with such a request, the supplier generally must describe the reasons for the deviation and present a plan of action for meeting the restrictions in the future.

Suppliers to automotive assemblers must also register their products into the International Material Data System (IMDS), a database that contains information (including chemical

composition) on all materials used in the manufacture of cars. The supplier's registration can then be checked against the automotive assemblers' gray and black lists to determine whether there are any deviations.

The company investigated on the first part of the research develops and manufactures products for vehicle assembly. These products are subject to hazardous-materials restrictions and are registered on the IMDS.

#### **2.2.4 Reducing and reusing packaging**

The process of assembling an automotive product involves a large number of different items, and the assembly line requires a high degree of standardization. As a result, any reusable forms of packaging that are adopted also generally must be standardized. Boxes typically have identifying information that allows their supplier to be traced. In addition, pallets typically must meet standards that have been established for size dimensions and maximum weights.

The study company involved in the first part of this research is an approved supplier to automotive assemblers. The company employs reusable forms of packaging, even though doing so adds extra costs in terms of administration and transportation.

#### **2.2.5 Conflicts between ecodesign practices and automotive safety requirements**

In the automotive industry, parts that are related to safety must be disposed of if they fail. Under the applicable automotive assembler standards, such parts cannot be repaired and re-sold on the market. They may, however, be dismantled and recycled.

This disposal requirement conflicts with the principles of ecodesign. However, the integrity of the automotive product clearly must be safeguarded. In this instance, the automotive industry has indicated that it values accident prevention over the ecodesign principles related to component reuse.

### **2.3 Assessment of performance in ecodesign**

Tingström & Karlsson (2006) highlight the ecodesign's multidisciplinary, affirming this is not a linear and repetitive process, for it must be tested or measured the effect of the product on the environment by using models. They also point out that in environmental practices and strategies the execution of the plans must be measured by measuring systems that hold the complexity of the object. Sellitto et al. (2010) present the importance of performance measurement systems in several managerial strategies, including those regarding environmental issues. It is seen in Borchardt et al. (2009) the application of AHP (Analytic Hierarchy Process) in the integration of environmental goals in ecodesign.

It has been observed in the researched literature that there are no clear distinctions among performance measurement and performance evaluation terms. For this research, it was adopted the definition proposed by Sellitto et al. (2006): one should talk about performance evaluation when based on assessment of categorical variates and one should mention performance measurement when based on measurement of quantitative variates.

A system for measurement or for performance evaluation must: (a) avoid under-optimize the place; (b) unfold strategic goals up to operational levels; (c) help with full understanding of goals and conflicts structure, strategy trade-offs; and (d) consider aspects of the organizational culture (Bititci, 1995). The usage of several variates in performance measurement remits to multicriteria decision. As per French (1986), it is hardly ever found a



model to be clear and uniformly structured in a multicriteria decision. Deepened discussions about the theory of decision based on multicriterial focus are found in French (1986).

The evaluation of performance requires a model for measurement and communications, which is obtained by mental construction. The most abstract construction is the theoretical term that holds aspects of a definition wide enough, structured upon constructs and concepts. The other constructs are also of abstract construction, deliberately created to answer a scientific purpose, however closer to reality. The concept, at last, it is not the phenomena yet, but it can already communicate its implications. Its dimensions are represented by numerical values - the indicators - that might be combined and summed quantitatively in indexes, according hierarchical theoretical schemes that help represent the intangible reality (Voss et al., 2002).

The structure of performance, in this paper known as ecodesign performance, can be organized in a tree-like structure, illustrated in Figure 2. The tree-like shape can be pondered by methods of decision support, such as AHP (Analytic Hierarchy Process).

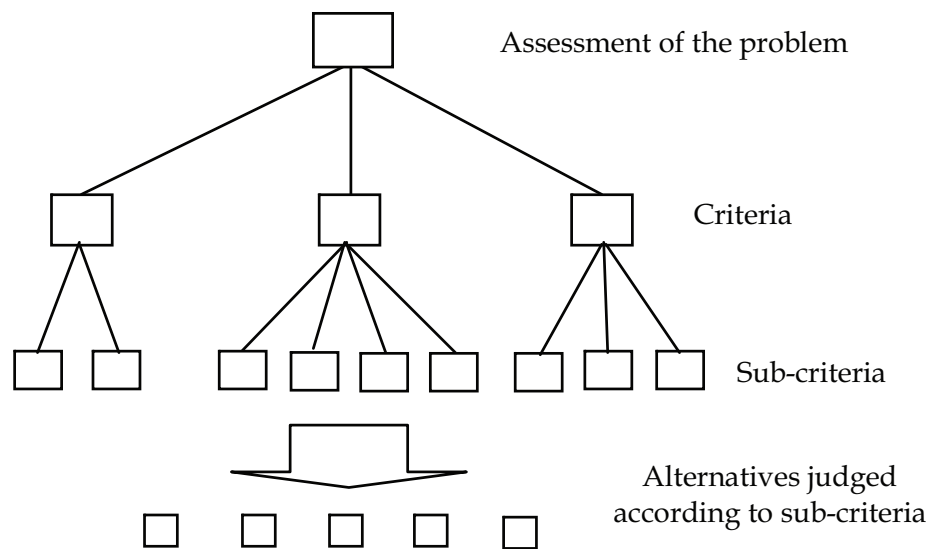


Fig. 2. Structure of hierarchic decision (adapted from Forman & Selly, 2001).

According to Forman & Selly (2001), the AHP forces the decision makers to consider perceptions, experience, intuitions and uncertainties in a rational manner, generating scales of priorities or weights. It is a methodology of compensatory decision, once weak alternatives to an objective can have strong performance in other objectives. The AHP operates in three steps: (a) description of a complex situation of interest under the shape of hierarchic concepts, shaped by criteria and sub-criteria up to the point when, as per decision makers, the assessment of the problem has been enough described; (b) comparing two by two the influence of the criteria and sub-criteria on higher hierarchic levels; and (c) computing the results. The options with preference on paret base comparison, used on AHP, are presented on Table 2. Saaty (1991) recommends the determination of the CRs, the reasons of consistency on assessments, which must be smaller than 0.10. Although the recommendation, we stress that the lower the CR is the better the decision will be, so it is worth seeking lower values for the variate by eventually reviewing judgements.

if $a_i$ related to $a_j =$	then $c_{ij} =$	if $a_i$ related to $a_j =$	then $c_{ij} =$
equals	1	equals	1
a little more important	3	a little less important	1/3
a lot more important	5	a lot less important	1/5
strongly more important	7	strongly less important	1/7
absolutely more important	9	absolutely less important	1/9

Source: Saaty, 1991, p.22 and 23.

Table 2. Preferential options based on pared comparison

### 3. 1<sup>st</sup> Part – Ecodesign implementation at manufacturing company

#### 3.1. Research methodology for the 1<sup>st</sup> part of the research

The research discussed in this part of the chapter involved a case study of an automotive supplier. The case study methodology allows researchers to examine a subject in depth without separating the subject from its contextual environment (Voss et al., 2002)

Authors have recognized three main types of case studies: exploratory, descriptive, and explanatory. An exploratory case study seeks information and suggests hypotheses for further studies. A descriptive case study investigates associations between the variables defined in exploratory studies. Finally, an explanatory case study presents plausible explanations for associations established in descriptive studies (Yin, 2001).

It has been suggested that a case study can contribute to theoretical research in at least five ways: first by providing, for subsequent studies, a deep and specific description of an object; second by interpreting some regularities as evidence of more generic and not yet verified theoretical postulates; third by heuristic: a situation is deliberately constructed to test an idea; fourth by doing a plausible search based on the theory proposed by the heuristic method; and fifth by the crucial case, which supports or refutes the theory (Easterby, 1975).

##### 3.1.1 Characteristics of the case study

The case study described here is exploratory; we have gathered information and hypotheses for future studies. The contribution this case study makes to theory is of the first type: a thorough description of a specific subject. It is also inductive, as the first in a potential series of studies that could lead to a grounded theory of motivation for ecodesign implementation. This case study was guided by the following questions:

- a. Why the company decided to adopt ecodesign practices?
- b. How are ecodesign practices being incorporated into routine product design at the study company?

Ultimately, the goal of the case study described here was to provide insights, at the exploratory level, about the elements that induce organizations to adopt ecodesign practices and about the ways in which ecodesign practices can be incorporated into organizations' product design procedures.

##### 3.1.2 Data collection

Much of the information for this case study was collected via five semi-structured interviews with managers in the company's research and development (R&D) department, managers in product design, and the manager of the company's environmental management system. In order to further develop data, we also relied on direct observation and document analysis.

### **3.2 Results and discussion for ecodesign implementation analysis**

The research described here was carried out at a company that supplies electronic components to the automotive industry. The study company operates in Rio Grande do Sul, a state of Brazil and can be classified as mid-sized. The company has obtained certification to both ISO 9001 and ISO 14001.

#### **3.2.1 Products made by the study company**

The company produces on-board electronic components for vehicles. Some of the items it supplies were developed to meet individual customer specifications, while others are standardized products.

The first product category consists mainly of electrical relays for switching and voltage converters; these items affect automotive safety since they directly influence the basic function of vehicles. The latter product group includes standardized components used for entertainment applications, such as on-board video and audio systems for buses.

#### **3.2.2 Relationships with vehicle assemblers**

The study company supplies its products directly to assemblers of trucks and buses. Some of the company's personnel have in-depth knowledge regarding the design of the vehicles that use its components. As a result, there are confidentiality agreements between the study company and its key employees and between the study company and the assemblers it supplies.

The company has developed a complex business-to-business relationship with its customers. The company must meet applicable regulatory requirements and also depends on customers' approval in order to make changes to its products. The study company has little autonomy in making such decisions.

Since the products manufactured often involve special safety and security features, the company is not allowed to reuse parts, since doing so could compromise functional reliability. However, raw materials (such as plastics, metals, and other materials) can be recycled since they are routed to the primary supplier for inclusion in the overall process of manufacture.

#### **3.2.3 Company environmental management policy**

For the past nine years, the study company's environmental management policy has included provisions that are intended to address problems related to resource scarcity. Key issues covered in the company's environmental management policy include (a) energy consumption, (b) materials consumption, and (c) waste handling and treatment.

When automotive assemblers go through the process of qualifying suppliers, they primarily evaluate characteristics such as the supplier's ability to deliver products reliably. Suppliers also must be able to meet all relevant environmental requirements, such as those pertaining to restrictions on the use of hazardous substances. However, using techniques that exceed the applicable environmental protection requirements does not constitute a preferential factor for a given supplier.

#### **3.2.4 Motivations for adopting ecodesign**

When asked about their motivation for adopting ecodesign practices in strategic planning, respondents at the study company said that the main drivers involved reducing costs, which had the effect of increasing the company's profit margin and providing it with more flexibility. In the study company's view, cost reduction could be facilitated by dematerializing (using the

smallest possible amount of raw material) and by lowering expenditures related to the treatment of waste.

The study company sees implementation of ecodesign as a way to formalize eco-concepts in the new-product development process, allowing for better control of results and continuous improvement.

### **3.2.5 Ecodesign implementation process**

Because the scope of ecodesign is broad, the company formed a multidisciplinary group to handle the study, planning, and strategic deployment of ecodesign techniques. Top management at the company organized a working group that included people with expertise in a range of relevant areas, such as trade, development, product quality, logistics, and industrialization.

The working group focused on activities related to the development of products and processes. The steps they followed in implementing ecodesign are outlined in the following sections.

#### **Study phase**

Members of the working group read the relevant literature and made contact with other companies that had already implemented ecodesign methods. Personnel throughout the whole company received training on the basic principles of ecodesign, and staff members' suggestions were collected.

At this stage of the process, the company also analyzed customer demands, along with internal company rules and the requirements of applicable standards such as ISO 9001, ISO/TS 16949 (a quality management system for the automotive industry), and ISO 14001.

#### **Planning**

The ecodesign implementation project was framed using the company's projects management methodology, with timelines and financial guidelines established. Regular meetings were held for critical and risk analyses.

#### **Formulation of primary guidelines**

The company prepared primary guidelines (IMP - Integrated Management Procedure) that incorporated ecodesign practices and guidance on the development of products and industrial processes.

#### **Formulation of secondary guidelines (operating procedures)**

The actual operating procedures for application of ecodesign were deployed via engineering specifications. These procedures involved a high degree of detail and were implemented through checklists, as recommended by Donnelly et al. (2006) for "knowledge management in ecodesign." The company frequently reviews and updates its checklists, allowing new contributions to be recorded and preserving the knowledge gained for future use.

Table 3 offers sample checklists of items to be considered in electric-electronic design and mechanical design of products, along with ecodesign-related recommendations. The checklists consider aspects such as materials recovery, energy efficiency, product simplification, separation of materials, and use of specific manufacturing components, including plastics, metals, and printed circuit boards. These parts are used in various phases of the product design process, including detailing and meeting critical analysis.

The development team suggested extending the principles of ecodesign to software development. Ecodesign principles can be applied to extend the useful life of installed software by providing the ability to receive updates, making the product multifunctional,

and preventing downtime with software maintenance routines and remote systems. The company encountered some difficulties in the course of implementing ecodesign practices. In particular, when assessing ecodesign concepts and seeking to apply checklists, it lacked technical information on environmental impacts.

For example, in a case where the project team was trying to choose among alternatives for the surface treatment of metals, it was hard to make a choice due to the lack of information indicating the environmental impacts. The team also believes that ecodesign implementation could be expanded to include the company's suppliers. The members agreed that suppliers could be educated about ecodesign and encouraged to adopt proactive attitudes regarding the environmental impact of manufacturing. It was understood, by the group, that sustainability can be achieved only with the engagement of the whole production chain.

Ecodesign item	Checklist to Electric-Electronic Design of the Product	Checklist to Mechanical Design of the Product
1. Material recovery	Give priority to constituents who may have recoverable raw material: for example electrolytic capacitors have recyclable aluminum; tantalum capacitors have not.	Try using plastics and thermoplastics instead of termofixes; do not unite incompatible plastic materials that would make the separation impossible therefore recycling impossible.
2. Components recovery	As standards in the automotive industry, electronic items cannot be repaired at risk of compromising the reliability.	Metal trimmings should be used for smaller parts manufacturing
3. Ease of access to components	Allow repairs during the production line and during the use of the vehicle.	Ease of assembly of the product with minimal fixing components.
4. Simplicity aimed projects	Developing projects with as few electronic components as possible to not compromise the MTBF (Mean Time Between Fails) of the product; occupy less area of the printed circuit board.	Using forms that allow a maximized use of the metal sheet; plastic boxes that allow multiple applications. Using modular cabinets.
5. Reducing the use of raw material	Using SMT (Surface Mountain Technology) components: small electronic components, fixed directly on the printed circuit card, without the use of terminal and connectors. Use the thickest PCB (printed circuit board) possible.	Using aluminized metal sheets, which exempt anti-corrosive treatment preliminary. Using the thickest sheet metal possible avoids screws and painting process.
6. Severability	Using electro-electronic products with fixing elements allowing easy separation of the parties. Identify the requirements of the RoHS on PCB.	Identify all plastic parties with the code of recycling; using adhesives that do not prevent the separation of not compatible parts in terms of recycling.

Ecodesign item	Checklist to Electric-Electronic Design of the Product	Checklist to Mechanical Design of the Product
7. No use of contaminant materials	No use of welding material with lead alloys (lead free solder)	Do not use mechanical materials with contaminants.
8. Recovery and reuse of waste	Waste of paper, copper and aluminum must be separated for subsequent recycling.	Remains of the process of plastic injection should be recycled; all metallic material must be separated for subsequent forwarding to recycling.
9. Waste incineration	All components must meet the regulatory ROHS, with no emission of toxic waste in the incineration process.	All components must meet the regulatory RoHS, with no emission of toxic waste in the incineration process.
10. Reduction of the use of energy in production	Using only one side component PCBs simplifies the solder process and saves energy	Avoid using ultrasound, laser, and other kinds of modern production tools.
11. Employment of devices for reducing energy consumption	Using intelligent electronic circuits that save energy while on stand-by. Using as low speed microprocessors as possible to avoid high energy consumption. Decrease backlight LCD (liquid cristal display) intensity during the night to save energy. Using energy dissipated in equipment for electrical testing of power as heating for stages of the manufacturing process (cure of painting oven, for example).	Design the mechanical parts as light as possible to save fuel during the vehicle's life cycle.
12. Reduction of the use of energy in the distribution	Optimize the process of transport of raw materials and the distribution of the final product.	Optimize the process of transport of raw materials and the distribution of the final product. Package as compact as possible to save transport volume in the transport.
13. Use of renewable energy.	Not applicable.	Not applicable.
14. Multifunctional products	Developing printed circuit board that meet more than one use by mounting options.	Developing plastics and metal cabinets that meet more than one use by assembly options.
15. Specific use of recycled materials	Use of recycled welding material, copper cables, etc.	Using plastic and metal with a high content of recycled material.
16. Use of renewable materials	Use of printed circuit boards made of cellulose.	Use of packaging made of cellulose.

Ecodesign item	Checklist to Electric-Electronic Design of the Product	Checklist to Mechanical Design of the Product
17. Products with higher durability	Implement protection devices to prevent damage to the product in the event of overload or short circuit.	Plastic and/or metal cabinets with index of protection consistent with the application and UV (ultra-violet) resistant, corrosion, temperature and vibration.
18. Packaging recovery	Returnable packaging, reuse of the packaging of raw materials as pads for the packaging of the final products.	Returnable packaging, reuse of the packaging of raw materials as pads for the packaging of the final products.
19. No use of hazardous substances	Mounting boards using solder free of lead. Using only ROHS components.	Answering the RoHS standards.
20. Use of substances with water basis	Using flux to solder type "no clean," that is, with a water-based solvent	Use of paints and adhesives with a water-based solvent.
21. Use of biodegradable products	Not applicable to automotive industry.	Not applicable to automotive industry.
22. Accident prevention	In the event of electrical failure, the product should take the vehicle to a safe state of operation.	In the event of mechanical failure, the product should take the vehicle to a safe state of operation.

Table 3. Checklist to electro-electronic design and mechanical design

**a. Training**

Employees at all levels of the company were provided with information on the operating procedures involved in applying ecodesign techniques. This training was adapted to the employee's particular involvement with ecodesign implementation.

**b. Implementation**

This step marked the point at which the company began using ecodesign procedures on both new and ongoing projects, as well as in activities related to improvement of existing products.

**c. Maintaining improvement**

As knowledge management procedures require, the ecodesign checklists established by the company are continuously updated whenever new information is developed. New insights and experience arising from the application of ecodesign techniques are also incorporated into the company's critical analysis mechanisms.

**d. Consideration of Life-Cycle Assessment**

After studying the commercial software available for life-cycle assessment (LCA), the working group decided not to adopt the technique. As Chehebe (2002) has noted, LCA results are considered reliable only when the database used for analysis is compatible with the actual conditions at the application site. Thus, in order to be effective for the study company, an LCA database would have to accurately reflect factors such as the availability

of raw materials, the cost of transport, and the matrix of energy generation as they exist in Brazil. When a trustworthy LCA database is not available, companies typically will not adopt life-cycle assessment methods.

### **3.2.6 Shortage of technical information**

The company encountered some difficulties in the course of implementing ecodesign practices. In particular, when assessing ecodesign concepts and seeking to apply checklists, it lacked technical information on environmental impacts.

For example, in a case where the project team was trying to choose among alternatives for the surface treatment of metals, it was hard to make a choice due to the lack of information indicating the environmental impacts.

### **3.2.7 Results of ecodesign implementation at the study company**

The study company is still in the process of measuring the results of its ecodesign implementation effort. In addition, products developed entirely under the company's ecodesign system are still undergoing approval by customers.

However, the company has already recognized a positive change in its R&D team's degree of involvement with new materials, new technologies, and environmental issues generally in the design of products. Moreover, the company has observed the following results (short-term, medium-term and long-term) as a consequence of using ecodesign practices:

- a. reductions in product costs resulting from dematerialization (medium-term);
- b. reduction in the number of products offered by the company as a result of increases in product multifunctionality (long-term);
- c. improvement in knowledge management through systematically recording in checklists the development of practices learned (short-term);
- d. decrease in the number of raw material items in stock (medium-term);
- e. decrease in the number of test sets and assembly devices used in the manufacturing process as a result of streamlining the life cycle of these items (long-term);
- f. reduction in the need for investment in the industrial process as a result of the less extensive and diverse set of devices now required (long-term);
- g. reduction in environmental management costs, especially with respect to waste (medium-term); and
- h. reduction in transport costs for raw materials and semi-ready products (short term).

### **3.2.8 Prospects for future expansion of ecodesign**

As the process of ecodesign continues to be incorporated into the study company's management system, the respondents interviewed reported their optimism about the eventual long-term results. They hope they can effectively transmit their experiences with ecodesign to their suppliers, thereby broadening the range of small and medium-sized businesses that use ecodesign principles as guidelines in the development of products.

## **4. 2<sup>nd</sup> Part – Assessing ecodesign implementation dimensions**

### **4.1 Research methodology for the 2<sup>nd</sup> part of the research**

In this part of the chapter a method to evaluate the performance in ecodesign is presented. To exemplify and improve the method, the same has been applied to a company on the chemical sector that supplies the automotive industry.



#### **4.1.1 Characteristics of the research developed on the 2<sup>nd</sup> part**

This second part of the study was guided by the following question: how to assess the ecodesign performance of an industrial operation.

The main objective was to assess the ecodesign performance of a manufacturing operation. Secondary objectives were: (a) to identify latent key words and indicators that explain the key factors of the ecodesign performance of the operation; (b) to assess the relative importance of ecodesign constructs (practices), supported by the Analytic Hierarchy Process (AHP); (c) to assess the degree of application of ecodesign constructs (practices); (d) to evaluate the gaps between importance and application of ecodesign constructs. For doing so, it was developed a method to evaluate the performance in ecodesign.

In the intention of keeping coherence on the terminology used in this chapter, it has been adopted: ecodesign is the top term; ecodesign practices are the constructs; the elements part of the ecodesign practices are the items of application (also known as concepts).

#### **4.1.2 Data collection and method of work**

The stages of development of this research were: (a) the construction of a tree-like structure able of representing the top end ecodesign and its constructs, (b) the weighing of the structure using the AHP method, suitable for chemical company, (c) the split of the ecodesign constructs into items of application, and the preparation of a questionnaire to identify the degree in which every item is reached, (d) the comparison of the performance obtained for each item of a particular construct with the degree of importance assigned for that construct.

The tree-like structure for ecodesign, unfolded in constructs has been built in focus group meetings. Four researches that act in ecodesign co-related areas and two managers, one from an automotive company and another from a chemical company that supplies the automotive industry, both with expertise in environmental management have participated. They all fully know about productive processes, products employment and logistic processes. The procedures of the focus group followed the Thietart et al (2001) recommendations. The same focus group, guided by the researchers, weighing the ecodesign constructs by AHP method. The researchers split the ecodesign constructs into items of application and prepared a questionnaire; the same was validated and tested with the members of focus group. The questionnaire was answered by four engineers from the company.

### **4.2 Results and discussion for the assessment of ecodesign implementation dimensions in the automotive industry**

#### **4.2.1 Characteristics of the company**

The company has six manufacture units in the country; the study took place in a large unit located at the South region in Brazil. The main products are adhesives and laminated for the shoe making industry, as well as furniture and automotive industries.

The following characteristics were identified in the company: (a) a history of environmental concern since the late 1980s; (b) strategic positioning and focusing on developing innovative products and solutions and new technologies; and (c) cost reduction in developing new products or in the redesign of existing ones.

The company provides products and services for the automotive industry, furniture industry and footwear industry, especially adhesives and laminates. Besides these points related to the company, aligned with Vercauteren (2001) point of view, the company had expressed interest in ecodesign.

**4.2.2 Three-like structure for ecodesign**

The first line (the criteria) of the tree-like structure for ecodesign, unfolded in constructs, is presented on Figure 3. The requirements proposed by Fiksel (1996), Luttrupp & Lagersted (2006) and Wimmer et al. (2005) and the expertise of the group members served as base for the development of this part of the research.

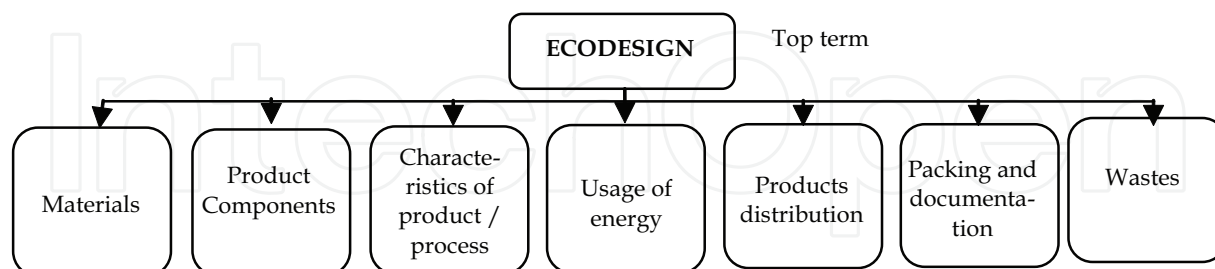


Fig. 3. Tree-like structure representative of ecodesign

**4.2.3 Weighing the ecodesign tree-like structure and unfolding the constructs**

This section consisted on the weighing of a tree-like structure using AHP. This weighing was based on the criteria presented on Table 2 at the company of study. The authors of this paper mediated the sections.

Table 4 illustrates the matrix of ecodesign construct preferences using AHP for the company studied. The computing of matrix preference data shows the relative importance of each ecodesign construct. For the company in study it was obtained: Materials with 12% of relative importance; Product components with 3%; Characteristics of the product and process 34%; Usage of energy 3%; Distribution of products with 8%, Packaging and documentation with 11% and Wastes with 29% of relative importance for the ecodesign. The CR index was of 0.064, what indicates the preferences of the decision makers have an acceptable degree of rationality.

Company	materials: choice and employment	product components	characteristics of the product	usage of energy	distribution of the products	packing and documentation	wastes
materials: choice and employment	1	3	1/3	5	3	1	1/3
product components	1/3	1	1/7	1	1/3	1/5	1/9
characteristics of the product	3	7	1	7	3	3	3
usage of energy	1/5	1	1/7	1	1/5	1/7	1/9
distribution of the products	1/3	3	1/3	5	1	1	1/5
packing and documentation	1	5	1/3	7	1	1	1/5
wastes	3	9	1/3	9	5	5	1

Table 4. Matrix of ecodesign construct preferences

The next step of the research consisted in unfolding the constructs into application items (concepts) of ecodesign, elaborating an evaluation instrument that allows identifying the degree of performance of each item. The instrument has 32 evaluation questions and each

question refers to an application item. The evaluation items and its respective constructs can be identified on Table 5. For the answers, it was used a Likert scale from 1 to 5, where 1 represents the case where the item is not present or is never reached, and 5 is equivalent to the case where the item is completely met. NA (not applicable) indicates that the item is not applicable in its presence; in this case, this item is not considered by the company in the calculation of the degree of construct application. The degree of performance of each evaluated item will be determined in a consensual manner among the participants of the company.

Construct	Query (evaluation items)	Application
Materials	1) ability to use raw material closer to its natural state	1
	2) ability to avoid mixtures of non-compatible materials aiming recycling or reusing materials	5
	3) ability to eliminate or not use toxic, hazardous or carcinogenic substances	3
	4) ability to eliminate or not use raw material that generate Class 1 residuous - hazardous	2
	5) ability to use recycled and/or renewable materials	5
	6) ability to limit atmospheric emissions originated by the use of volatile organic compounds	2
Product components	7) ability to recover or use recovered components	2
	8) ability to easy the access of components	NA
	9) ability to identify materials and components to help in later recycling or reuse	2
	10) ability to determine the degree of recycling of a material or component	1
Characteristics of the product / process	11) ability to elaborate products with simpler shapes and that reduce the employment or use of raw material	4
	12) ability to project products with longer lifetime	5
	13) ability to project multifunctional products	4
	14) ability to generate an upgrade on the product	4
Usage of energy	15) ability to use energy generated by renewable resources	2
	16) ability to employ energy reduction batches during the use of the product	3
	17) ability to reduce employment of energy during the production of the product	3
	18) ability to reduce employment of energy during storage of the product	NA
Distribution of products / storage	19) ability to plan in a wise manner and optimize the distribution logistics	5
	20) ability to privilege suppliers and distributors closer located	1
	21) ability to minimize raw material storage, during productive process, finished product and product for reuse	3
	22) ability to use more efficient transport model in energetic terms	1

Construct	Query (evaluation items)	Application
Packing and documen-tation	23) ability to reduce packages weight and complexity	2
	24) ability to use packages that can be reused	2
	25) ability to use packages produced from reused raw material (eg.: recycled paper)	3
	26) ability to use electronic documentation	3
	27) ability to use refilled products	3
Wastes	28) ability to minimize wastings generated in the productive process	4
	29) ability to minimize wastings generated during usage of the product	3
	30) ability to reuse generated wastings	4
	31) ability to assure acceptable emission limits	3
	32) ability to eliminate Class 1 wastings presence - hazardous	2

Table 5. Application of evaluation items referent to ecodesign constructs

#### 4.2.4 Analysis of the results

The degree of the application of each construct is obtained by the average of values attributed to each query related to the evaluated construct. The average grade of each construct is converted into percent points. In doing so, when all percent points related to the degree of application of all constructs are summed, one obtains an ecodesign performance index for the company. Table 6 indicates the degree of implementation of each ecodesign construct and the level of total implementation.

Construct	Weight of construct	Degree of application
Materials	12%	7.2pp
Products components	3%	1.0pp
Characteristics of the product / process	34%	28.9pp
Usage of energy	3%	1.6pp
Distribution of products / storage	8%	4.0pp
Packing and documentation	11%	5.7pp
Wastes	29%	18.6pp
<b>Total</b>	<b>100%</b>	<b>67.0pp</b>
CR	0,064	

Table 6. Degree of ecodesign implementation

The analysis of the results indicates the company answers 67% of what could be reached related to ecodesign. The construct Characteristic of the product/process appears with higher relative importance; this construct is answered in 85% out of total (28.9pp out of possible 34%). The second construct of importance is Wastes; this construct is answered in 60%. The third construct of importance is Materials which is answered in 60%. Packaging and documentation is the fourth important construct, answering 51.8% of constructs' demands. The next is Distribution of products/storage, Usage of energy and Products components with 50%, 53.3% e 33.3%. Fig. 4 presents the values (% to the weight and pp to the application) for each ecodesign constructs.

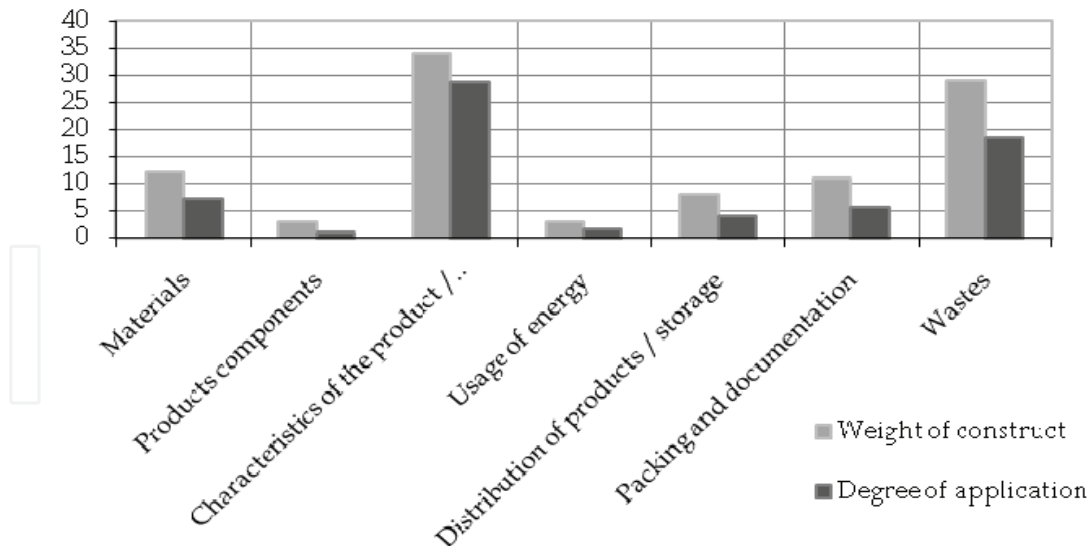


Fig. 4. Weight of ecodesign constructs and degree of application

If the company decides to simply increase the overall presence of ecodesign, the gaps should be reduced by managerial actions. Those actions may require new productive resources. Once resources are finite and constrained, before allocating more resources to developing new products, it might be better to relocate the current resources.

For such relocation, the two-dimensional graphical analysis [Importance - Performance] can be used. As far as research has gone, the earliest reference to the method was Slack (1993). It is considered that the importance of the elements or success key factors (constructs) and their assessed performance (presence) should be similar. According to this idea, in a graph [Importance - Presence], it would be ideal that the constructs be distributed along a diagonal: constructs with more importance would have more presence.

If, for a construct, the represented point by importance  $\times$  presence intersection is below the diagonal, this may mean that improvement actions in relation to this construct shall be taken. If this point is far above, it means there is an excess in the construct performance in relation to its importance. In this case, resources might be reallocated to constructs located far below the diagonal (urgent acting zone).

Figure 5 presents the analysis. The two-dimensional space consists of the area for urgent action (priority much higher than presence); area of improvement (priority higher than presence); appropriate area (priority and presence balanced) and zone over (priority lower than presence). Characteristics, Materials and Energy constructs are balanced and should not be modified. Components and Wastes should be the target of improvement actions. Packaging and distribution are in the bordering areas. Constructs in the urgent area and the overflow area were not observed. Therefore, this may mean that there is no construct that removes productive resources for allocation to other constructs.

There are no "urgent" or constructs in zone "excess". At first, constructs that are in the excess performance area or that need urgent acting and therefore justify the reallocation of the resources of the organization were not observed.

Under the managerial view, according to the perception of the participants from the company, the relative importance of ecodesign constructs shows the strategy and the actions of the company. It is primarily focused in the characteristics of the product and process, bound directly with management and wastes. The innovative characteristics of the products make their differences. The non generation of wastes is prioritized; once not possible, it is aimed the maximization of wastes usage on the productive process of the company itself.

Energy was one of the constructs with the smallest degree of importance; the usage and the respective costs with energy in the company are considered low when compared to the others; yet, there is the concern to have the user of the company product (usually shoes maker companies and furniture industry) to reduce the consume of energy in drying of adhesives, and in doing so focusing in the reduction of the usage of energy when using the product. Components also present a low relative importance; it is observed few presence of this construct due to the product technical characteristics.

A criticism that can be made to the method relates to the subjectivity of the focus group. To avoid skewness on constructs appraisal it can be made up ad hoc, by experts with no interest in operation, but with knowledge on it. Another criticism concerns the AHP method. The method allows some inconsistency: the 10% limit was arbitrarily set by its proposers. Other methods can reach less than 10%. Another point is the lack of coherence in the results when the alternatives change, by criteria that is entered or already exist. The use of AHP is research delimitation. If this criticism is unsurpassed, the essential contribution of the case becomes the method and not the specific outcome of the case.

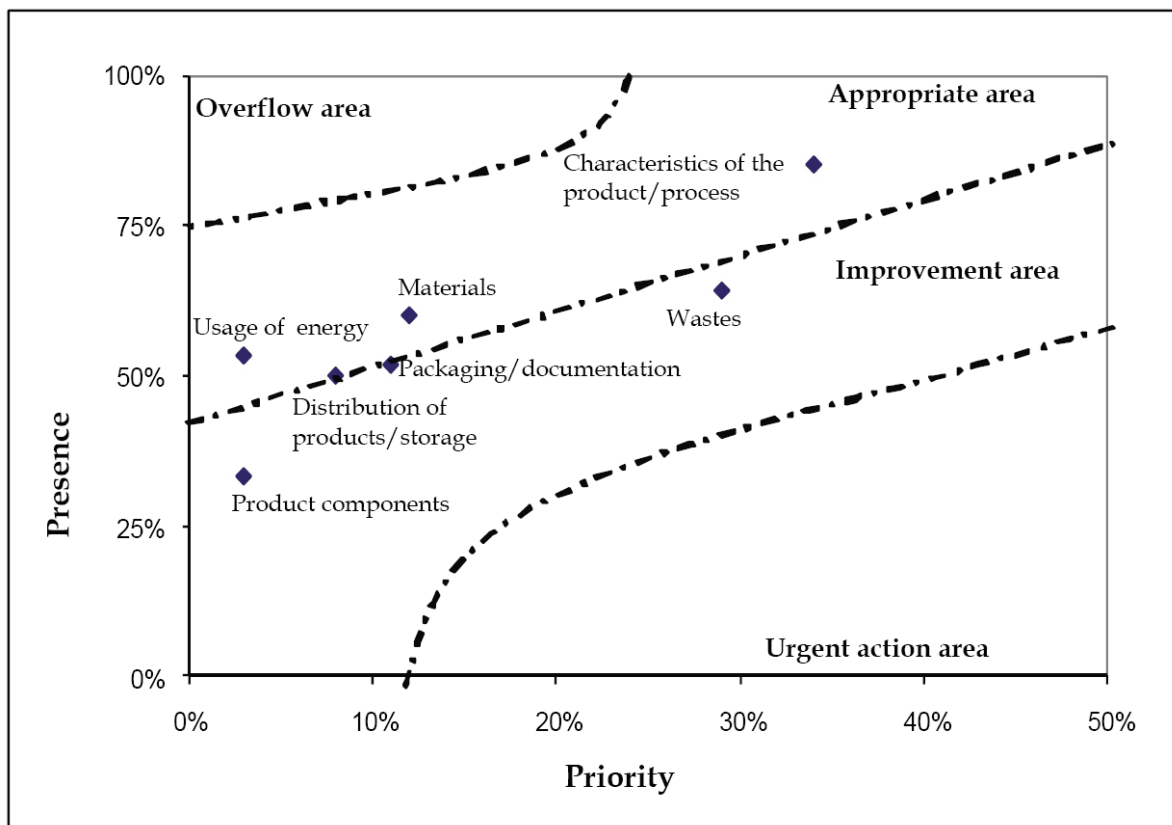


Fig. 5. Analysis [Priority x Presence] of the constructs of ecodesign

## 7. Conclusion

The main objective of the first part of this article was to analyze the process of deployment of ecodesign in a company belonging to the automotive electronics industry in order to identify the elements that justified the motivation for the employment of this technique. The study was exploratory and does not allow generalizations about the process of implementation of ecodesign in automotive electronics industry. The repetition of the cases will allow that.

The theoretical reference approached the concept of ecodesign, the critical factors for success and difficulties of implementation.

Among the elements capable of sustaining the implementation of ecodesign in the company studied, there is the prospect of cutting costs, because the technique is based on dematerialization and the reduction of waste and its subsequent treatment.

The introduction of the ecodesign practices in the process of the company was guaranteed by the adoption of existing routines of project management. A multifunctional team with coordinator was constituted, and the scope, the schedule and the risk analysis were accompanied by the high management, similar to other products and processes developments in the company.

Another essential element to ensure the implementation of ecodesign in the studied company was the commitment of top management. Indeed, this point can be demonstrated in the strategies of the company - performance indicators related to ecodesign were inserted in the Balanced Scorecard. It is also highlighted the training in ecodesign to all employees of the company, according to each one's involvement with the process of implementation of ecodesign.

The assumptions of ecodesign were implemented through checklists for the procedures of development of product and process. These checklists should be regarded as "living documents", i.e. each new event or experience of an aspect of ecodesign should be added as information to the correspondent checklist.

It was also noticed that the industry of automotive electronics has peculiarities which must be adapted in the adoption of the technique. Problems of a technical nature were addressed in the implementation, such as the absence of information about the local reality in the analysis of the Life Cycle Assessment of products. The lack of information about the environmental impact of each alternative available in the design phase was also another problem identified. It suggests fronts for the development of future work in the area.

As a continuity of this research is proposed to examine, in the medium and long term, the parameters about development of products affected by ecodesign and their impact on indicators of the organization. Similarly, it is suggested to extend the study to other organizations of various sizes and segments, in order to determine a method of deployment of ecodesign that is adaptable to various organizational realities.

In relation to the second part of the chapter, the main objective was to assess the ecodesign performance on a chemical company. The constructs that compose and explain the ecodesign were established in the theoretical framework, based on the set of practical proposals by Fiksel (1996), Wimmer et al. (2005) and Luttrupp & Lagersted (2006). The group of managers who participated in the survey felt that the scope is adequate, it is not necessary to include other practices. The importance of the constructs was obtained from a tree-like structure representing the ecodesign and it was weighted by AHP. An assessment tool was used to determine the degree of presence of each construct. Finally, the overall performance of the company in relation to the practice of ecodesign was determined. It is understood that this work contributes to further development of performance indicators associated with the ecodesign, complementing the exposed by Cabezas et al. (2005) and Svensson et al. (2006). The key performance indicators could be related to items included in ecodesign practice with a greater degree of importance.

The research findings from the perspective of organizations will enable decision making, involving resources and priority for actions related to ecodesign and focusing on the constructs that most contribute to it. Under the scientific perspective, the contribution is focused on developing a method applicable to other organizations, including other industries.

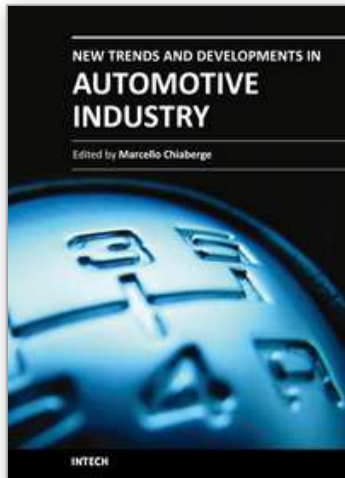
It is understood that a study could be continued by widely assessing the performance of an industry, or even establishing performance indicators tied to each construct.

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