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Sustainability Indicators for the Product Development Process in the Auto Parts Industry

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Abstract. The severe environmental degradation caused by human activities in recent decades has forced organizations, especially those related to the auto parts industry, to take actions and measures in order to reduce or eliminate the negative effects caused by industrial activities. Those measures aim to cover various aspects within companies, and require an appropriate measurement system for the verification of their effectiveness. In this sense, sustainability indicators have grown in importance because they allow assessing the level of sustainability from various entities, identifying the potential for improvement and the progress achieved. Despite the great variety of existing indicators, there are still unexplored areas, such as indicators for product development. The present paper proposed a set of sustainability indicators, aiming to contribute to the creation of more sustainable products and guiding the development process from the earliest stages of product development. This set of indicators, which were divided into product and design indicators, were defined based on the best practices and recommendations from various techniques such as design for environment and sustainability, and the study of existing sustainability indicators. While product indicators present a technical character, as they provide means for evaluating the product characteristics in a quantitative way, design indicators present a managerial approach, in order to assess whether the main aspects and techniques of design for sustainability are being considered throughout the development process, in a qualitative way. The result was a set of 23 product indicators and 26 design indicators, including metrics that were simplified and adapted according to the characteristics and requirements of each phase of a product development process. The proposed indicators were applied on the development of a new component for the auto parts industry and demonstrated to be very useful in guiding the development team to design sustainable products.

Keywords. Sustainability indicators, Product Development Process, Ecodesign

1. Introduction

The great economic, scientific and technological progress occurred in the twentieth century caused great changes in various aspects of people's lives. On one hand, they provided a major improvement in the quality of life to people with access to these advances, due to the benefits provided by new technologies and services. On the other

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hand, they have caused great social differences and a significant damage to the environment, due to the increasing consumption of materials and energy, and increased emissions of waste and pollution in the environment [1].

Many companies and organizations are working to reduce the negative impacts caused by their products and activities, including those related to the automotive industry, as it is responsible for a large environmental impact [2]. That work requires, among other needs, a reliable measurement system to verify the level of sustainability of those various institutions, in order to assess the current situation, set goals and follow up the implementation of improvements. In this direction, sustainability indicators provide an important framework for identifying strengths and weaknesses, monitoring sustainability goals and plot future plans [3].

There are currently many sustainability indicators developed for various purposes, such as the indicators for sustainable manufacturing, products, companies, cities and nations, just to name a few [3]. However, there are still unexplored areas, such as the product development process. During the development of a new product, many decisions are made, and these decisions can affect, among other aspects, the sustainability of that product [4]. Therefore, it is important to define sustainability indicators since the preliminary design phases, in order to guide the design team in direction of developing a sustainable product.

In this context, this paper aims to develop a set of sustainability indicators for the product development process in the auto parts industry. In section 2, the sustainability concepts are presented, including some methods for the development of sustainable products. The concept of indicator and correlated terms are presented in the section 3, as well as some existing sets of sustainability indicators. The proposed sustainability indicators are presented in the section 4, and the final comments and conclusions are presented in the section 5.

2. Fundamental concepts

Sustainability can be defined as a pattern of natural resource use that aims to meet human needs of current generations, without compromising the ability of future generations to meet their own needs [5]. For that to happen, it is necessary to consider social and economical aspects within an integrated model with the environmental actions, in a three dimensional model.

On the environmental aspect, the aim is to consume natural resources in a rational and efficient way, reducing undesirable emissions in the environment. On the economical aspect, the objective is to achieve a sustainable profit, maximizing financial returns with a constant capital. The social aspect considers the equality of conditions and rights provided to people such as quality of life, education and health [3].

There are many methods and recommendations for development of sustainable products. DFE (Design for Environment) is one of these methods and combines a variety of design approaches for reducing the environmental impact of a product, including the use of recyclable materials, mass reduction and easier disassembly to enable remanufacturing and material separation at end of life [6]. Another method is D4S (Design for Sustainability), which consists of several design guidelines for developing a new product or reviewing an existing one, with focus on the three aspects of the sustainability [7]. And LCD (Life Cycle Design) is a method that presents several proposals for the reduction of environmental impact in each phase of a typical product life cycle [8]. The recommendations suggested by these methods were considered in the development of the sustainability indicators proposed in this paper.

3. Existing sustainability indicators and indexes

Several sets of indicators and indexes assess sustainability of various entities, with different objectives. For assessing sustainability of manufacturing processes, the Lowell Center for Sustainable Production has developed a set of 22 indicators distributed in 6 distinct groups, which evaluate the use of materials and energy, environmental damage, economical performance, final products performance and social aspects [9]. General Motors has also employed a set of manufacturing indicators, aiming to evaluate the sustainability of their production processes by using 30 indicators distributed in 6 groups, based on the three aspects of sustainability [10].

For product assessment, Ford has developed a set of 8 indexes for an entire vehicle appraisal named Product Sustainability Index (PSI) [11]. They are based on LCA (Life Cycle Assessment) guidelines and evaluate life cycle cost, safety, noise level, passenger capacity, use of recycling and toxic material and emissions level during the whole life cycle. Another set of indicators for product assessment is the Environmental Product Declaration (EPD) which aims to inform to the final customer the environmental impact produced by a vehicle during its life cycle. It evaluates ~~the~~ production, materials use, fuel consumption, emissions, maintenance and end of life impact [12]. The LiDS Wheel is another example of set of indicators designed to evaluate the performance of a product according to 8 recommended design strategies, using qualitative metrics, based on the various phases of its life cycle [13].

Other sets of indicators were developed to evaluate entire companies, industries and other contexts such as cities and nations. For example, the Global Reporting Indicators (GRI) is a set of indicators that reports sustainability levels of entire companies. It consists of a set of more than 100 indicators to evaluate environmental and economical performance, social aspects such as working conditions and social responsibility practices and human rights, just to name a few [14]. The ecological footprint is an example of indicator for environmental impact evaluation of cities and nations, based on the consumption of renewable and non-renewable resources [15].

Despite the great variety of existing indicators and indexes for different purposes, there are few sustainability indicators designed for application during the product development process. For that reason, considering the importance of indicators for the decision making process during product development, there is an opportunity to be explored, and the indicators proposed in this paper aim to fill in that gap.

4. Proposed sustainability indicators

Based on the concepts, methods and recommendations for development of sustainable products, a set of sustainability indicators was developed for application during the product development process in the auto parts industry.

The proposed set was divided in two major groups. The first group is called Product Indicators, and they present a technical approach, in order to evaluate the product and related processes. The second group is called Design Indicators, and they present a managerial approach, by focusing on the application of recommended design practices and guidelines for development of sustainable products. Anyway, both groups are based on the three dimensions of sustainability.

These major groups are presented in details in the following sections.

4.1. Product Indicators

Product Indicators have been defined based on the most important design characteristics that a design team must address when developing a sustainable product, throughout its life cycle. They may be used as pass/no-pass criteria on gates at the end of each product development phase, along other phase approval criteria. Such characteristics have been identified based on recommendations derived from methods for the development of sustainable products and existing sets of sustainability indicators. Product Indicators are presented in table 1.

The metric for each proposed indicator has also been simplified to allow data gathering since the initial product development phases, thus avoiding complex calculation or information searching that may not be available at the beginning of a product development process.

Product Indicators are considered performance indicators, because they may be used for evaluating the design progress towards a goal. Therefore, it is recommended to set a goal for each indicator, preferably in the informational design phase. In this case, the information available from the strategic and project planning phases, besides the data gathered during the informational phase itself may be used. It is also recommended to select an existing product to be used as a reference in setting goals for the indicators, as well as evaluating the design progress.

For a better understanding of an indicator's function and characteristics, Product Indicators have been divided into six distinct categories, namely: Use of Materials, Manufacturing Processes, Social Manufacturing Process, Economics, Logistics, Product Use and End-of-Life. Product Indicators are presented in Table 1.

The first category, Use of Materials, consists of indicators defined to evaluate the materials embedded in the product or component itself. The first indicator in this category is Mass, which is an important parameter to evaluate the existing amount of material in the product. Mass reduction is one of the most recommended strategies to develop sustainable products, due to its implication over the whole life cycle. Another indicator included in category Use of Material is the toxicity of materials, which is considered a social indicator, because it may affect the health of workers and customers. The basis for this indicator is the Global Automotive Declarable Substance List (GADSL), and the indicator metric is the percentage of the total mass that is considered declarable or prohibited in this list [16]. The last indicator included in this category is the number of different materials present in the component or product. This indicator has implications over the end-of-life of a product, because the higher the number of different materials, the more difficult it will be to separate them for recycling or reuse.

The second category is Manufacturing Processes. Manufacturing processes have a major influence in sustainability, because they may generate waste, consume energy and cause health risks to workers, as well as social problems [9]. The indicators included in this category are Electrical Energy Consumption, Water Consumption and Fossil Fuel Consumption. These are process inputs that need to be reduced due to their related environmental impact. Electrical energy consumption, for example, may be related to several environmental impacts, such as fossil fuel consumption or land use, depending on the way energy is generated. Water is also an important natural resource, and there are many manufacturing process that use this input, such as boilers or part cleaning machines. Fossil fuels may be applied in some processes such as heat treatment, welding and water heating. They are very harmful to the environment, so the consumption of this kind of energy source needs to be reduced eliminated.

Table 1. Product indicators

#	Indicator	Metric	Category
1	Total mass	Gram	Use of materials
2	Materials toxicity	% of total mass that contain toxic materials, acc. to GADSL	
3	Amount of different materials	Qty of different materials in the component	
4	Electrical energy consumed at manufacturing processes	W/h	Manufacturing process
5	Water consumption	l/Component	
6	Fossil fuel consumption	(Nm^3/h)/Component	
7	Total number of workers	Total num. of workers in the production line.	Social manufacturing indicators
8	Number of accidents at work	Total num. of accidents (with or without lost time) / year	
9	Total cost	$	Economics
10	Productivity	Qty. products (h) / workers (h)	
11	Maintenance cost	$ (Repair kit)	
12	Fossil fuel consumption during distribution per product	[Transported distance (km) / fuel consumption (km/l)] / Total qty. of products transported	Logistics
13	Packaging mass	Gram	
14	Packaging's end of life	1- Package cannot be reused nor recycled 3- Package cannot be reused but can be recycled 5- Package can be reused and recycled	
15	Part fuel consumption caused by addition of mass to the vehicle (Cp)	km/l [Cp = (Ct x Mp)/Mt], where: Ct = total vehicle consumption; Mp = part mass; Mt = total vehicle mass	Product use
16	Driving power consumption (for automotive components that consume engine power)	CV	
17	Durability	km	
18	Maintenance	% of components that can be repaired or replaced in the field	
19	Field complaints	Qty. of field complaints/year	
20	Disassembly	1- Product cannot be disassembled 2- Product can be disassembled with effort and use of specific tools 3- Product can be disassembled with effort and use of common tools 4- Product can be disassembled with effort but manually (no tools required) 5- Product can be manually disassembled without effort (no tools required)	End of life
21	Amount of fixing elements	Qty. of screws and rivets	
22	Remanufacturing	% of components that can be reused or remanufactured at end of life	
23	Materials recyclability	% of recycled materials	

The next category is Social Manufacturing. According to the social aspect of sustainability, manufacturing processes have to contribute to the progress of local communities. Two indicators have been defined in this category, namely: number of workers in the production line and number of accidents at work. The first one is usually defined during the design process, at conceptual and detailed design phases, and it has great influence on the social development of local communities. The latter has been conceived for use the Product and Process Monitoring phase, after product launch. It is an important social aspect, as identified by many guidelines for the development of sustainable products.

In category Economics, indicators for Manufacturing Cost, Productivity and Maintenance Cost evaluation have been included. Manufacturing cost represents the total product cost, and its metric is the sum of all component costs, either purchased from suppliers or produced internally. Productivity basically measures the amount of workers required to produce a certain amount of products in a given period [17]. It is an important indicator of production line performance. And maintenance cost is an important parameter to make the maintenance process economically feasible, in order to extend a product's life. As its metric, one could suggest to consider the cost of a maintenance kit that brings the most frequently used field repair components.

Logistics includes 3 indicators, which are fossil fuel consumption during distribution, packaging mass and end-of-life of packaging. All these indicators focus on the reduction of the environmental impact caused by distribution processes. Fossil fuel consumption per product is related to transportation efficiency and distance, as well as the number of units transported simultaneously. The higher the number of units, the lower the fossil fuel consumption per part will be. Packaging indicators, on the other hand, aim to evaluate the amount of material required to produce the package and its destination at end-of-life, considering its reuse and/or recycling.

Category Product Use brings indicators to assess the environmental impact during product use phase, which is one the most harmful phases of a product's life cycle. Included in this category are the additional fuel consumption that an auto part may cause by the addition of mass to the vehicle (Cp), the driving power consumption (only for auto parts that need engine power to work such as alternators or compressors), durability (km), percentage of components that can be repaired or replaced in the field, and quantity of field complaints, which is an indicator designed to be used at product monitoring phase, after a product is launched in the market, while the other ones can be used from the informational design phase on.

Finally, in category End-of-Life, indicators have been created to assess end-of-life strategies and consider disassembly, amount of fixing elements, remanufacturing potential and recyclability. These indicators aim to evaluate easiness of disassembly, both in qualitative and quantitative ways, as well as reuse and recyclability of the materials when it is no longer possible to reuse a component.

4.2. Design indicators

A series of design indicators has been defined to evaluate a project at each phase of the product development process, with a managerial approach. The purpose is to guide a design team through the application of recommended tools, methods and best practices for the development of sustainable products, in all three aspects of sustainability, namely environmental, social and economical. The metrics are mostly qualitative, defined individually for each proposed indicator, and present a grade from 1 to 5, which will be assigned to each indicator according to the answer given to a specific question.

The sustainable design indicators were divided into eight distinct categories, according to each phase of a product development process, based on the reference model proposed by Rozenfeld *et al*. (2006) [4]. Such categories are: Strategic Planning, Project Planning, Informational Design, Conceptual Design, Detailed Design, Production Preparation, Product Launch and Product Monitoring.

In the Strategic Planning phase, the aim is to review a company's product portfolio for putting together business plans of products that are to be delivered in the coming years [4]. The first indicator in this category ensures that the strategic business planning is oriented to sustainability in its three dimensions. The second indicator evaluates if the product portfolio has been developed with a sustainability-oriented thinking, resulting in the definition of products that present potential to improve sustainability, by comparing current products of a company. And the last indicator included in Strategic Planning is related to the new project protocol, as it assesses elements of sustainability in its three dimensions.

The next category is Project Planning. In this phase, responsibilities, activities and resources required to implement a project are defined. According to the reference model [4], this phase starts with the identification of ~~the~~ project stakeholders, and the first indicator assesses if they are concerned with the three aspects of sustainability [16]. Another important activity of Project Planning is the definition of project scope and deliverables. So, the second and third indicators in this category aim to assess if scope and deliverables consider elements of sustainability. The last indicator aims to assess if sustainability indicators have been defined for the next phases of the design process, considering the three dimensions of sustainability.

The objective of phase Informational Design is to collect and analyze data for defining target specifications for the product, which will guide the development process until product launch [4]. The indicators defined for this phase are related to the product's life cycle, for assessing if sustainable solutions have been considered for its end-of-life, and if target specifications have been defined for improving sustainability.

With the target specifications for the new product defined, the next phase is Conceptual Design. It consists of creating new concepts for meeting the project proposal [4]. There are several sustainability methods developed to assist the process of defining solution principles and new concepts, such as DFE, D4S and LCD, as described in section 2. The first indicator in this category evaluates whether these methods have been considered. The second indicator checks if the new concept selected for development presents potential for improving sustainability on all dimensions.

After defining the concept to be developed, the project team starts the Detailed Design phase, which consists of the development and definition of all product specifications and related processes. The first indicator in this category is related to the supplier definition. It assesses whether the selected suppliers are ISO 14000 certified. The second indicator evaluates if ergonomics and operator safety have been considered during the manufacturing process definition. The third indicator is related to packaging, assessing if sustainable alternatives for its end-of-life have been considered, such as reuse and recycling. The product's end-of-life is also an important aspect, and the fourth indicator aims to analyze whether sustainable solutions have been considered as well. The fifth indicator assesses if maintenance processes are economically feasible. The last indicator was developed to verify if the new product is economically viable.

Once product specifications and manufacturing processes are defined, the next phase of development process is Preparation for Production. The indicators defined in this category aim to assess the efficiency of manufacturing processes, ergonomics and operator safety, environmental legislation compliance for products and processes, and the product economical feasibility after the investments in this phase are made.

After the implementation of manufacturing processes, a design team starts Product Launch phase. In order to evaluate if the most efficient means of transportation and distribution for a given product have been selected, an indicator for evaluating logistics processes has been added.

When a product in launched in the market, the Product Monitoring phase starts. It consists of collecting and processing information about product performance. The indicators defined for this phase were Economical Feasibility, Customer Safety and Compliance to Existing Environmental Legislation.

The indicators for phase Product Monitoring can be tracked while a product is continuously supplied to the market, according to the frequency defined by a project team, until a company decides to withdraw it from the market (discontinuation), driven by factors such as declining sales or reduced profit margins.

Table 2 contains all indicators presented in this section, including the proposed qualitative metrics for each indicator.

Table 2. Proposed design indicators

#	Indicator	Metric	Design phase
1	Strategic business planning	Does the strategic business planning of the company contain elements related to sustainability in the 3 aspects (social, environmental or economic)? 1 - Does not contain 2 - Contains only one aspect of sustainability 3 - Contains two aspects of sustainability 5 - Contains all 3 aspects of sustainability	Product strategic planning
2	Product Portfolio	Does the product portfolio have new products with potential for improving sustainability in the 3 aspects (social, environmental or economic)? 1 - It has no potential for improvement 2 - It has potential improvement in just one aspect of sustainability 3 - It has potential for improvement in two aspects of sustainability 5 - It has potential for improvement in all 3 aspects of sustainability	
3	Project protocol	Does the project protocol have elements of sustainability in the 3 aspects? 1 - It has elements of sustainability 2 - It has elements of sustainability in only one aspect of sustainability. 3 - It has elements of sustainability in two aspects of sustainability 5 - It has elements of sustainability in all 3 aspects of sustainability	
4	Project stakeholders	Are the stakeholders concerned about producing products that include improvements to issues of sustainability? 1 - They are not concerned 2 - They are concerned with only one aspect of sustainability 3 - They are concerned with two aspects of sustainability 5 - They are concerned with all three aspects of sustainability	Project Planning
5	Project scope	Does the project scope consider elements of sustainability? 1 - It does not include elements of sustainability 2 - It includes elements of sustainability in only one aspect of sustainability 3 - It includes elements of sustainability in two aspects of sustainability 5 – It includes elements of sustainability in all 3 aspects of sustainability	
6	Project deliverables	Were the project deliverables thought to be more sustainable? 1 - They were not thought to be sustainable 2 - They were thought to be sustainable in only one aspect 3 - They were thought to be sustainable in two aspects 5 - They were thought to be sustainable in all 3 aspects.	

7	Performance Indicators	Were they defined indicators related to the 3 main aspects of sustainability? 1 - They were not defined 2 - They were defined for only one aspect of sustainability 3 - They were defined for 2 aspects of sustainability 5 - They were defined for all 3 aspects of sustainability	
8	Product life cycle	Does the definition of product life cycle consider elements that contribute to improving sustainability at the end of life? 1 – It does not include elements of sustainability 3 – It partially includes elements that contribute to sustainability. 5 – It totally includes elements that contribute to sustainability.	Informa-tional design
9	Product requirements	Do the requirements of the product elements have the potential to improve the sustainability? 1 - They have potential to improve sustainability 2 - They have potential for improving sustainability in only one aspect 3 - They have potential for improving sustainability in two aspects 5 - They have potential for improvements in all 3 aspects.	
10	Development of new concepts	Does the development of new concepts consider methods to support the development of sustainable products, such as DFE, LCD and D4S? 1 – They were not considered 3 – They were considered partially 5 – They were considered fully	Conceptual Design
11	Concept selected	Does the selected concept have potential to improve sustainability? 1 - It has no potential 2 - It has potential for improving sustainability in only one aspect 3 - It has potential for improving sustainability in 2 aspects 5 - It has potential for improving sustainability in all 3 aspects.	
12	Suppliers definition	Are the selected suppliers certified ISO 14000? 1 - 0 ~ 20% of suppliers are certified 2 - 21 ~ 40% of suppliers are certified 3 - 41 ~ 60% of suppliers are certified 4 - 61 ~ 80% of suppliers are certified 5 - 81 ~ 100% of suppliers are certified	
13	Manufacturing processes safety	Are the defined manufacturing processes safe for the operators? 1 - They are unsafe for operators 3 - They are partially safe for the operators 5 - They are completely safe for the operators	
14	Packaging	Were they verified sustainable alternatives for packaging, such as returnable packaging, recyclable or biodegradable? 1 – They were not considered sustainable alternatives for packaging 3 – They were partially considered sustainable alternatives 5 – They are fully considered sustainable alternatives	Detailed Design
15	End of Life planning	Does the end of life planning consider sustainable alternatives? 1 - They were not considered sustainable alternatives 3 - They were partially considered sustainable alternatives 5 - They were fully considered sustainable alternatives	
16	Maintenance Process	Is the maintenance process economically feasible? 1 - The process is not feasible 2 - The process is only feasible for the company 3 - The process is feasible only to the customer 5 - The process is feasible for the company and for the customer	
17	Economical feasibility (in detailed design)	Is the new product economically feasible (detailed design)? 1 - The new product is not feasible 3 - The new product is partially feasible 5 - The new product is fully feasible	
18	Efficiency of manufacturing processes	Are the selected processes, equipments and manufacturing technologies the most energetically efficient in the market? 1 – The processes are not the most efficient in the market 3 – The processes are partially the most efficient in the market 5 – The processes are fully the most efficient in the market	Production preparation

19	Ergonomics and operator safety	Were they considered ergonomics and safety of operators in the development of the productive process? 1 - They were not considered ergonomics and safety aspects 3 - They were partially considered aspects of safety and ergonomics 5 - They were fully considered aspects of ergonomics and safety	
20	Environmental laws for processes	Will the current environmental laws for manufacturing processes be met? 1 - They will not be met 3 - They will be partially met 5 - They will be fully met	Production preparation
21	Environmental laws for products	Will the current environmental laws for products be met? 1 - They will not be met 3 - They will be partially met 5 - They will be fully met	
22	Economical feasibility	Is the product economically feasible (at preparation for production)? 1 - The product is not feasible 3 - The product is partially feasible 5 - The product is fully feasible	
23	Logistics processes	Were they considered efficient solutions for the logistics process, such as railroad or maritime transportation instead of truck transportation? 1 - They were not considered sustainable alternatives 3 - They were partially considered sustainable alternatives 5 - They were fully considered sustainable alternatives	Product launch
24	Financial return	Is the product within the expected financial return? 1 - The product is experiencing financial loss. 3 - The product is profitable, but lower than expected. 5 - The product presents financial return as expected or above.	Product monitoring
25	Safety end users of the product	Is the product hazardous for users in the field? 1 - The product has presented safety issues in the field. 3 - The product has safety warnings, but the issues were detected earlier. 5 - The product has not presented any safety issue.	
26	Legislation and environmental demands	Did the product meet environmental legislation requirements? 1 - The product did not meet environmental legislation demands 3 - The product partially met environmental legislation demands 5 - The product fully met environmental legislation demands	

4.3. Application example

The proposed indicators were applied on the development of a new diesel fuel injection pump for commercial vehicles by an auto parts company, in order to demonstrate the applicability of those indicators during the design process. The design indicators applied during the project are shown in table 3, while product indicators are presented in table 4.

Design indicators were applied from the beginning of the development process. By using the proposed indicators, the team identified that the strategic planning contained only two aspects of sustainability, as there was a strong concern on the economical and environmental aspects of sustainability, but the social aspect was missing. For that reason, grade 3 was assigned for the first design indicator. Therefore, the design team decided to include a social requirement in that step, regarding maintenance of jobs. That is an example of guidance provided by the proposed indicators through the project.

During phase Project Planning, indicators helped the team to analyze the project scope, which led them to the conclusion that all three aspects of sustainability were considered. However, even though project deliverables regarded economic and environmental aspects of sustainability, social aspects were touched only by a maintenance target.

Table 3. Design indicators

#	Indicator	Strategic planning	Project planning	Info design	Conceptual design	Detailed Design	Production preparation
10	Strategic planning	3	-	-	-	-	-
11	Project protocol	5	-	-	-	-	-
12	Project scope	-	5	-	-	-	-
13	Deliverables	-	3	-	-	-	-
14	Product life cycle	-		5	-	-	-
15	Product requirements	-	-	5	-	-	-
16	Concept selected	-	-	-	3	-	-
17	Suppliers definition	-	-	-	-	5	-
18	Packaging	-	-	-	-	3	-
20	Economical feasibility	-	-	-	-	5	-
21	Efficiency of manuf. processes	-	-	-	-	-	3
22	Ergonomics and operator safety	-	-	-	-	-	5
24	Economical feasibility	-	-	-	-	-	5

In phase Informational Design, product indicators were applied for the first time. In order to support the definition of targets, some product indicators were calculated for an existing product. Total mass was measured using a scale. The percentage of toxic materials was calculated based on mass of toxic materials divided by total mass. The electrical energy consumed by the machines during production was measured in the plant. Data such as number of workers, cost and productivity were gathered in the plant. Packaging mass was measured with a scale, and maintenance and remanufacturing indicators were calculated based on the number of parts that can be repaired or remanufactured, divided by the total number of parts. That information from a reference product, along with QFD and project scope, helped the team to define technical goals for the new product and sustainability indicators. Design indicators were applied at the end of phase Informational Design to evaluate its deliverables.

Table 4. Product indicators

#	Indicator	Info design (ref product)	Info design (goal)	Conceptual design	Detailed Design	Production preparation
1	Total Mass (g)	2766	2490	2378	2490	2490
2	Toxicity (%)	3,0	2,7	1,1	1,1	1,1
3	Electrical energy (W/h)	3183	2865	2865	3025	2893
4	Number of workers	40	40	40	40	40
5	Total cost (R$)	156,5	140,85	142,15	141,95	140,85
6	Productivity (Parts/Oper.)	5,0	5,5	5,0	5,3	5,3
7	Packaging mass (g)	0,7	0,63	0,65	0,66	0,66
8	Maintenance (%)	79	86,9	85	85	85
9	Remanufacturing (%).	50	55	50	50	50

In phase Conceptual Design, product indicators were used to evaluate a new product concept, even though little technical information was available at that stage. The lack of data required the use of computer simulations for those estimates. Thus, a comparison between estimates and goals helped the design team to conclude that the new concept had potential for improvement on the economical and environmental dimensions of sustainability, so they took the concept to next design phase.

In phase Detailed Design, product indicators could be re-calculated based on more precise product technical specifications. The indicators showed to the team that the new product reached goals for total mass, toxicity, number of workers and total cost. The indicators related to manufacturing processes would still be optimized in the next design phase, but most of them were near the target and much better than those of the reference product. Design indicators helped the team to conclude that suppliers were environmentally conscious, the product was economically feasible but packaging end-of-life could be more sustainable as biodegradable materials were not considered.

In phase Production Preparation, product indicators related to manufacturing were updated. The final result showed that production parameters were near the target, but continuous improvement was still required. Design indicators showed to the team that the manufacturing processes were not the most efficient in industry, as existing machines were used to avoid the need for further investments. However, they were considered the best solutions available for ergonomics and safety, and the product is economically feasible.

At end of the project, the team concluded that the proposed indicators presented appropriate metrics, which helped them to identify areas for improvement and provided guidance in the decision making process. For that reason, they can be incorporated into the development process for auto parts companies.

5. Conclusion

The proposed indicators comply with the initial target, which was the development of a set of sustainability indicators for the auto parts industry, as they demonstrated to be a valuable tool to guide design teams for developing more sustainable products.

The application example demonstrated that the proposed indicators can help a design team to define goals and identify areas for improvement, during each phase of the design process. Design indicators can be applied since the preliminary phases, while the product indicators can be applied from the informational design phase, in order to aid the team defining goals, based on the scope and data from an existing product. From the concept design phase on, product indicators are used to guide a design team for evaluating the new development, as presented in the application example.

Further research is suggested to define additional sustainability indicators for application during the development process, improving even more the metrics and optimizing the calculations for a more accurate estimation of the important aspects of product design, starting on the strategic planning phase, when little information about a new product is available. Additionally, quantitative metrics can be studied for design indicators, as oppose to qualitative, in order to eliminate any subjectivity that might happen during estimation of indicators.

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