

# **Modular Design and Production: An Investigation on Practices in an Assembler and Two First-Tier Suppliers**

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## **Abstract**

Modularity includes a set of concepts that leads to new possibilities of product architecture and production organization, enabling the transfer of activities throughout the automotive supply chain. In this context, the aim of this paper is to investigate the use of modularity in product design and in production within the context of a commercial vehicle assembler and engine suppliers. Case-based research was used as a methodological approach. Results show some influences that occur between product design and production and vice versa. Part of those results was expected reinforcing the confirmatory nature of this study. At some extent, the concept of modularity might be applied to the production process regardless whether the product has been fully designed in modules. Data also confirmed that the product architecture of a commercial vehicle favors its sorting into modules. Additionally, supply chain management at the automaker can be simplified compared to a traditional production system, since part of the activities is transferred to the suppliers.

## **Keywords**

Automobile industry, modular production, modular design, modularity, product development

## **1. Introduction**

In response to global competition, companies seek to customize their products, as well as reduce their lifespan without increasing development and production costs (Kotler, 2003). Modularity can be understood as the perspective on which a product uses subsets, called modules, which operate as an integrated whole (Baldwin and Clark, 1997). This suggests that the designing of various product modules can be performed simultaneously (Sanchez and Mahoney, 1996). In the scope of production, it means that the modules can be assembled and tested on separate lines and only then sent to the final assembly of the vehicle in the required sequence, instead of having several loose components, as it is in the conventional system (Sako and Murray, 2000). From the standpoint of first-tier suppliers, employing modularity means to have a different role than the conventional one, with regard to design, assembly, and delivery tasks (Lung et al., 1999, Marx et al., 1997).

The automotive industry uses modularity as a way to reduce manufacturing costs, as an alternative to deal with the reduced life cycle of products (Lau Antonio et al., 2007), as well as to provide a greater number of models and variations in the market, without making the system too complex (Piller; Waringer, 1999). Moreover, the time of product development tends to be reduced by the reuse of modules and components among the different types of vehicles (Persson and Ahlstrom, 2006; Arnheiter and Harren, 2005). Another benefit resulting from the adoption of modularity is that it has changed the relationship among automakers and their suppliers, because the decisions also involve the sharing of responsibilities and risks, and investments between the parties (Salerno et al., 2008).

In this context, this work investigates the use of modularity with regard to the relationship of a commercial vehicle automaker and engine suppliers. It analyzes the adoption of modularity in terms of product design and production and it examines that relationship. Despite advances in the use of modularity, there are few empirical studies that examine this relationship. Next section presents the research approach, including the procedures for collecting and analyzing data. Section 3 provides a brief literature review on some important aspects associated with modular design and modular production. Section 4 presents the empirical result and, finally, the section 5 offers concluding remarks of this study.

## **2. Research Methods**

To meet the objective of this work, a literature review on modularity was conducted by searching major databases. From that, relevant issues were raised for further analysis. Some issues - presented at the end of the theoretical work - were identified. Case study was chosen as the research approach to research due to the nature of data and the context of the study (organizations from the automotive sector). The choice of case-based research is suitable especially when the boundaries between the phenomenon under investigation and the context are not clearly defined (Yin, 2005). This work may be considered as exploratory due to the fact that the relationship between modularity in design and in production is not yet fully established in the body of the literature.

Semi-structured interviews were conducted for gathering field data. Senior executives who work in product and process engineering were interviewed at the companies (chief engineers and managers). The content of the interviews were tape-recorded, transcribed and then sent to the respondents for adjustments considering the accuracy of remarks and confidentiality of data. Besides the interviews, other sources of evidence were used such as attending a corporate meeting and direct observation of the automaker and suppliers production processes.

For data analysis, firstly the data set was to organize, considering the different sources of evidence. Then, a general narrative was constructed. From this narrative, content analysis was performed in the light of the literature.

One original equipment manufacturer (OEM) and two first-tier suppliers were selected. They adopt the concept of modularity and perform activities related to the aspects modular product design and modular production. Another aspect that favored the choice of the automaker is its autonomy to develop new products in Brazil, although it is a subsidiary. Finally, they operate within the automotive supply chain.

The units of analysis were chosen suitably to fulfill the research purposes. The OEM produces commercial vehicles by operating in the system known as modular consortium. The two suppliers are positioned on the first level of the automotive supply chain. They have been defined as supplier A and B, and they joined together to form a *joint venture* to provide services for the assembly of the powertrain set (engine, transmission, and cooling system). These suppliers design and produce the engine module, providing it in a "black box" system.

## **3. Related Literature on Modularity**

Modularity is basically the process of dividing a product into smaller subsets, called modules, assembled from various components (Persson, 2004). With a broader view on the subject, Salerno et al. (2008) suggest that modularity is similar to a relation of services, because besides the tasks already practiced and known as design, production, and delivery of modules by the supplier, the use of modularity means sharing risks with first-tier suppliers. These suppliers take responsibility for some services such as technical support, troubleshooting, assembly line, production scheduling, and changes in product design.

The goal is to achieve modularity of a product in which the different modules are independent of each other, connecting via interfaces that are specified and standardized, allowing individual changes without having to interfere with other modules (Mikkola, 2003; Ulrich, 1995). In order to do so, however, some aspects of modularity that influence subsequent decisions in the process of obtaining the product must be considered, such as (Baldwin and Clark, 1997: (i) the product architecture, which specifies the modules of the systems and their functions, (ii) interfaces, which are responsible for the interaction of modules, and (iii) the determining of standards, aimed at verifying the compliance of module. From the standpoint of engineering, modularity has three main objectives (Baldwin, Clark, 2000): (i) dealing with the complexity of product and process, (ii) enabling simultaneous activities and (ii) gathering future uncertainties.

### **3.1 Modularity in Design**

Modularity applied to product design aims at reducing product development time through parallel execution of activities (Baldwin, Clark, 2000; Ulrich, 1995), i.e. once interfaces have been specified, the modules can be developed independently and simultaneously to other modules. Interfaces determine how the modules connect, communicate and fit together (Chen, Liu, 2005; Baldwin, Clark, 1997). Thus, engineering can design and develop

modules more freely, because it reduces the direct dependence of other stages of product design (Ulrich, 1995). Another important factor attributed to the independence of modules is the intense innovation in design, because engineering can create and test different solutions in their own modules, with multiple product options by the relations of modules (Baldwin, Clark, 2000).

### 3.2 Modularity in Production

Efficient production of a diversified portfolio of products is often attributed to the flexibility of manufacturing (Ulrich, 1995), which is primarily a function of product architecture, and then, the technology used in manufacturing, of distribution centers and of the supply chain (Ramdas, 2002). In conventional facilities, individual components and sub-assemblies of a vehicle are mounted almost individually in the body of the vehicle in the final assembly. Modularity allows these components to be mounted in separate lines, thus forming modules that are sent to the final assembly line and installed directly on the vehicle (Sako, Murray, 1999; Takeishi; Fujimoto, 2001). Thus, there is a significant reduction in the complexity of the production process (Ulrich, Tung, 1991; Sako, Murray, 1999; Takeishi; Fujimoto, 2001) and, consequently, reduced assembly costs (Ulrich, Tung, 1991). Another important aspect attributed to modularity in production is the quality of final product, as the modules facilitate inspection (Takeishi; Fujimoto, 2001), making it possible to identify and resolve problems as early as possible.

### 3.3 Integration of Design and Production

The organization of the production process is generally composed similarly to the structure of the product that companies design. For a modular product, in particular, as the interfaces are clearly defined, the ideal is that the manufacturing process is developed following the same product structure (Fredriksson, 2006). For this to occur, the PDP (Product Development Process) requires production information to carry out its tasks, thus avoiding future problems in the manufacture and assembly, unnecessary expenses and delays in the launching of new products. Manufacturing in turn, can contribute by providing information on the restriction of production capacity, of process and of technologies available. Thus, product design and production process must follow together.

### 3.4 Integration of Design and Production

Some relevant issues related to product design and modular production are shown in Table 3. Those issues were selected according to their importance with regard to the purpose of this work.

Table 1: Issues found in the literature

Main items	Summary	References
Modular architecture of the product	The physical arrangement of the product components and how their relations occur	Fredriksson (2006), Baldwin and Clark (2000), Camuffo (2000), Ulrich (1995)
Standardization of components, modules, and systems	Allows reuse of components, modules, and system	Krishnan and Gupta (2001), Lee and Tang (1997)
Modularity in production	Possibility of assembling modules in separate lines and later sending to the final assembly line	Worren et al. (2002), Takeishi and Fujimoto (2001), Sako and Murray (2000), Baldwin and Clark (1997)
Modular flexibility in production	Modules can be assembled in different configurations of the product	Doran and Hill (2008), Arnheiter and Harren (2005), Chen and Liu (2005), Sanchez and Collins (2001), Ulrich and Eppinger (2000), Baldwin and Clark (1997), Sanchez and Mahoney (1996)
Modularity in production and its influence in product design	The organization of the productive process existent in modules can affect modular product design	Fredriksson (2006); Takeishi and Fujimoto (2001), Henderson and Clark (1990)

Table 2: Issues found in the literature – continued

Main items	Summary	References
Modular product development and its influence in the production line	The structure of the modular product is used to determine the structure of the productive process	Fredriksson (2006); Takeishi and Fujimoto (2001), Henderson and Clark (1990)
Management of product and modular production	Supply chain management complexity reduction	Baldwin and Clark (2000), Ulrich (1995)
Modular production and product design task outsourcing	Outsourcing product design and production tasks works as an alternative to reduce costs	Doran (2005), Pires (1998), Collins; et al. (1997)

## 4. Results and Discussion

This section presents the results of cases by a general narrative, with the intention to compare them to the literature for the analysis of data collected.

### 4.1 Context and results of data collection – Automaker A

The commercial vehicle automaker investigated, according to the ANFAVEA (2009), occupies a prominent position in the manufacture of trucks and bus chassis, especially to what regards its production management known as modular consortium. In this system of organizational arrangement, seven first-tier suppliers provide and assemble the modules in the vehicles on the production line in seven modules (chassis, axles and suspension, wheels and tires, engines, transmissions and cooling system; booths, painting and cab interior finishings) under the supervision and monitoring of the automaker. Thus, the company can focus on product design, customer services, *marketing* and sales, introducing vehicles that are more appropriate to market needs. This is a benefit of modularity and it has been pointed out by the literature (Collins et al. 1997, Marx et al., 1997).

#### 4.1.1 Modular product development

The company has a center of research and development (R & D) in Brazil to design and launch trucks and bus chassis. This expertise in product development represents an important economic aspect, as it creates a need for more qualified staff (Salerno et al., 2001). Another important aspect is the possibility of having projects and co-projects (*co-design*) with suppliers, which somehow benefits the suppliers that are in the country (Salerno et al. 2009). These two aspects, highlighted in the literature, are seen in the company examined. The design of the vehicle is fully made by the automaker with respect to the vehicle requirements and it counts on the partnership with its suppliers for the development of modules, for example, cabins, engines and transmissions. The engineering of the maker is divided into specialties: *powertrain*, electrical, cab and chassis, and the product development is divided into a reference model of stages and *gates*, which is relatively common in the automotive sector.

The division of the "truck" and "bus chassis" products in modules is made easy, because the architectural features of these products are more appropriate. In the case of a truck, for instance, the separating of the cab and of the chassis is made easier for the composition of different models. In addition, the chassis works as the basis for the development of modular logic, supported by other literature sources (Cauchick Miguel, Pires, 2006, Marx et al., 1997). This is different from a passenger vehicle, considered a complex product (Persson, Ahlstrom, 2006), with more of an integrated architecture. In data collection, it has been identified that the initial division of the product into modules was done empirically, when the engineering of the automaker and its suppliers defined in the assembly line the interfaces of each module. Based on the inter-dependence of each module, and with the intention of having it function properly, it was determined which supplier would be responsible for mounting the accessories (hoses, fittings, etc.). That is, the automaker came from an existing product to create the concept of modular product, which is a possible indication that the modular design and modular production are not necessarily (and necessarily) dependent. The interviewee mentioned several changes to the project in order to adapt it to modularly, but they were not detailed in the interview.

Due to one of the most recent releases of the company, it was necessary to have the support of the engineering team in the headquarters to the development of the cabin, which apparently shows a possible contradiction of data collected in relation to the autonomy of the plant in R & D. For this release, it was necessary to develop a new cabin, engine and suspension. The project began with the participation and involvement of several areas of the automaker (logistics, quality, manufacturing and product). With the development of the new product they built the second line

of cab frame. In the same period, they also set up a pilot plant, and it aims to simulate the assembly process, identifying potential interference of a new product development.

#### **4.1.2 Relationship between the automaker and suppliers**

Data collection identified some important elements for the organization of production at the automaker examined, regarding its relationship with suppliers. These elements are presented below and compared with the literature when relevant:

- The automaker is responsible for the selection, development and payment of suppliers of second and third levels. However, it delegates first-tier suppliers there the responsibility for scheduling orders, assuring quality control, and delivering components. Thus, the automaker's monitoring with respect to these orders is made strictly, to avoid great physical inventory. The high bargaining power of the automaker can be considered as a further justification for it to keep controlling the purchase of components.
- The first-tier supplier has the infrastructure and resources needed for the assembly of modules in vehicles in the plant of modular consortium. These facilities are exclusive to the company. This can be considered one of the disadvantages of the modular consortium for the first-tier supplier, since it increases the interdependence among the companies in relation to the production demand of the automaker. On the other hand, it establishes a relationship of medium to long term, at least during the remaining term of contract between the parties.
- The credits for services rendered take place in two steps, which are determined in inspections points in the production. The supplier receives a partial payment when the vehicle assembly is completed, and the remaining payment when the vehicle is approved in the final quality tests. This fact has not changed since the beginning of the modular consortium.
- The new investments are negotiated between the first-tier suppliers and the automaker to determine the participation of each. Usually the supplier invests and the automaker pays off in the number of vehicles produced, ie, a fixed part due to the amortization of invested capital and other variable according to the number of vehicles produced and approved in the final assembly line in a given period. Such practice brings the automaker a great benefit, as part of the payment of the investment is made with the production of vehicles itself.
- The first-tier suppliers are responsible for the modules and the quality of services provided on the assembly line. This is another confirmatory fact, as highlighted in the theoretical basis, ie, the relationship between the automaker and the supplier goes beyond design and assembly, also with the responsibility for some services, as highlighted most recently by Salerno et al. (2008).
- In the production, daily meetings are held among representatives of the automaker and suppliers, with the purpose to review the programming master plan. Thus, if there is any quality or supply issues, they will decide along with the automaker to change the planning. This organizational practice is shown as a benefit of partnership generated by modularity (Arnheiter, Harren, 2005).
- The production schedule is the "*taylor made*" type, in which the vehicle sold at the dealership sends the request directly to the production line. In older literature (Collins et al., 1997), it is cited as "*make-to-order*". Although this element has not been investigated in detail, it is believed that both the product and production organized modularly favor this practice of the company in product customization (Mondragon et al., 2006).
- Regarding the development of new products, the company is responsible for developing the design of the vehicle. Although the respondent has not indicated the involvement of suppliers in the development of the module, the crossing with the data with the results of suppliers A and B (shown below) indicate the existence of such partnership.

#### **4.2 Context and results of data collection - suppliers A and B**

Data collection also involved first-tier suppliers manufacturers of engines, trying to understand how decisions were made to adapt products for the new modular production arrangement and how the development of new engines was made for the automaker. Suppliers A and B are multinational companies that adopt the concept of modularity.

In the modular consortium, suppliers A and B operate through a *joint venture* – partnership - formed among the companies to provide services in vehicle assembly in the plant of the examined automaker. It is noteworthy that, out of the modular consortium, the companies are competitors in the segment of medium-power engines. Figure 1 shows the clipping of the activities performed by suppliers A and B in the automotive supply chain. The first block of dashed lines shows the activities of suppliers A and B individually, i.e. each one in your plant, comprising the steps

of motor design, manufacture or acquisition of components and pre-assembled engine. The second block of dashed lines represents activities in the *joint venture* - made in the plant of the automaker. In this block, transmission and cooling system are added to the engine, forming the whole *powertrain*. Then, this module is mounted on the vehicle chassis.

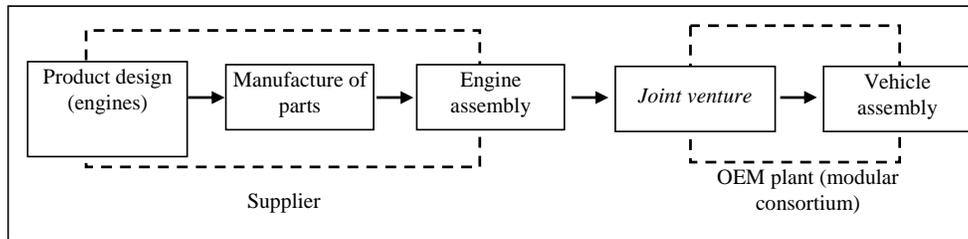


Figure 1: Representation of engine suppliers (suppliers A and B).

#### 4.2.1 Product design and assembly aspects in the modular consortium

The redefinition of responsibilities and transfer of product design tasks to first-tier suppliers were based on the operation of the module. For example, if for the functioning of the engine it was necessary to have a radiator, then all components and subsets required to interconnect these components relied on the supplier to mount the engine module. Suppliers A and B participated in the creation of the modular consortium assisting in organizational settings of *layout*, logistics and production process. At that time, each first-tier supplier determined their assembly process and the resources needed to perform their tasks.

The sites occupied by first-tier suppliers were set close to the final assembly area and arranged in a logical sequence of vehicle assembly. The site arrangement of suppliers in the final assembly line indicates that the organization of production bears some relationship to the product structure. Depending on the product architecture and modularity of design used in the new plant, some changes in the sequence assembly of the vehicle and the *layout* of the product were required compared to the conventional way of production. These changes aimed to improve the form of work also seeking to deal with a differentiated mounting, compared to the traditional production system, since this system consists of a module with the engine and its accessories. These results are consistent with previous study (Marx et al., 1997). However, with regard to the *smart* car design, a whole redesign was needed for the product, and the process of manufacture (Hoek and Weken, 1998), which did not occur in this research.

#### 4.2.2 The Development of Products by Suppliers

According to data collected, the development process of new products of suppliers A and B can occur in three ways: (i) to incorporate new technologies, such as electronic engine that replaces the mechanical motor in many applications, (ii) a need for customer service and market, or (iii) for compliance to new legislation. In the case of engines, requests with respect to greenhouse gas emissions are increasingly accurate and constant.

In addition, according to the data collected, the product development projects from suppliers A and B are classified into "basic" and "application" engine designs.

A "basic engine" involves the creation of a new engine. These engines can be undertaken without the existence of a specific customer, for example, aiming at a market niche not yet explored. An "application engine" is related to components and systems of engine interface with other modules and vehicle chassis, developed for the application of a basic engine in the vehicle of a particular client. It occurs as there is a basic engine developed or unless the project is at an advanced stage of development. The application of a basic engine that is still in development, must have been approved at least in tests of reliability and durability. A basic engine project development is made according to several requirements made by the automaker, but is fully developed by suppliers in a "black box" type of system. In this type of development, the OEM determines the performance specifications and design and deploys to the supplier. This can be considered as a co-design, because the supplier and automaker join forces to determine design requirements; this kind of practice is highlighted by Mikkola (2003).

During the development of the project of implementation, the automaker is in charge of providing the vehicle requirements, the timing of product development and providing a truck that will be used for testing during the development of new product. For the development of engines and accessories, supplier B strives to keep standardized interfaces, the same basic engines are different, even in different displacements. This significantly reduces expenditure in tools and changes in production processes. As such, product quality tends to increase as it reduces the risk of assembly errors. With respect to the external components or subsets of the engine, Arnheiter and Harren

(2006) point out, for instance, that services for replacement of oil filters and other external components of the engine, become faster as the interfaces are standardized.

The standardization in the development of new products, for example, the development of electronic control module for use in global standardization and piston engines, allows the use of a product development and process. Consequently, it generates a reduced variety of parts, physical inventory and logistics, as noted in the literature (Mikkola, 2003; Sanchez, 2002).

In a recent launch of commercial vehicle of the examined automaker, supplier A developed two lines of engines. Every new standard must be met; there is a need to add components to the adequacy of the engine module. In such cases, the product design is performed with a high degree of initial uncertainty, and as the most accurate information is set, changes occur in the later stages of development. With the emergence of new technologies such as, for example, the electronic control module of the engine, there were changes in the project application for a new truck assembly plant. This change allows greater customization of the product when meeting the needs of the client. The customization can be understood as a benefit of modularity (Danese, Romano, 2004; Mondragon et al., 2006).

With the transfer of knowledge and expertise of the automaker to supplier B, with regard to engine technology, it almost does not happen because *core* technology belongs to supplier B. On the other hand, although the supplier will learn a lot about the vehicle that is a risk because the continuous transfer of tasks to their suppliers have made some automotive makers lose their skills (Mondragon et al., 2006).

#### **4.2.3 Modular Consortium**

The suppliers A and B participate from the early part of the development of new products with a multifunctional team. First, this team works in the design of the engine, and in a second stage, it interacts with the *joint venture* in the vehicle assembly process development. According to the interviews and observations *in loco*, operations performed on the assembly line of the vehicle are relatively simple, usually performed with the aid of cranes, lifting device, etc, handled by operators, flexible to the mounting of different motors in any product family. The reduction of the handling of components in final assembly and the transfer of module assembly to other lines are highlighted as one of the benefits of using modularity (Fredriksson, 2006b; Hoek; Weken, 1998).

One of the difficulties found by suppliers A and B was the communization of the interfaces among their engines to the assembling of the module in the final assembly line. As the engines have different projects, thus the various components used in the interfaces of each product are stored in inventory. For supplier A, with respect to mechanical interfaces, the engines had different slopes when compared to old and current cab models. Thus, several changes were necessary because various accessories were also modified. However, according to the interviewee, these changes did not affect the final assembly of the *joint venture*, which seems to indicate, regarding the module of engines, there is some independence between product modularity and production. In the production process, changes occurred primarily due to the use of new technologies, i.e. the electronics has changed, because the interface electronics that did not exist before, it started to be made with the harnesses and the integration of a module electronic control and various sensors.

#### **4.2.4 Cooperation with Suppliers**

Supplier B's new product development has been increasingly performed along with its suppliers that have worked from the beginning of the project to the step of conducting functional tests in the final client (OEM). According to data collected, the partnership with suppliers to develop new products usually takes place in a system of co-design. The partnership with some key suppliers has as main objective the reduction of costs through the transfer of activities in the supply chain, for example, mounting rings on the piston engine. In this case, suppliers are considered members of the development team and the outsourcing that occurs in supplier B is consistent with the study of Doran (2004), who states that the first-tier suppliers tend to focus on higher value added activities and transfer less value tasks to suppliers down the supply chain.

### **5. Conclusions**

It can be observed that the concept of modularity can be applied to the production process regardless whether the product has been designed in modules or not. Certainly, this is not possible for any vehicle (e.g. passenger cars). However, data collected showed that the use of modularity has emerged in the automaker from production based on empirical decisions of assembly and operation of the module.

On the other hand, when a product is designed in modules, the result usually is that the production process is organized according to product structure. In this sense, modularity in product design can lead to the production process modularity. However, it is not possible to be conclusive on this remark in this present investigation. Both the

literature and the data collected showed that the product structure of a commercial vehicle division promotes product modules, since the chassis is suitable as a technical basis for the development of modular logic.

Regarding production, the application of the concept of modularity in the final assembly line seems to make the production process more simplified because the total number of components and subsets handled is reduced. In addition, modules are added to the vehicle by means of standardized interfaces. One can then conclude that some of the factors that contribute to the simplification of the production process require the use of standardized tools, since components between different lines of products are standardized and the use of modules common among different products. In the modular consortium, as the modules are supplied mounted, the final assembly line can be significantly reduced in extent, it will do just their integration. Consequently, there is no conclusive indication that the allocation of resources in the automaker's assembly line machines, equipment and tools is reduced, because expenditure should be lower. However, it was not possible to determine this amount in this investigation, because cost data were not available.

The development of modular product can also affect the production system (final assembly). This may occur mainly when the production process does not have the technological production capacity of the product developed. It is noted that the product structure affects the determination of resources needed for production, which are determined according to the methods of assembly, module configuration, which has different assembly characteristics when compared to an integrated product. These findings are relatively expected. Thus, this research is confirmatory. Even so, the differential of this work goes beyond the verification of the use of modularity in product design and production, resulting in an analysis, in confirmatory terms, of the relationship among such perspectives in the modular context.

In general, and restricted to this work, as much as product and production process are planned, the modular product is always subject to change during its lifespan. Changes may arise as a result of the production process optimizations and of existing products or with the introducing of new products, adaptations to new standards, quality control, cost reduction, among other needs. Thus, the analysis of product or process adaptation needs is made continuously during its lifespan. This should be further investigated in future studies.

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