Gest. Prod., São Carlos, v. 25, n. 4, p. 935-947, 2018
https://doi.org/10.1590/0104-530X0225-18

ISSN 0104-530X (Print)
ISSN 1806-9649 (Online)

Proposal of the PLM-PV3G model for product lifecycle management

Proposição do modelo PLM-PV3G para a gestão do ciclo de vida de produtos

Paulo Sergio Gonçalves de Oliveira[1]
André Luis Helleno[2]
Dirceu da Silva[3]
Meire dos Santos Lopes[4]
Fernando Celso de Campos[2]
Djair Picchiai[5,6]

Abstract: The objective of the article is to propose a model for product lifecycle management in the metalworking sector. This proposal intends to facilitate the adoption of good practices in the sector, by reducing complexity and improving action assertiveness. To achieve this goal, a survey was carried out with specialists from the sector, obtaining a total of 397 questionnaires. The focus of the model is to design green products to give support to the collaboration, manufacturing and knowledge management during product lifecycle management and making it easier to adopt this methodology. The model was developed using PLS (Partial Least Squares) analysis.

Keywords: Product lifecycle management; Partial least squares; Change management; Knowledge management.

Resumo: *O objetivo do artigo é propor um modelo de gestão de ciclo de vida de produtos no setor metal-mecânico. Essa proposição visa facilitar a adoção de boas práticas no setor, por meio da redução da complexidade e melhoria da assertividade das ações. Para atingir esse objetivo, foi realizado um levantamento com especialistas do setor, com o qual se obteve um total de 397 questionários. O modelo tem como foco principal o projeto de produtos verdes para apoiar a gestão da colaboração, da manufatura e do conhecimento durante a gestão do ciclo de vida de produtos, facilitando, dessa forma, a adoção de tal metodologia. O modelo foi desenvolvido utilizando-se a análise PLS (Partial Least Squares).*

Palavras-chave: *Gestão do ciclo de vida de produtos; Partial Least Squares; Gestão de mudanças; Gestão do conhecimento.*

1 Introduction

In recent years, investment in product lifecycle management (PLM) has grown in all corporate areas, mainly due to an increase in products complexity and in customers' requirements, which made companies begin integrating suppliers into the product development process (Tang & Qian, 2008).

Product Lifecycle Management is an approach to integrated management of business processes and information related to these items. This approach requires the use of computer systems (PLM Systems) to support collaboration within the company throughout the entire lifecycle (Zancul, 2009).

2 Product Lifecycle Management (PLM)

Product Lifecycle Management (PLM) is defined by Farouk et al. (2008) as the systematic integration of all information related to the product and lifecycle processes, from the initial idea for the project to its

[1] Universidade Anhembi Morumbi, Rua Casa do Ator, 275, Vila Olímpia, CEP 04546-001, São Paulo, SP, Brasil, e-mail: psoliveira@anhembi.br
[2] Universidade Metodista de Piracicaba, Rodovia Luis Ometto, Km 24, CEP 13451-900, Piracicaba, SP, Brasil, e-mail: alhelleno@gmail.com; fccampos@unimep.br
[3] Universidade Nove de Julho, Rua Deputado Salvado Julianelli, CEP 01156-080, São Paulo, SP, Brasil, e-mail: meiresl@uninove.br
[4] Universidade Estadual de Campinas, Av. Bertrand Russell, 801, CEP 13083-865, Campinas, SP, Brasil, e-mail: dirceu@g.unicamp.br
[5] Faculdade do Campo Limpo – FACCAMP, Rua Guatemala, 167, CEP 13231-230, Campo Limpo, SP, Brasil, e-mail: djair.picchiai@fgvsp.br
[6] Fundação Getulio Vargas – FGV, Avenida Nove de Julho, 2029, CEP 01313-902, São Paulo, SP, Brasil, e-mail: djair.picchiai@fgvsp.br
Received Dec. 01, 2017 - Accepted Apr. 27, 2018
Financial support: None.

disposal, which makes PLM a business strategy that supports collective creation, management, dissemination and use of product information in the extended enterprise.

The goal of PLM is to optimize the configuration of processes, especially the product development process, as well as the management of all product information throughout the product's lifecycle. Updated information can be accessed directly by all authorized people, at any time, making it possible, for example, to reduce the time needed to develop new products with lower costs (Lambert, 2010).

PLM enables creative collaboration, management, dissemination and use of the product's definition and operational processes information in the extended enterprise, from the marketing concept to product withdrawal from the market (Lee et al., 2008). As a result, in recent years, PLM has been proposed as a business approach with the purpose to integrate people, processes, business systems and information management into the complete product development cycle between companies.

In this way, PLM is a business strategy that proposes the consistent management of all stages of the product lifecycle, from the beginning of its commercialization to its disposal, thus involving a large number of stakeholders (customers, suppliers and regulators), which require different levels of detail and information representations (Thimm et al., 2006).

The process of Product Lifecycle Management (PLM) will be discussed in the following eight subchapters.

2.1 New product development management

According to Nisson & Fagerström (2006), to develop a well-balanced product, it is necessary to consider the opinion of the stakeholders throughout the product lifecycle.

Another fundamental aspect is the product specification, which needs to mirror the aspirations of the customers as closely as possible. The QFD (Quality Function Deployment) methodology can be used for this. It can be implemented in phases, by creating modules, with the objective of making the management easier.

To validate the phases of product development, a formal review and verification can be used at the end of each phase, called a review in *Gates*, to verify that all requirements have been fulfilled. This approach can benefit the organization greatly (Rozenfeld & Forcellini, 2006).

Nantes & Lucent (2009) state that in order to meet the real needs of customers, the product development process (PDP) needs to be supported by technological innovations that differentiate products in the market, improving the company's participation in the market, which will ensure its survival.

The more technology is incorporated into the products, the greater the chances they will be successful, when compared to those that do not present differentiations or do not incorporate innovations (Gecevska et al., 2010).

However, Nantes & Lucent (2009) warn that in Brazil product development is characterized, mainly, by the improvement of products, through small adaptations to incorporate them to the local market. Another Brazilian production feature is the lack of involvement of universities and research centers; however, there is an increase in partnerships between raw material suppliers and customers, characterizing the innovation as belonging to the company and incremental.

Lee et al. (2008) argue that this type of approach, aimed at product improvement, poses several challenges, such as continuous innovation, global collaboration and complex risk management. For this type of approach to be successful, intellectual resources, like data regarding processes and products, should be accessible to anyone in the value chain, through efficient knowledge management, so as to favor innovation (Trotta, 2010).

2.2 Supplier involvement and supply chain development

Companies have embraced the integration of suppliers into the product development process, and even offer training to these suppliers to develop the supply chain and achieve better results.

In fact, this phenomenon has found support in contemporary research in the fields of concurring engineering and supply chain management (SCM), which demonstrate that significant benefits can be achieved by integrating and involving suppliers in the early stages of product development, also known by the acronym ESI (Tang & Qian, 2008).

The typical supply chain definition refers to all activities associated with the transformation and flow of goods and services, from raw materials in products or services to the end user; the chain is responsible for managing both the internal and external activities of the company (Kainuma & Tawara, 2006).

Traditionally, the concept of supply chain refers to the product transformation flow from the bottom to the top, from the raw material to the delivery of the product to the final consumer, and the main focus was the flow of materials. The supply chain refers to the management of relations between companies, through business processes, to create value stream (Santos & Forcellini, 2009).

The activities in the SCM process are influenced by several variables, such as the product type, what is the commercial phase in the product lifecycle, the changes demanded by the customers, the launch of new technologies, the pressures by regulatory organs, the competitors available in the market, among others. These variables impose changes in the strategic goals of the business processes, making internal and external customers and suppliers interact through the business process activities. The sharing of information and knowledge among those involved helps to create a value stream to fulfill the different requirements of the product development cycle (Santos & Forcellini, 2009).

A methodology called ESI (Early Supplier Involvement) is used to manage relationships with suppliers. It verifies the external co-operation between the product developer (designer) and the developer of the parts or modules. According to this methodology, the relations basically fall into three modalities (Tang et al., 2004):

- **Classic ESI:** refers to the traditional customer-supplier relationship, in which both parties tend to improve their own positions to the detriment of the company;
- **Model I ESI:** the supplier is integrated into the process chain and, thus, contributes with their know-how throughout the entire product lifecycle;
- **Model II ESI:** suggests that the customer is responsible only for presenting the needs while the supplier assumes the responsibilities of designing the product and the tools; however, since it is a more advanced model, it does not fit the reality of many companies, because it presupposes a high degree of confidence and also of maturity.

To achieve better performance in the joint development of new products, Sharma (2005) proposes a model called CPI (Collaborative Product Innovation), which aims to unify three practices: collaboration, development and innovation, which are usually developed separately.

In this sense, great efforts have been made to solve communication problems between different areas of the company and between suppliers during new product development (NPDI). In general, both NPDI and product lifecycle management have the same challenges in the decision-making process. The improvement of the decision process occurs through the integration of people and processes around the product lifecycle (Trotta, 2010; Sharma, 2005).

2.3 Collaborative network management and extended enterprise management

To overcome the challenge of developing global products and to reduce design time and production costs, companies are creating design centers around the world to take advantage of regional expertise and low labor costs as well. These initiatives are called virtual projects, in which the members rarely have physical contact with the other project participants (Brito et al., 2009). These are virtual teams that use advanced technology for global product development.

One of the advantages of using virtual teams is that a project can be in progress for almost 24 hours a day, since employees will be working in different time zones. However, the disadvantage of these teams is that the employees have little or no physical contact, which creates difficulties in establishing relationships of trust, a fact that significantly reduces collaboration.

Despite advanced technologies, virtual teams rely heavily on human factors, strong coordination and well-defined project objectives to reach their full potential.

Many companies have developed collaborative networks between suppliers and partners, with the goal of shortening the product development cycle and mitigating uncertainties during the decision-making process, to meet the demands of the market faster and more precisely (Sharma, 2005).

However, to achieve improved collaboration, it is essential to stick to collaborative engineering processes, focusing on the following requirements: promoting shared data, providing location transparency, facilitating access to product data, providing user notifications, and monitoring progress (Rouibah & Oud-Ali, 2007).

2.4 Concurrent engineering and use of PDM systems

The competitive global environment is putting pressure on the market, a fact that has forced organizations to adopt many practices that modify the nature of competition, as new product development (PDP) and concurrent engineering are becoming increasingly significant (Possamai et al., 2007).

In addition to concurrent engineering, there is also the improvement, and, to some extent, in parallel, the emphasis on supply chain synchronization and participation in product development decisions. This emphasis is due to the recognition of many interrelated factors and the outsourcing of both manufacturing and design activities (Santos & Forcellini, 2009).

Concurrent engineering has two essential resources: competitive processes and the ability of multifunctional design teams. In a concurrent engineering process, all elements of product development are named from the outset as a group of activities and goals focused on the customers' wishes (Possamai et al., 2007).

To collaborate with partners and suppliers, it is often necessary to create interfaces between the company's and the suppliers' PDM systems. PDM systems play an important role in concurrent engineering, as they enable documents to be shared in different formats and help to maintain the strategic alignment of the areas of product development and manufacturing. In this way, the use of PDM software is key to define the digital product and to share knowledge with business partners, to enable concurrent engineering (Su & Liu, 2008).

Because partner companies typically use different types of PDM systems, the file and data sharing mechanisms from these systems should be used, and it is a good idea to use a representation in Lightweight programming model.

2.5 Change management during the product lifecycle

Product lifecycle management also involves monitoring products after they have been launched, not just during the initial design, to make the necessary changes, allowing for planned discontinuity and incorporation of lessons learned during the product lifecycle, within the development process (Brigatini & Miguel, 2009).

However, Rouibah & Caskey (2003) argue that the design of a product in a company, or a consortium, is an interactive process and requires change. Companies' ability to better manage engineering changes (ECs) during product development can reduce costs, shorten development time, and produce high-quality products. However, changes occur throughout the product lifecycle and can come from different sources, such as the use of a collaborative network between several partner companies.

In this collaborative environment, it is necessary to involve all parties in to assess the change impact and control and jointly decide how to conduct it. Change control requires several coordinated activities, while assessing the impact of the change requires managing the relationship between the modified components and the interface between the other components, or developing activities. That is, one must manage the relationship between the objects (parts, components, parameters, etc.) with the objects that will undergo changes, observing how they will impact the product as a whole.

During product development, engineers need to make certain decisions without creating documents or following processes. These decisions are called specific engineering variables, and these elementary variables are defined as parameters. During a collaborative project, different people decide on the values of the parameters, capturing their relationship and, consequently, specifying the relationship between decision makers (Rouibah & Caskey, 2003).

The parameters to be managed can be selected at an initial meeting between supply chain partners. The parameters may be distinguished as functional, for example, a motor, a geometry, or related to the material, such as a metal number. The parameters defined and declared to be able to perform supply chain management are categorized, such as a parameter system and parameter interface (Yang et al., 2004).

For the management of the parameters, it is possible to use a system of assessment of their degree of maturity, that vary in a scale of HG1 until HG5, which represents the degrees of maturity between the departments. HG1 refers to a parameter that has an estimated value, while HG5 refers to a parameter with exact value with set tolerances (Rouibah & Caskey, 2003).

This flow can be automated, using the concept of service-oriented architecture (SOA) and process mapping. Based on the BPM model, physical implementation can be achieved using BPEL software (Siller et al., 2008).

For the changes to be propagated, it is necessary to integrate systems, such as ERP and PDM. Currently, the concept of table creation is used to perform data intermediation, because there are few interfaces available in the market. To exchange data, it is also possible to use the concept of services or SOA (Hou & Su et al., 2008).

There is concern about change management because advances in modern technology have resulted in many complex systems, products, and processes that make project management very difficult, considerably increasing the complexity of project changes, analysis and management and also for the entire product lifecycle (Venkatasubramanian, 2005).

2.6 Knowledge management distributed over the product lifecycle

When developing global products, many companies look for cooperation between their units around the world. This cooperation requires project teams, in which members are culturally diverse and geographically dispersed. These circumstances introduce a great degree of complexity to the management of the projects, specifically regarding communication and coordination, through a team of multicultural and dispersed projects (Livieiro & Kaminski, 2009).

Interactions between team members and the exchange of experiences in problem solving generate knowledge, causing organizations to dynamically create knowledge. Nonaka et al. (2000) proposed a model that consists of three elements, composed of Seci (Socialization, Outsourcing, Combination and Internalization), Ba (Place where knowledge is created) and Knowledge Assets.

Efficient management of product engineering data is critical to effective corporate improvement. Companies are looking for techniques and tools that will allow them to control the design, the engineering and the measurement, through collaboration technologies (Rouibah & Oud-Ali, 2007).

In response to the demand for project knowledge management and product change management, in September 2005, OMG (Object Management Group) published a RFP (Request for proposal) for an international standard of knowledge-based engineering, called KBE, for product lifecycle management (PLM) (Fan & Bermell-Garcia, 2008).

The standard requires KBE systems to have several features, such as (Fan & Bermell-Garcia, 2008):

- Consult and return the geometry and topology generation services, including data entry, output, available messages, and internal features of the object.
- Explicitly define the data input and output streams, instantiating services within applications.

Knowledge management is applied through configuration processes, in which product modules or components are selected and assembled, according to the customer's request. Product configuration typically uses large knowledge volumes due to the complex relationships between components, such as configuration rules and assembly constraints (Gecevska et al., 2010; Jinsong et al., 2008).

2.7 Manufacturing management throughout the product lifecycle

Manufacturing flexibility is important because it provides companies with a more dynamic response to market changes, to meet customer needs. Not being able to measure it makes it difficult to assess the resulting benefits (Gerwin, 2005).

To achieve manufacturing flexibility, Cui & Qi (2006) propose PLM integration, thus creating a uniform and integrated platform that supports the company's operations, allowing the management of product data, with speed and efficiency, controlling the changes and also sharing information among all involved.

The importance of PLM lies in integrating data from CAx (CAD, CAM, CAIP etc.), ERP, CRM and SCM systems (Trotta, 2010). This integration enables faster decision-making and enables managers to better assess the impact of these changes.

For this reason, PLM is considered a paradigm that brings innovation into the manufacturing area, allowing organizations to develop engineering content and integrate all business processes, throughout the complete lifecycle of the product in the extended enterprise (Kim et al., 2008).

On the other hand, the production department faces some problems, such as inventory maintenance and challenges in preparing an effective production plan. The development of ERP systems focuses on solving these types of problems (Ou-Yang & Chang, 2006).

Among the available applications, the enterprise application modules, PDM and ERP are prominent in the design and production departments. PDM helps engineers manage product development process data and ERP acts as the primary tool for order, production, and inventory processes (Ou-Yang & Chang, 2006).

The information generated by the PDM and ERP systems supports the planning process, which is called CAPP (Computer-Aided Process Planning) and is supported by software applications. This process comprises the procedure or set of procedures that uses engineering drawings, bill of materials and other specifications as input to identify and select the processes, features, sequence of operations and parameters required to convert raw material into finished products (Trotta, 2010; Siller et al., 2008).

Regarding the outsourcing of manufacturing demanded by modern industries, the use of systems via the Internet, PDM legacy systems (antiquated), are being migrated to systems based on Web technology, becoming an essential tool for e-manufacturing. Recent advances in PDM technology address the use of Web technology, but there are still limits on availability, security, reliability and scalability for the global marketplace (Sung & Park, 2007).

2.8 Product design considering disposal

According to Yang et al. (2007), most software is intended to manage the early stages of the product lifecycle, such as product design and manufacturing preparation, and very few focus on the final cycles of the product. In view of this, a PLM system was developed for consumers in the European Union, with the aim of managing the data from domestic use of products, to get information about product distribution, maintenance, use and end of lifecycle.

Managing this information became a concern after Eco92, when consumers became more and more aware, and companies were required to use practices such as Eco-design, which is used in Europe and is promoting the diffusion of vehicle recyclability worldwide. The action affected even developing countries, as is the case of Brazil, reflected in government policies and also in environmental legislation (Medina & Naveiro, 2009).

To achieve these goals, Possamai & Valentina (2007) propose the creation of an indicator that considers the assembly levels, the difficulty of dismantling and the use of materials that are easily reused.

Medina & Naveiro (2009), in turn, suggest the use of long-term partnerships, which are established between manufacturers and their network providers to share risks and profits, and seek innovative solutions to encourage that materials be recycled.

In this scenario, reverse logistics is very important, even though, currently, companies are more concerned with direct logistics, between their manufacturing plants and the final consumer, which involves complex planning systems, so that the entire process is accurate, aiming at customer satisfaction and business profitability. Contrary to what many managers think, the reverse movement, that is, reverse logistics, is not only a package recycling process that, most of the time, due to the limitation of reverse planning, ends up being very costly (Gonçalves-Dias & Teodósio, 2006).

3 Materials and methods

For the development of the study, a transversal survey (Babbie, 1999) was carried out with 397 professionals from the metalworking sector, using LinkedIn (professional social network) discussion groups. Thus, the following profiles were identified: professionals who, preferably, had participated in product development projects, managers and process and product engineers. The survey members were interviewed using a questionnaire based on a 10-point Likert scale (Hair et al., 2005). Participants stated if they agree of disagreed with each of the 37 statements submitted to them.

The results were tabulated and the SmartPls software (Ringle et al., 2005) was used for the analysis of the PLS (Partial Least Squares), the analysis of the paths and for the composition of the final model.

4 Analysis of the results

Figure 1 presents the theoretical model that will be assessed using the structural equations technique. The hypotheses are shown after the figure.

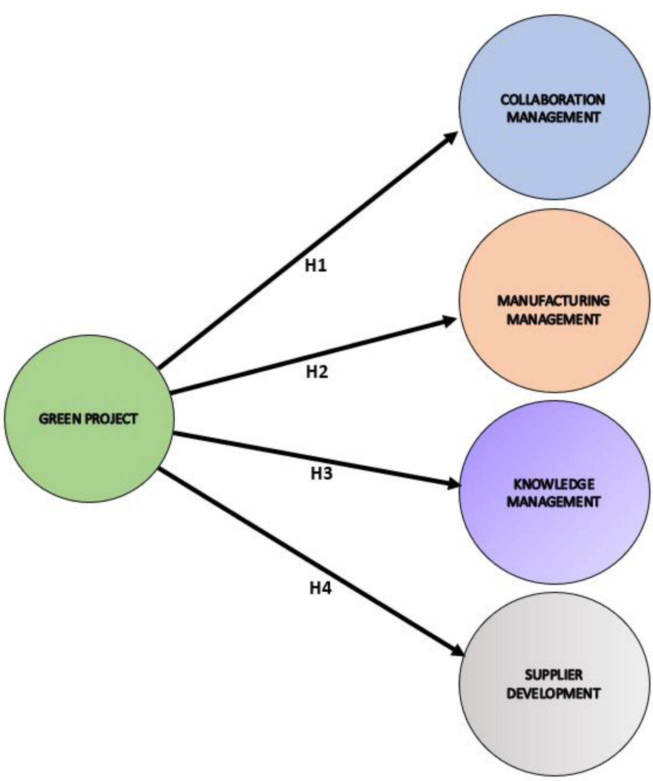

Figure 1. Product Lifecycle Management Model.

Hypothesis 1 of this research was formulated based on the fact that collaboration management needs to occur throughout the product lifecycles, from the initial design to its disposal, and also due to the fact that the green design, whose great concern is to develop environmentally sound products and thus needs to be created collaboratively, and should be part of the organization's strategic planning (Medina & Naveiro, 2009):

H1: The "Green design" affects " Collaboration Management", favoring it.

Due to the aspects presented by Possamai & Valentina (2007), who discuss the importance of manufacturing flexibility, regarding the development of products that are easier to dismantle, and to the one proposed by Scalice et al. (2009), regarding strategies that can be used by product engineers, Hypothesis 2 was elaborated as follows:

H2: The "green design" of products favors "Manufacturing Management" regarding its flexibility, creating environmentally friendly products.

Hypothesis 3 was formulated based on the fact that the management makes knowledge exchange and creation of collaboration networks possible by using standards that favor ontologies (Nonaka et al., 2000), and should be used in all phases of product lifecycle, even in the follow-up of their use by customers and use of the supplier network (Kainuma & Tawara, 2006):

H3: The "green design" of products favors "Knowledge Management", regarding the sharing of information between suppliers and other stakeholders in the process.

Green product design benefits from long-standing partnerships, as pointed out by Kainuma & Tawara (2006) and Leite (2005), regarding reverse logistics. Therefore, Hypothesis 4 was as follows:

H4: The "green design" of products is enhanced by supplier development, favoring long-standing partnerships and facilitating reverse logistics.

The software "SmartPls" was used for the PLS Analysis. For this, blank data (no response) in the questionnaire were replaced by -99. The variables also needed to be regrouped to facilitate the analysis.

Factor issues were renamed to facilitate data analysis

The model proposed in Figure 1 was used for the PLS analysis, which served as the basis for the generation of the path model.

Firstly, we analyzed the factorial loads of the "outer model" (Ringle et al., 2005), by analyzing the variables loads, dismissing values below 0.5. For this reason, the variables GECOL1, GECOL2, GECOL3, GECOL5, GECOL6 and GECOL7 were eliminated from the "Collaboration Management" factor; and the variable "DEFOR2" from the "Supplier Development" factor, which eliminated this factor. Since the variable "DEFOR2" presented a very high value and was shown to be related to the Collaboration Management factor, it was transferred to this factor.

Then, the "PLS algorithm" was calculated again, resulting in the model shown in Figure 2:

The model presented in Figure 2 was more suitable, since the loads of the variables increased, besides showing higher values for the R^2 and for the constructs factorial loads (Hair et al., 2005).

The coefficient paths were very adequate: "Green Design" → "Collaboration Management" = 0.655; "Green Design"→ Manufacturing Management= 0.722; and "Green Design" →Knowledge Management = 0.692 (see Figure 2). These values show that there are strong relationships between the constructs (Hair et al., 2005), as can be seen in Table 1.

R^2 assesses the portion of the variables that explain the constructs. It indicates the quality of the adjusted model. Values of 0.75, 0.50 and 0.25 are considered substantial, moderate and weak respectively (Hair et al., 2014).

The reliability of the construct presents values above 0.70, indicating good reliability, while the Cronbach's Alpha presents values between 0.6 and 0.8 (Hair et al., 2005), indicating that the constructs are valid. The AVE values were higher or very close to 0.50 and, therefore, within the acceptable limit (Henseler et al., 2009). Moreover, the factorial loads of the relationships between the constructs and the variables were above 0.50, indicating a good fit of the general model (Henseler et al., 2009). The results are shown in Table 2.

Table 2 shows the correlations between the factors, indicating that the chosen model has good correlation indexes, and the chosen path is highlighted (Chang, 2011). The square roots of the AVEs were shown (highlighted in gray in Table 2), with values above the correlations. This comparison shows that the general model has good discriminant validity (Fornell & Larcker, 1981).

To verify the validity of the latent variables, that is, the constructs, the Bootstrapping mode of the software SmartPLS 2.0 (Ringle et al., 2005) was used to make the regression coefficients Student t-test values significant. The value of 1.96 (significance level of 5%) is very adequate to ensure that each path (or load) was considered, with predictive validity (Hayduk, 1987). These values are shown in Table 3.

Table 4 shows the validity values of the regression coefficients of the "outer model", that is, the individual variables that compose the latent variable.

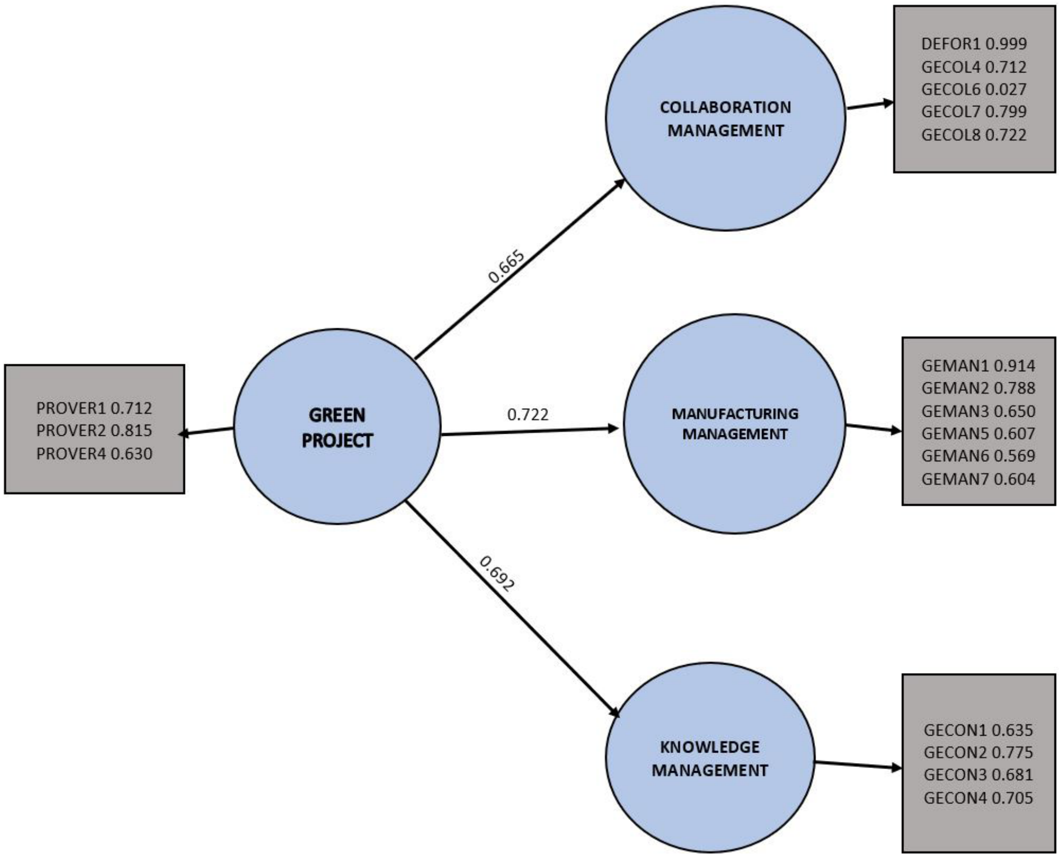

Figure 2. Product Lifecycle Management Model. Source: research data (2012).

Table 1. Values of the model adjustment tests.

	AVE	Composite Reliability	R Square	Cronbach's Alpha
Collaboration Management	0.532	0.773	0.475	0.560
Manufacturing Management	0.498	0.852	0.499	0.790
Knowledge Management	0.557	0.788	0.478	0.606
Green Design	0.495	0.792	----------	0.654

Source: research data (2012).

Table 2. Correlation between factors and square roots of AVEs.

	Collaboration Management	Manufacturing Management	Knowledge Management	Green Design
Collaboration Management	0.730			
Manufacturing Management	0.654	0.747		
Knowledge Management	0.691	0.706	0.706	
Green Design	0.689	0.720	0.691	0.701

Source: research data (2012).

The table shows that the values are significant, since the results obtained in the Student's t-tests are higher than 1.92, indicating that, at a significance level of 0.05, they are significant, which confirms that the variables are valid according to each factor that they make up.

Finally, a general quality index of the model, called GoF (Goodness-of-fit), was calculated, which is the geometric mean of AVE average values and regression coefficients of the SEM model, resulting in 0.499 (Tenenhaus et al., 2005). This value is very appropriate, since the value of 0.36 is recommended as appropriate (Wetzels et al., 2009). Thus, this test shows that the general model is well adjusted and completes what was proposed in the research.

Chart 1 shows the hypotheses that were confirmed and not confirmed after the PLS analysis.

5 Discussion of results and comparison with existing models

The model proposed in Figure 2 refers to the idea that, for companies to be able to establish Product Lifecycle Management, they must first adopt practices for better use of raw materials and be environmentally aware of their actions. However, for this to happen, the green design needs to be considered in the early stages of product development, searching for recyclable materials and recycling existing materials.

However, Yang et al. (2007), pointed out the need to develop a PLM software that focuses on the product's lifecycle, which led the European Union to develop software to manage the data from the domestic use of products; however, the model proposed here demonstrated that this concern already exists in Brazil.

The difference from the previous model is that, in addition to the concern of developing environmentally sound products, these practices need to be supported

Table 3. Validity of the Latent Variable Regression Coefficient.

	T Statistics (|O/STERR|)
Green Design -> Collaboration Management	6.097
Green Design -> Manufacturing Management	3.894
Green Design -> Knowledge Management	6.272

Source: research data (2012).

Table 4. Validity of coefficients of relations between variables and constructs.

Model paths	T Statistics (|O/STERR|)
DEFOR1 <- Collaboration Management	4.073
GECOL4 <- Collaboration Management	2.688
GECOL8 <- Collaboration Management	4.168
GECON1 <- Knowledge Management	3.802
GECON2 <- Knowledge Management	3.794
GECON3 <- Knowledge Management	3.531
GECON4 <- Knowledge Management	2.244
GEMAN1 <- Manufacturing Management	4.168
GEMAN2 <- Manufacturing Management	2.534
GEMAN3 <- Manufacturing Management	3.781
GEMAN4 <- Manufacturing Management	2.060
GEMAN5 <- Manufacturing Management	2.455
GEMAN6 <- Manufacturing Management	3.634
GEMAN7 <- Manufacturing Management	3.335
PROVER1 <- Green Design	3.811
PROVER2 <- Green Design	3.261
PROVER3 <- Green Design	3.742
PROVER4 <- Green Design	4.320

Source: research data (2012).

Chart 1. Confirmed / Unconfirmed Hypotheses.

H1	The "Green design" affects " Collaboration Management", favoring it.	**Confirmed**
H2	The "green design" of products favors "Manufacturing Management" regarding its flexibility, creating environmentally friendly products.	**Confirmed**
H3	The "green design" of products favors "Knowledge Management", regarding the sharing of information between suppliers and other stakeholders in the process.	**Confirmed**
H4	The "green design" of products is enhanced by supplier development, favoring long-standing partnerships and facilitating reverse logistics.	**Unconfirmed**

Source: the author (2012).

by consistent collaboration management; that is, without the participation of suppliers, customers, company, government and other stakeholders, it is not possible to develop consistent lifecycle management.

To achieve the goal of developing environmentally sound products, supported by product lifecycle management, Possamai & Valentina (2007) propose a model that focuses on the creation of an index of product dismantling difficulty. The great difference between this model and the one proposed here is that this practice must be supported by a consistent manufacturing management, since it must incorporate a practice presented by Gerwin (2005), which suggests improving manufacture flexibility. This practice is important to support green designs because, regarding the use of new materials, the manufacturing area must be able to adapt to changes.

To achieve this goal, Qiu et al. (2007) propose the use of PLM systems. According to Trotta (2010), the importance of this type of system lies in the ability to integrate several other types of systems, such as CAx (CAD, CAM etc.), SCM, ERPs, and produce information that is consistent and shared by all organization, so cooperation becomes possible.

For this, consistent knowledge management is important, so companies can integrate all areas in a consistent manner, respecting the ontology of each area, as suggested by Nonaka et al. (2000), enabling knowledge transfer. However, the model demonstrated that for Knowledge Management to be effective, it must be supported by a green design, so that this practice is disseminated throughout the organization and is rooted in organizational and also engineering actions.

To achieve this goal, Fan & Bermell-Garcia (2008) propose the use of KBE, which allows project participants to assess changes of parameters and, in this way, collaborate and jointly evaluate the use and application of new materials, in addition to developing long-term partnerships with suppliers, in order to manage the final cycles of product life.

The model points out that in order to achieve Product Lifecycle Management, it is important to integrate green product design with product management in all cycles, from design to disposal. For this, collaboration, manufacturing and knowledge management practices must be distributed throughout the organization and the extended enterprise, so that there is cooperation and integration of all stakeholders.

The importance of the model proposed here lies in the fact that environmental awareness already exists, along with the general perception that the resources of the planet need to be used more conscientiously, so that future generations have more quality of life. The researcher's opinion is that entrepreneurs need to become aware of which products should be environmentally sound. In addition to adding value and preserving the environment, these products are also more accepted by customers, who already perceive the problems generated by the lack of environmental awareness.

Medina & Naveiro (2009) point out that this concern became even greater after Eco92, which occurred in Brazil, as clients became more aware, which demanded that the European Union seek practices such as the Eco-Project and an increase in vehicle recyclability.

This awareness has just emerged in Brazil, but the findings in this research suggest that it is already spreading among professionals working in the metalworking industry and that somehow have the perception that it is necessary to develop environmentally correct products that can be reused.

The concern about the environment perceived in clients and in some companies is already reflected in government policies and in environmental legislation, which forces companies to include these practices in their strategic planning (Medina & Naveiro, 2009).

Increasing customer environmental awareness can also bring competitive advantages to companies that adopt this policy.

6 Final considerations

The objective of the article was reached; a product lifecycle management model was proposed and named PLM-PV3G, the acronym for Green Design that boosts three management mechanisms, namely: manufacturing, collaboration and knowledge management. Three elements are important in the proposed model: firstly, using the green design from the beginning until the end of the product lifecycle; the second element is that the manufacturing management uses tools, such as CAD and CAM, to share information and decisions regarding changes and assessments of product manufacturability; the third element is Knowledge Management, which should permeate all aspects of development and improve product creation, using the skills of all involved in the project. However, for this model to work, it must be supported by solid collaboration management, building partnership networks between suppliers, customers and other elements of the production chain. It is a model that can be adopted by several companies in the market, since it consistently presents aspects that involve product lifecycle management.

The main limitations of the model are that it only used mechanical engineering professionals, and so the model could not be validated in other scenarios; and that the research questionnaire was only developed in Portuguese, because it would be interesting to study these factors in other realities, in other countries. These limitations can be used to develop new research.

A suggestion for new research would be validating the model in other scenarios, like different types of industries and with professionals of other hierarchical levels such as managers and directors of companies, since the research was totally developed with technicians and engineers of the metalworking sector. Research in other countries could also be developed to analyze the suitability of the scale in other scenarios. New constructs and new variables could be added to the questionnaire in order to adapt it to the needs of researchers, students and entrepreneurs who are interested in developing research in this area.

References

Babbie, E. (1999). *Métodos de pesquisas de survey*. (Vol. 1). Belo Horizonte: UFMG.

Brigatini, J. A. D., & Miguel, P. A. C. (2009). A preliminary proposal to improve product development process at an engine manufacturing company. *Product: Management & Development*, 7(2), 161-169.

Brito, A. C., Ferreira, C. V., & Sampaio, R. R. (2009). Communication management in virtual projects. *Product: Management & Development*, 7(2), 171-176.

Chang, C. H. (2011). The Influence of user's trait on public e-service usage:a self-service technology perspective. *Asian Social Science*, 7(7), 3-11.

Cui, J., & Qi, G. (2006). Research on integration technology for product lifecycle management system. In *Proceedings of the VI International Conference on Intelligent Systems Design and Applications* (pp. 1109-113). Jinan: IEEE.

Fan, I., & Bermell-Garcia, P. (2008). International standard development for knowledge based engineering services for product lifecycle management. *Concurrent Engineering, Research and Applications*, 16(4), 271-277. http://dx.doi.org/10.1177/1063293X08100027.

Farouk, B., Troussier, N., Huet, F., Gidel, T., Bonjour, E., Eynard, B. (2008). PLM-based approach for collaborative design between OEM and suppliers: case study of aeronautic industry. *Computer-Aided Innovation*, 277(1), 157-168.

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *JMR, Journal of Marketing Research*, 18(1), 39-50. http://dx.doi.org/10.2307/3151312.

Gecevska, V., Chiabert, P., Anisic, Z., Lombardi, F., & Cus, F. (2010). Product lifecycle management through innovative and competitive business environment. *Journal of Industrial Engineering and Management*, 3(2), 323-336. http://dx.doi.org/10.3926/jiem.2010.v3n2.p323-336.

Gerwin, D. (2005). An agenda for research on the flexibility of manufacturing process. *International Journal of Operations & Production Management*, 25(12), 1171-1182. http://dx.doi.org/10.1108/01443570510633576.

Gonçalves-Dias, S. L. F., & Teodósio, A. S. S. (2006). Estrutura da cadeia reversa:"caminhos" e "descaminhos" da embalagem PET. *Produção*, 16(3), 429-441. http://dx.doi.org/10.1590/S0103-65132006000300006.

Hair, J. F., Anderson, R. E.; Tatham, R. L. & Black, W. C. (2005). *Análise Multivariada de dados*. (5. ed. Vol. 1). Porto Alegre: Bookman.

Hair, J., Hult, G., Ringle, C., & Sarstedt, M. (2014). *A Primer on Partial Least Squares Structural Equation Modeling (PLM-SEM)*. Los Angeles: SAGE Publications.

Hayduk, L. A. (1987). *Structural equation modeling with LISREL*. Baltimore: The Johns Hopkins University Press.

Henseler, J., Ringle, C. M., & Sinkovics, R. R. (2009). The use of partial least squares path modeling in international marketing. *Advances in International Marketing*, 20, 277-319.

Hou, J., Su, C., Zhu, L., & Wang, W. (2008) Integration of CAD/PDM/ERP system based on collaborative design. In *ISECS - International Colloquium on Computing Communication* (pp. 561-566). Guagnzhow: ISECS.

Jinsong, Z., Qifu, W., Li, W., & Yifang, Z. (2008). Configuration-oriented product modeling and knowledge management for made-to-order manufacturing enterprises. *International Journal of Advanced Manufacturing Technology*, 25(1-2), 41-52. http://dx.doi.org/10.1007/s00170-003-1871-z.

Kainuma, Y., & Tawara, N. (2006). A multiple attribute utility theory approach to lean and green supply chain management. *International Journal of Production Economics*, 101(1), 99-108. http://dx.doi.org/10.1016/j.ijpe.2005.05.010.

Kim, G. Y., Noh, S. D., Rim, Y. H., & Mun, J. H. (2008). XML-based concurrent and integrated ergonomic analysis in PLM. *International Journal of Advanced Manufacturing Technology*, 39(9-10), 1045-1106. http://dx.doi.org/10.1007/s00170-008-1400-1.

Lambert, S. C. (2010). E-infrastructure, science and Cris. *Data Science Journal*, 9, 1-6. http://dx.doi.org/10.2481/dsj.CRIS7.

Lee, S. G., Ma, Y.-S., Thimm, G. L. & Verstraeten, J. (2008). Product lifecycle in aviation repair and overhaul. *Computers in Industry*, 59(2-3), 296-303. http://dx.doi.org/10.1016/j.compind.2007.06.022.

Leite, P. R. Logistica Reversa: categorias e práticas empresariais em programas implementados no Brasil - um ensaio de categorização. In *XXIX EnANPAD - Encontro da ANPAD*. Brasília: ANPAD. 2005.

Livieiro, F., & Kaminski, P. C. (2009). Managing transnational product development project teams. *Product: Management & Development*, 7(1), 3-15.

Medina, H. V., & Naveiro, R. M. (2009). Eco-design practices in Europe fostering automotive vehicles recyclability in Brasil. *Product: Management & Development*, 7(1), 81-90.

Nantes, J. F. D., & Lucent, A. R. (2009). Evaluation of product development process from technological innovation: a study in the segment of agricultural machinery and equipment. *Product: Management & Development*, 7(2), 190-193.

Nisson, P., & Fagerström, B. (2006). Managing stakeholder requirements in a product modeling system. *Computers in Industry*, 57(2), 167-177. http://dx.doi.org/10.1016/j.compind.2005.06.003.

Nonaka, I., Toyama, R., & Konno, N. (2000). SECI, Ba and Leadership: a unified model of dynamic knowledge creation. *Long Range Planning*, 33(1), 5-34. http://dx.doi.org/10.1016/S0024-6301(99)00115-6.

Ou-Yang, C., & Chang, M. J. (2006). Developing an agent-based PDM/ERP collaboration system. *International Journal of Manufacturing Technology*, 30(3-4), 369-384. http://dx.doi.org/10.1007/s00170-005-0076-z.

Possamai, O., & Valentina, L. V. O. D. (2007). A model of evaluation of design for disassembly. *Product: Management & Development*, 5(2), 133-138.

Possamai, O., Valentina, L. V. O. D., & Futami, A. H. (2007). Concurrent engineering: a good practice of product development in machine bureacracy organization. *Product: Management & Development*, 5(1), 51-56.

Qiu, Z. M., Kok, K. F., Wong, Y. S., & Fuh, J. Y. H. (2007). Role-based 3D visualization for assynchronous PLM collaboration. *Computers in Industry*, 58(8-9), 747-755. http://dx.doi.org/10.1016/j.compind.2007.02.006.

Ringle, C., Wende, S., & Will, A. (2005). *SMARTPLS. Smarpls*. Recuperado em 21 de janeiro de 2012, de www.smartpls.de

Rouibah, K., & Caskey, K. R. (2003). Change Management in concurrent engineering from a parameter perspective. *Computers in Industry*, 50(1), 15-34. http://dx.doi.org/10.1016/S0166-3615(02)00138-0.

Rouibah, K., & Oud-Ali, S. (2007). Dynamic data sharing and security in a collaborative product definition management system. *Robotics and Computer-integrated Manufacturing*, 23(2), 217-233. http://dx.doi.org/10.1016/j.rcim.2006.02.011.

Rozenfeld, H. & Forcellini, F. A. (2006). *Gestão do desenvolvimento de produtos: uma referência para a melhoria do processo*. (1. ed.). São Paulo: Saraiva.

Santos, A. C. & Forcellini, F. A. (2009). Effects of product development decision-making process on the supply chain. *Product: Management & Development*

Scalice, R. K., Becker, D., & Silveira, R. C. (2009). Developing a new compatibility table for design for recycling. *Product: Management & Development*, 7(2), 141-148.

Sharma, A. (2005). *Collaborative product innovation: integrating elements of CPI via PLM framework* (Vol. 37, pp. 1425-1434). United States: Computer-Aided Design.

Siller, H. R., Estruch, A., Vila, C., Abellan, J. V., & Romero, F. (2008). Modeling workflow activities for collaborative process planning with product lifecycle management tools. *Journal of Intelligent Manufacturing*, 19(6), 689-700. http://dx.doi.org/10.1007/s10845-008-0120-6.

Su, S., & Liu, Y. (2008). Research on Management of Ship Concurrent Collaborative Design based on PDM. In *Proceding of the 2008 International Conference on Computer Science and Software Engineering* (pp. 19-22). Washington: [s.n.].

Sung, C. S., & Park, S. J. (2007). A component-based product data management system. *International Journal of Advanced Manufacturing Technology*, 33(5-6), 614-626. http://dx.doi.org/10.1007/s00170-006-0482-x.

Tang, D., & Qian, X. (2008). Product lifecycle management for automotive development focusing on supplier integration. *Computers in Industry*, 59(2-3), 288-295. http://dx.doi.org/10.1016/j.compind.2007.07.002.

Tang, D., Eversheim, W., & Shuh, G. (2004). A new generation of cooperative development paradigm in the toll and die making braching: strategy and technology. *Robotics and Computer-integrated Manufacturing*, 20(4), 301-311. http://dx.doi.org/10.1016/j.rcim.2003.11.001.

Tenenhaus, M., Vinzi, V. E., Chatelin, Y., & Lauro, C. (2005). PLS Path Modeling. *Computational Statistics & Data Analysis*, 48, 159-205. Recuperado em 15 de março de 2012, de https://studies2.hec.fr/jahia/webdav/site/hec/shared/sites/tenenhaus/acces_anonyme/home/art icles/PLS_PM_5.pdf

Thimm, G., Lee, S. G., & Ma, Y. S. (2006). Towards unified modeling of product life-cycles. *Computers in Industry*, 57(4), 331-341. http://dx.doi.org/10.1016/j.compind.2005.09.003.

Trotta, M. G. (2010). Product Lifecycle Management: Sustainability and Knowledge management as keys in a complex system of product development. *Journal of Industrial Engineering and Management*, 3(2), 309-322. http://dx.doi.org/10.3926/jiem.2010.v3n2.p309-322.

Venkatasubramanian, V. (2005). Prognostic and diagnostic monitoring of complex systems for product lifecycle management: Challenges and opportunities. *Computers & Chemical Engineering*, 29(6), 1253-1263. http://dx.doi.org/10.1016/j.compchemeng.2005.02.026.

Wetzels, M., Odekerken-Schröder, G. & van Oppen, C. (2009). Using PLS path modeling for assessing hierarchical construct models: guidelines and empirical illustration. *Management Information Systems Quarterly*, 33(1), 177-195. http://dx.doi.org/10.2307/20650284.

Yang, J., Goltz, M., & Han, S. (2004). Parameter-based engineering: research and applications. *Concurrent Engineering, Research and Applications*, 12(4), 275-286. http://dx.doi.org/10.1177/1063293X04041528.

Yang, X., Moore, P. R., Wong, C.-B., Pu, J.-S., & Kwong Chong, S. (2007). Product lifecycle acquisition and management for consumer products. *Industrial Management & Data Systems*, 107(7), 936-953. http://dx.doi.org/10.1108/02635570710816685.

Zancul, E. S. (2009). *Gestão do ciclo de vida de produtos: seleção de sistemas PLM com base em modelos de referência*. (Tese de doutorado). Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos.