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Abstract: The literature on the planning and development of new products is of great interest to both the academic and industry communities, especially within the automotive industry. However, the same cannot be stated as easily about studies related to the implementation of new products and their processes in manufacturing, which also requires careful planning and development. For this, the purpose of this article is to present a consistent and effective reference model for the implementation of new assembly processes in the automotive sector. The model consists of a description of steps, quality checks, actions, and validations required by the product manufactured in the serial production process. The methodology has its consistency and relevance assessed by means of a practical application in the development of an automotive component assembly process, located during the final assembly. For the validation of the model, indicators of the assembly process are compared in two stages: one with the process developed by the traditional method and the other considering a process developed with the proposed method. Results show that the traditional method offer a higher rate of defective products, when compared to the presented reference model for the implementation of new assembly processes in the automotive sector. A qualitative assessment is also

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PUBLIC INTEREST STATEMENT
There is currently a lack of academic work related to the planning and preparation for implementation of new products and their processes in manufacturing. This work proposes a reference model for the implementation of new assembly processes in the automotive sector, establishing the basic theoretical foundations of production process development, with a special emphasis on the automotive industry. The model consists of a description of steps, quality checks, actions, and validations required by the product manufactured in the serial production process. Consistency and relevance of the model are assessed by means of a practical application, using the proposed method of production process development in a real process in an industry of the automotive sector. In addition, a qualitative evaluation was carried out through a field research with experts of notorious knowledge in the area.
presented through a survey with recognized experts of the automotive environment, thus validating the proposed model.

**Subjects:** Engineering Education; Operations Research; Manufacturing & Processing; Engineering Project Management; Manufacturing Engineering; Automotive Technology & Engineering

**Keywords:** product development process; new products; assembly line; automotive industry; automotive engineering; automobile industry

1. **Introduction**

The competition among automotive companies increases every year around the world. Traditional automotive companies and their traditional markets in Europe and North America have become targets for the expansion of new global automotive companies such as Asian ones. One of the motivations for the expansion of these new automotive companies to the global market is based on sales volumes in the old automotive markets such as the European and North American ones. These markets are stable or even shrinking, in contrast to emerging markets that are expanding. It is important to mention an exception, the United States market. Due to the volume of sales and the type of vehicle it absorbs, this is also the target of new automotive companies in the global market.

The new products are decisive in the competitive business scenario, and a new product of success must increase the manufacturer's participation in the market, gain new customers, have their cost of production reduced, and their quality improved compared to the previous product (Clark & Fujimoto, 1991). Cohen, Eliashberg, and Ho (1997) corroborate Clark and Fujimoto (1991), stating that for most industrial and consumer products companies, new successful products are responsible for sales growth and profitability.

As a way to ensure sustainability in the market, companies seek to control the three critical variables that are: cost, quality, and delivery time (Passos & Cerqueira, 2013).

1.1. **Product development**

The process of developing new products can be seen from different perspectives, and the most common is seeing the process as a continuous sequence of development measures (Gerhard, Brem, & Voigt, 2008). Rozenfeld et al. (2006) cite in more detail that: product development consists of a set of activities that, from the market's needs and the technological possibilities and constraints, seeks to obtain the design specifications of a product and its production process, to enable the manufacture to produce it.

The amount of money spent on product development is known to increase as its phases go on (Dieter & Schmidt, 2009). The same correlation applies to the costs of repair, which also become higher. A correction in the product or the manufacturing process still during the manufacturing process will have much lower costs if compared with the additional costs of repairing a product that has already been distributed on the market.

The composition of the costs of a recall goes well beyond the costs of correcting a product nonconformity (Kumar & Schmitz, 2011; Slack, Chambers, & Johnston, 2010). In this case, other factors must be considered, such as the association of the brand with quality problems, customer's dissatisfaction by having purchased a defective product, customer's discomfort in taking the product to be repaired, possible risk to people's safety, possibility of market loss, legal punishments, and civil liability, among others.

There is a growing concern among automakers around the world regarding aspects of quality flaws, especially in serious failures, that may affect the safety of users or those who interact with their products.
Automotive companies, like other companies, are susceptible to variability in product quality. Even not desired, there are cases of failures that go beyond the manufacturer’s internal quality assurance barriers.

The adoption of socially responsible behavior is recognized as enabling to get competitive advantages. In addition, that strategies that take into account sustainability criteria are able to create value in the long term. These facts led to the emergence of sustainability indexes linked to financial markets, such as the Dow Jones Sustainability Index (DJSI) (López, García, & Rodríguez, 2007).

A product development failure may occur due to development errors, product specifications, validations, and tests, among others. A development failure in the production process can occur due to errors during the development of manufacturing processes, planning of process controls, defects in manufacturing means, improper storage, damage to the product during distribution, and use of defective raw material, among others.

1.2. Scientific and technical justification

There are many academic papers and publications available on the development process of new products and also in its various phases. However, it can be stated that there is a lack of academic work on the planning or preparation for production, or even more specifically in the implementation of new products and their processes in the manufacturing area.

The book automotive development processes by Weber (2009), which is one of the few that refers to the product development process (PDP) in companies of the automotive segment, presents only a brief explanation of the planning and production process development (DPPr).

Wynn and Clarkson (2018) most recently published an article that summarizes current thinking in providing an up-to-date overview of DDP models. It is noted however, that even this latest study, presents no details of the planning and production process development (DPPr).

Krishnan and Ulrich (2001) developed a research that involved more than 200 scientific papers from leading academic journals on marketing, operation management, and engineering design, selecting product development e product design and development. The results of this research presented only three articles that deal with: investments in infrastructure, tools, and training for the manufacturing of the product.

Aiming to reaffirm the importance of studying the production process development (DPPr), a research was carried out on the various causes of recall in the Brazilian territory for the subject of this work, which is the automotive segment.

For data collection, the Brazilian Ministry of Justice’s website was consulted (BRASIL, 2016). In order to consolidate this information, a cross-check of these data was carried out with those obtained in the Consumer’s Health and Safety Bulletin 2015 and in the Brazilian Open Data Portal, (MINISTÉRIO DA JUSTIÇA, 2015; PORTAL BRASILEIRO DE DADOS ABERTOS, 2016).

The text of each recall campaign of the Ministry of Justice between 2013 and 2014 was analyzed. More specifically, “technical reasons” was the field assessed. Based on the text, recalls were then classified: as related to the process, product, and others. Subsequently, process causes were also categorized in assembly process and in other processes, in addition to tabulation of the volumes of vehicles involved.

The survey covered all models and brands of domestic and imported vehicles sold in the Brazilian market. As a result in this period, 24 vehicle brands were found, being responsible for the 127 recalls that occurred in Brazil related to the automobile’s category.
It is important to mention that the 127 recalls that took place in the period comprise national and imported vehicles of the most varied categories, from high-cost and low-volume vehicles sold to popular vehicles with high sales volumes. For this reason, recalls can be found that have affected dozens of units and others that have impacted hundreds of thousands of units.

Of the 127 recalls, a total of 50 relates to causes directly linked to failures in the manufacturing process. Therefore, at least 39% of the total number of recalls that occurred in Brazil during the survey’s period came from defects originating from the manufacturing process. It is also noted that a part of the considered “indeterminate cause” may initially also have defects in the process as origin of the failure.

In the automotive segment, the design of the processes is of fundamental importance and should deliver, as output, the whole number of their products as reliable. Products with no manufacturing defects that could compromise the safety of the users and others interacting with them are understood to be reliable. However, according to Baraldi and Kaminski (2016) the recall processes involved a total of 2,028,141 vehicles in Brazil, only in 2013 and 2014. See Table 1 for recall causes.

According to the results of this research, at least 576,683 vehicles, or 28% of the total vehicles involved in recall, had in the description of the official recall the root cause of the defect described as originated from the manufacturing process (Table 2).

In addition, recall causes related to the manufacturing process were checked. At least 279,161 vehicles or 48% of vehicles involved in recall with causes linked to the manufacturing process had their causes derived from manufacturing defects in the assembly process. Table 3 shows the causes of recall related to the manufacturing process in 2013 and 2014.

A properly planned manufacturing process offers its customer products manufactured and controlled within determined parameters. That means that products can vary between tolerances that, under normal conditions, do not allow the manufacture of nonconforming products. Should this occurs, the manufacturing process must be able to identify the nonconforming product, so that it is segregated within the production process.

| Brands involved in vehicle recall in 2013 and 2014 | Total amount of vehicles involved in recalls in 2013 and 2014 | Total amount of involved vehicles with process causes | Total amount of involved vehicles with product causes | Total amount of involved vehicles with undetermined cause |
|-------------------------------------------------|-------------------------------------------------------------|-----------------------------------------------------|----------------------------------------------------|--------------------------------------------------------|
| 24                                              | 2,028,141                                                  | 576,683                                            | 147,528                                            | 1,303,930                                               |
| *                                               | *                                                          | 28%                                                | 7%                                                 | 64%                                                    |

| Total amount of involved vehicles with process causes | Total amount of involved vehicles with assembly process cause | Total amount of involved vehicles with undetermined process cause |
|------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| 576,683                                              | 279,161                                                       | 297,522                                                       |
| 28%                                                  | 48%                                                           | 52%                                                           |

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Process capability is the capability of a given process to meet product specifications, offering products within specified tolerance limits, establishing new specifications, or modifying existing specifications (Hill, 2012).

1.3. Search limits
To define the limits of this research, vehicle assembly was chosen as the study area, since this activity is considered as the core business of automotive vehicle manufacturers, also known as automakers.

A partial application of the proposed model was chosen to test the consistency and relevance of the methodology, in the development of a process of assembly of components in the final assembly. This was performed together with a qualitative validation of the reference model, through a survey with recognized experts in the automotive industry.

| Table 3. Causes of recall related to the manufacturing process in the period from 2013 to 2014 |
|------------------------------------------------------------------------------------------|
| Fueled with (...) instead of (...)                                                       |
| Present torque below specification                                                      |
| Contamination by fluid used in assembly                                                 |
| Deriving from assembly process                                                          |
| Quality deviation in manufacturing process                                              |
| Quality deviation in production process                                                 |
| Due to composition (...), there might be no protection against (...)                     |
| During assembly process (...) might have been deformed                                   |
| As consequence of low torque (tighten)                                                  |
| Excessive torque                                                                        |
| Intermittent flaw during process                                                        |
| Flaw in application                                                                     |
| Positioning flaw                                                                        |
| Flaw in manufacturing process                                                           |
| Flaw in assembly process                                                                |
| Flaw in welding process                                                                 |
| Misadjusted or lack of a bolt                                                           |
| Poor fastening                                                                          |
| Assembled with lack of                                                                  |
| Assembly of incorrect component                                                         |
| Incorrect assembly                                                                      |
| Noncompliance in assembly                                                               |
| Noncompliance in welding                                                                |
| Noncompliance in assembly process                                                       |
| Not properly adjusted                                                                   |
| With no adequate torque                                                                 |
| Not performed properly                                                                  |
| Not positioned correctly                                                                |
| May not be properly tightened                                                           |
| Deriving from application process                                                       |
| Torque lower than standard value                                                        |
| A programming flaw                                                                      |
| Use of bolts with length outside design specification                                   |
| Variations in production process                                                        |

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1.4. Research methodology and work organization

According to Blessing and Chakrabarti (2009), a comprehensive study of an existing situation for the development of a model was selected for this research. This type of research is indicated for the development of a support, where the level of understanding of the existing situation is poor. This type of research includes a review of the literature, as well as an empirical study, where a support is developed and/or evaluated, in which the results are produced by the researcher.

The present text has the following structure: Chapter 2 provides a theoretical background concerning the topic of Product Development Process (PDP), while Chapter 3 provides a review on Production Process Development (DPPPr). Chapter 4 describes how the method was developed, which models were chosen as foundations as well as how the field research and questionnaire assessment were conducted. Chapter 5 presents in detail the actual reference model for the implementation of new assembly processes in the automotive sector. Chapter 6 details the consistency and relevance tests applied to the reference model, including an analysis of the results found in the application of the model in a real production process. Finally, Chapter 7 presents the authors’ conclusions and final considerations, and also gives directions to future research topics.

Figure 1 presents the work organization of this work.

2. Theoretical background of the product development process

The PDP can be defined as a set of interrelated activities, with measurable and sequential results (also called milestones), which involve almost every department of the company, with the goal of transforming market needs into economically feasible products and/or services (Kaminski, 2000).

PDP is an activity characterized by a design, build, and test cycle, which makes intensive use of the existing knowledge in the company. It can be said that a part of this knowledge is stored in the documents generated during this process, which is the explicit knowledge (Amaral, 2001).

Product design is a vital part of the product development process, and involves much more than the project since the product must provide profit to shareholders. For-profit companies are known to have as their main objective the generation of profit for their shareholders. A nonprofitable for-profit company suffers from lack of investment (Dieter & Schmidt, 2009).

Clark and Fujimoto (1991) and later Rozenfeld et al. (2006) and Dieter and Schmidt (2009), cited that the choices of alternatives occurring at the beginning of product development are responsible for values that vary between 70 and 85% of the cost of the final product.
2.1. The PDP reference models

The model of phases of a complete project developed by Asimow (1962) considers the whole cycle of production and consumption. According to the type of product, it will have differentiated priorities. The author defines the seven phases for the development of a project, mentioning that each one has specific characteristics and purposes.

Stage-Gate Systems developed by Cooper (1990) recognizes that product innovation is a process that, like other processes, can be managed. Stage-gate systems simply apply process-management methodologies.

PDP model developed by Dieter and Schmidt (2009) is based on stage-gates. The authors’ PDP model is structured by six phases that occur in an orderly fashion. This model’s phases are defined as: planning, concept and development, system level design, project details, testing and refinement, and start of production.

According to APQP—advanced product quality planning, a product must meet the expectations of its users as well as the planning of deadlines and costs, among many other factors. During PDP quality teams involved in product development should, when required, modify quality plans to meet customer’s expectations (AIAG [Automotive Industry Action Group], 1995).

The generic product development process developed by Ulrich and Eppinger (2004) presents a generic model with six phases, including some of the typical tasks and responsibilities of the key business functions phase.

In Rozenfeld et al. (2006) reference model, PDP is represented by three macrophases that are defined as predevelopment, development and postdevelopment. Subsequently, macrophases are subdivided into the phases of product strategic planning, project planning, informational design, conceptual design, detailed design, preparation for production, product launch, product/process follow-up, and product discontinuity. Each of these phases is formed by several activities.

According to Schuh, Rozenfeld, Assmus, and Zancul (2008), the lifecycle of a product comprises all phases of product passing, and is composed of the macrophases: development, production, use and services, and disposal. Product Lifecycle Management is an approach that supports the management of business processes and information related to the product lifecycle.

Silva and Kaminski (2017) developed a reference model specific for the automotive product development process, known as PDP—Automotive. This model is made up of three macrophases: product strategy, product and process development, and continuous production and improvement.

When carrying out a review of the literature with the main researchers and works related to the PDP, its theoretical background is determined. This enables to analyze its evolution in relation to the time, and to perform a critical comparison of the proposed definitions of each of the authors.

It should be noted that among the models and publications studied, there are generic PDP models and models aimed at the subject of this work, which is the automotive industry. The presented models contributed significantly to the development of the PDP in the industrial and automotive area, besides presenting the evolution of the PDP in relation to the time.

Table 4 presents the theoretical background on product development process PDP.

3. Theoretical background of the production process development—DPPr

Production process development (DPPr) is, like product development process, an activity characterized by a design, build and test cycle. DPPr makes intensive use of existing knowledge in the company, and has a part of this explicit knowledge stored in the documents and
procedures generated during this process. However, the management of this type of knowl-
edge demonstrates several problems, such as lack of an appropriate conceptual model, 
limitations regarding the types of knowledge stored, among others.

Planning is an important part of any project, as the definitions and decisions made at this stage 
impact the whole continuity of the project. The same occurs for DPPr planning, since the better 
detailed and more deeply planned, the less likely it is to present future problems with the process 
of production process development.

ABNT ISO/TS 16949 standard states that during the inputs to the production process development, 
the entry requirements for the production process development must be critically identified, 
documented, and analyzed. Output data from product design, productivity goals, process and cost 
capacity, customer requirements (if any), and use of experience from previous developments 
should also be included (ABNT [Associação Brasileira de Normas Técnicas], 2010).

The determination of a possible assembly sequence of the various parts of the vehicle is a typical 
problem of the assembly process. This is important to obtain a distribution of activities between 
the operators, in which they have the greatest possible occupation in the time interval of cycle 
work on each vehicle. Time of cycle of work is understood as the time spent between the beginning 
to the end of the work in a unit (Hill, 2012).

A properly planned assembly manufacturing process can increase process efficiency, product 
quality, decrease the time required for activities, and consequently the cost of manufacturing the 
product at this production stage.

| Table 4. Theoretical background on product development process PDP |
|---------------------------------------------------------------|
| **Ref.** | **First edition (year)** | **Title** | **PDP approaches** |
| Asimow (1962) | 1962 | Introduction to design | The phases of a complete project |
| Cooper (1990) | 1990 | Stage-Gate Systems: a new tool for managing new products | Stage-Gate Systems |
| Dieter and Schmidt (2009) | 1993 | Engineering design | The product development process |
| AIAG (1995) | 1995 | Advanced Product Quality Planning & Control Plan (APQP) | Schedule of product quality planning |
| Ulrich and Eppinger (2004) | 1995 | Product design and development | The generic product development process |
| Rozenfeld et al. (2006) | 2006 | Gestão de desenvolvimento de produtos: uma referência para melhoria do processo | The product development process model |
| Schuh et al. (2008) | 2008 | Process oriented framework to support PLM implementation | Product Lifecycle Management (PLM) |
| Silva and Kaminski (2017) | 2017 | Proposal of framework to managing the automotive product development process | Framework to managing the automotive product development process |
| Wynn and Clarkson (2018) | 2018 | Process models in design and development | Topology of the literature on design and development process models |

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Virtual prototyping techniques during the product development process enable to detect design and manufacturing problems early in the product development cycle, supports concurrent engineering approaches to engineering activities, and reduces the lead time involved in manufacturing (Cecil & Kanchanapiboon, 2007).

Computational technologies presented (CAD/CAE) are also used to design and validate the manufacturing. The computational technique named digital factory (DF) is commonly used to design and validate the manufacturing (Silva & Kaminski, 2016).

Nevertheless, several efforts have been made to find a way to automate the key process of sequencing assembly activities, through the use of software. However, these efforts have not been successful. They are a large part of the assembly process plans, still based on traditional methods, that is, on the experience of the engineers, technicians and assemblers responsible for the activity (Hongmin, Dianliang, & Xiumin, 2010; Wang, Keshavarzmanesh, Feng, & Buchal, 2009).

The production process development in an automotive assembly line occurs using several process planners, working together in a cooperative way. During planning, assembly methods, location of operations and means, assembly sequences, tools, equipment, number of workers needed, and time required to perform each operation must be defined, among others (Noh et al., 2005).

A tool applied in automakers to assist in process development and validation is the preparation of production processes (3P). By using physical simulations in this tool, a team formed by customers and internal suppliers evaluate, test, and propose improvements to the already planned process. Thus, the team decides which is the best way to implement this process in manufacturing (Baraldi & Kaminski, 2008).

Due to the large number of parts, workstations, tools, equipment, assemblers and assembly sequences required, the activity of sequencing and distributing tasks on an automobile assembly line becomes very complex (Papakostas, Pintzos, Giannoulis, & Chryssolouris, 2015).

Even with the current use of software to assist in this task, it still depends on physical simulations of assembly and disassembly and the experience of the engineers, technicians, and assemblers responsible for the activity. Li, Liu, Wang, and Zeng (2014) corroborates the idea, and points out that even with advances in virtual simulations to sequence and distribute tasks in complex activities, the use of experience of the engineers, technicians, and assemblers responsible for the activity is still required. For Hirz, Dietrich, Gferrer, and Lang (2013) a combination of virtual methods and simulation methods, coupled with physical development and test procedures, represent the current state of the art in development.

Another important factor to be developed during DPPr is the ergonomic conditions of the workstations. In current companies, there is a growing concern with ergonomics, including the hiring of ergonomist physicians, to support the development of new workstation and correction of existing ones. The application of ergonomics in industry is not necessarily a complex activity and can be developed in a simple way, for example, with the use of a list of basic recommendations for jobs (Baraldi & Kaminski, 2011; Moreau, 2003).

As a way of minimizing risks to the employee due to ergonomically unfavorable working conditions, companies in the automotive segment have included methods for estimating the ergonomic risk of jobs in their routine of verification of the production environment. During these evaluations, when unfavorable conditions are found in a job, actions are taken to eliminate or reduce these conditions. As an example, Toyota’s Toyota Verification of Assembly Line, General Motors’ GM-UAW and Volkswagen’s AP-Ergo can be cited (Otto & Scholl, 2011).
It is a fact that jobs with acceptable ergonomic conditions present great advantages for the employee as well as for the employer, such as prevention of occupational diseases, reduction of absenteeism, improvement of productivity, better product quality, and workers’ quality of life. Another advantage of developing ergonomically acceptable jobs for companies is the use of labor with physical limitations, thus avoiding the idleness of physically limited employees (Baraldi & Kaminski, 2011).

The operator’s difficulty in executing a task increases the chance of error. It is stated, therefore, when developing new processes, this should be planned in order to facilitate the activity of the collaborator in both the physical and mental aspects. It is recognized that assembly lines with ergonomics problems at the jobs present a potential risk of having quality problems 3.0–3.7 times higher in high and medium physical loads, when compared to low one (Falck, Örtengren, & Högborg, 2010; Womack, Armstrong, & Liker, 2009).

The use of virtual simulations to verify the access of assemblers and tools during DPPr is very common in automotive companies. This simulation procedure presents many benefits, since they help planners in their evaluations during the production process development (Pappas, Karabatsou, Mavrikios, & Chryssolouris, 2006; Silva & Kaminski, 2015; Wu, Zhu, Zhen, & Fan, 2011).

4. Development of the proposed model
In order to define the phases and validations of the process to be studied, the three models referenced in this work were used, as well as ABNT ISO/TS 16949 and VDI 5200 standards. This choice of models and standards is justified as they are directed to the subject of this work, which is the industry, or more specifically the automobile industry. In the presentation of these works, it was decided to use a chronological order referring to the date of publication of the first editions. The aforementioned papers describe the various activities of the production process development and its milestones, serving as a theoretical basis to assist in the development of what should be analyzed during field research.

The three models plus ABNT ISO/TS 16949 and VDI 5200 standards describe with different approaches and objectives the various activities that must occur during the production process development as follows:

- **AIAG (1995)** describes the activities of the production process development considering product quality;
- **ABNT (2010)** describes the activities of the production process development for relevant automotive production and spare parts organizations;
- **Rozenfeld et al. (2006)** describes the activities of the production process development for a generic product;
- **VDI (Verein Deutscher Ingenieure) (2011)** describes the procedures for plant planning and its various activities, from the start of planning to the beginning of production; and
- **Silva and Kaminski (2017)** describes the activities of the production process development for the automotive product development process.

Due to the different objectives of each of the authors in the referenced works, different details of the activities described by them are observed. Table 5 shows how the different activities and milestones of each of the three models are compared as well as ABNT ISO/TS 16949 and VDI 5200 standards.

VDI 5200 standard describes the planning procedures and their activities from the start of planning to the beginning of production. For this reason, this standard was chosen as the theoretical basis for ordering the activities of the development stages of the production process, with only a few exceptions:
Phase one (setting of objectives) and phase two (establishment of the product basis), which will be classified as a single phase (because the two phases are contained in the macro planning of the production process development); and

- Phase seven (ramp-up support), which will not be studied (because this is a phase that occurs after the start of the serial production).

The way to present the relationship of production process development phases (defined according to VDI 5200), with the phases of the other four works, was the use of different colors. Thus, a color was defined for each of the phases of VDI 5200 standard. This was later used in the classification of the activities of the other four works, according to the corresponding phase in VDI 5200 standard.

Thus, the five stages of the production process development are determined as:

- Macro planning of the production process development (PMP);
- Development of the concept of the production process (DCP);
- Production process development (DPP);
- Test of the production process (TPP); and

![Table 5. Phases of the production process development](https://doi.org/10.1080/23311916.2018.1482984)
Table 6: Comparison of the phases of the production process development

| Model | Milestone | Milestone | Milestone | Milestone | Milestone |
|-------|-----------|-----------|-----------|-----------|-----------|
| VDI 5200 | Plan approval | Plan approval | Plan approval | Plan approval | Plan approval |
| ISO/TS 16949 | Process planning | Process planning | Process planning | Process planning | Process planning |
| APQP | Planning | Planning | Planning | Planning | Planning |
| | Conceptual planning | Conceptual planning | Conceptual planning | Conceptual planning | Conceptual planning |
| | Detailed planning | Detailed planning | Detailed planning | Detailed planning | Detailed planning |
| | Infrastructure planning | Infrastructure planning | Infrastructure planning | Infrastructure planning | Infrastructure planning |
| | Project planning | Project planning | Project planning | Project planning | Project planning |
| | Milestone planning | Milestone planning | Milestone planning | Milestone planning | Milestone planning |

- Validation of the production process (VPP).

Table 6 shows the way used to identify each activity and milestone, with the five phases defined according to VDI 5200 standard.

When comparing each of the models and standards chosen for this activity, the unification of the activities and milestones that correspond is promoted. Thus, the milestone activities of the development of the productive process are defined.

Subsequently, to standardize the writing, activities were described in the form of action (substantive and verb), and the milestones in the form of decision-making (with the use of nouns).

The details of the phases of production process development are presented in Table 7.

4.1. Field research
In order to develop the field research in this work, the largest automaker in the world in 2016 was selected. The OEM plant is of European origin, with several plants established in Brazil.
| Table 7. Detail of the phases of the production process development |
|---------------------------------------------------------------|
| **A - Macro planning of the production process development - PMP** |
| **B - Development of the concept of the production process - DCP** |
| **C - Production process development - DPP** |
| **D - Test of the production process - TPP** |
| **E - Validation of the production process - VPP** |

| Milestones | I | II | III | IV | V | VI |
|------------|---|----|-----|----|---|----|
| **Activities** | Update economic-financial feasibility study | Define process concept | Define project objectives | Define process macro plan | Establish the foundations of the project | Get product specifications and drawings |
| | Define project objectives | Analyze the product/process quality system | Update detailed project plan | Create infrastructures needs | Create and detail lists of parts, systems, sub-systems, and components (SSC) | Define process macro plan |
| | Define project objectives | Define instructions for the manufacturing process | Create control plan | Create systems, sub-systems, and components (SSC), configuration, and product and process documentation | Define technology and process automation | Define product concept |
| | Define project objectives | Approve vehicle manufacturing with production means | Approve vehicle manufacturing with production means | Evaluate measurement systems | Perform preliminary process capability study | Apprrove vehicle manufacturing with production means |
| | Define project objectives | Approve phase and release production | Approve phase and release production | Start serial production | Start serial production | Approve phase and release production |

**Caption**
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For this, a questionnaire was developed describing to the automaker’s participants, the purpose of the research, the confidentiality of the information provided as well as the contact information in the event of respondents’ doubts.

4.2. Development of the questionnaire
The instrument used to collect data from the studied company's professionals was the questionnaire. For its development, there were different proposals, approaches, reflections on the content, and on the desired results with the research, which were widely discussed and worked out.

The formulations of the questions were based on the theoretical review of this work, and the activities described in the questionnaire developed were obtained from the activities previously presented. In order to avoid inducing the respondents’ responses, DPPr activities described in the survey questionnaire were presented in alphabetical order.

4.3. Selection of research participants
The professionals selected to participate in the field research were chosen for their expertise in their area of activity in the industry studied, thus ensuring a broad and deep view of the business as well as the knowledge and experience necessary for a critical and competent analysis of the questions. Figure 2 presents the OEM organization chart.

Data collection was performed in the first quarter of 2016. A total of 23 questionnaires were distributed, divided among the four departments selected for research:

- Product planning and management (PGP) with 3 questionnaires delivered (2 answered);
- Product development (DP) with 7 questionnaires delivered (3 answered and 1 declined);
- Operations (O) with 9 questionnaires delivered (7 answered); and
- Quality (Q) with 4 questionnaires delivered (2 answered).

From the total of 23 questionnaires delivered, 14 were answered, 1 declined, and 8 nonanswered, obtaining a percentage of 60.87% of questionnaires answered. The characterization of the respondents according to their professional occupation is presented in Table 8.
Table 8. Characterization of respondents according to professional occupation

| Type of position of respondents | Quantity | Level |
|--------------------------------|----------|-------|
| Managers                       | 3        | EX    |
| Supervisors                    | 7        | EX    |
| Board of Directors Advisor     | 1        | T     |
| Engineers                      | 3        | T     |

EX—executive T—technical

Table 9. Characterization of respondents according to their position, education, highest level of education, and professional experience

| Respondent | Position               | Education (undergraduate) | Highest level of education                           | Years of experience in the field |
|------------|------------------------|---------------------------|------------------------------------------------------|---------------------------------|
| 1          | Supervisor             | Not informed              | Master's degree, lato-sensu (MBA)                   | 17                              |
| 2          | Supervisor             | Bachelor of Mathematics   | Master's degree, lato-sensu (MBA)                   | 33                              |
| 3          | Manager                | Bachelor of Physics       | Master's degree, stricto-sensu                      | 28                              |
| 4          | Manager                | Mechanical Engineering    | Master's degree, lato-sensu (MBA)                   | 16                              |
| 5          | Supervisor             | Production Engineering    | Master's degree, lato-sensu (MBA)                   | 15                              |
| 6          | Board of Directors     | Mechanical Engineering    | Master's degree, lato-sensu (MBA)                   | 12                              |
| 7          | Supervisor             | Industrial Engineering    | Master's degree, lato-sensu (MBA)                   | 30                              |
| 8          | Engineer               | Electrical Engineering    | Master's degree, stricto-sensu                      | 16                              |
| 9          | Supervisor             | Not informed              | Master's degree, lato-sensu (MBA)                   | 12                              |
| 10         | Manager                | Mechanical Engineering    | Undergraduate                                      | 35                              |
| 11         | Supervisor             | Technologist in Mechanics | Technologist                                        | 19                              |
| 12         | Supervisor             | Bachelor of Mathematics   | Undergraduate                                      | 40                              |
| 13         | Engineer               | Electronic Engineering    | Master's degree, lato-sensu (MBA)                   | 20                              |
| 14         | Engineer               | Mechanical Engineering    | Not informed                                        | 22                              |

Table 9 shows the characterization of the respondents according to their position, education, highest level of education, and professional experience.

Regarding the answers obtained in the questionnaire, a high homogeneity was identified, ratifying the conceptual validity of the proposal. Among the data obtained, the following stand out: ordering of activities, validation of proposed milestones, survey of average duration of activities, temporal placement of activities, and achievement of responsibilities of each one of the activities.
Therefore, the validity of this field research is concluded as a source of practical and valid knowledge. This will serve as a contributing basis to the reference model for implementation of new assembly processes in the automotive sector.

5. Reference model for the implementation of new assembly processes in the automotive sector

For the development of the reference model for the implementation of new assembly processes in the automotive sector, the theoretical knowledge acquired in this work was considered. The practical knowledge was obtained by consulting the internal documents and experienced professionals of the automotive sector.

5.1. Propositions of the reference model for the implementation of new assembly processes in the automotive sector

The model consists of five phases: macro—planning of the production process development—PMP, development of the concept of the production process—DCP, production process development—DPP, test of the production process—TPP, and validation of the production process—VPP.

The milestones are elements of decision-making, which in this model are in their entirety managerial milestones. The milestones are represented in the upper line of the figure, being numbered in Roman numerals: approval for program funding, approval of concept/start of planning, approval of planning/release of purchase contracts, approval of the infrastructure, equipment and means of production/release of the start of the preseries, approval of production process facilities/production release, and approval of the start of the serial production of the automobile.

Below the line of representation of the milestones are the activities defined in each of the phases (also identified by the corresponding color of the phase).

At the bottom of the model, after the activities, there is a time scale in weeks indicating the duration of the reference model’s phases and activities for implementation of new assembly processes in the automotive sector.

At the bottom of the model, after the time scale, there is a caption with the description of Roman numerals and acronyms used. To the right side of the activities, the departments responsible for each activity are described, and the caption is also identified by the corresponding colors of the phases.

Figure 3 presents a representation of the proposed model.

The macro planning phase of the production process development—PMP is characterized by the beginning of the investigations for the production process development, being constituted by the following activities: define the objectives of the project—DODP, establish the foundations of the project—EBDP, define process concept—DCDP, define process macro plan—DPMP, get specifications and drawings of the product—OEDP, check requirements of new equipment, tools and facilities—VRNE, and update economic and financial feasibility study—AEVE.

The outputs of the macro planning phase of the production process development are: the certification of the feasibility of the project in the process, decision about production site, definition of production concept, decision about manufacturing technologies to be used, confirmation of vehicle production requirements, definition of EHPV goal—engineered hours per vehicle, definition of the manufacturing time goal to be spent per unit VBZ—Verbrauchtzeit, and validation of financial viability.

The development phase of the concept of the production process—DCP is characterized by the start of planning and development of the concept of the production process. It consists of the following activities: plan the development of the concept of the production process—PDCP, define
the concept of the production system—DCSP, define flowchart/physical arrangement of the manufacturing process—DFAF, assess infrastructure needs—and ANDI, update detailed design plan—APPD, run failure mode and effects analyses of manufacturing process (FMEA)—EAME, analyze the product/process quality system—ASQP, define packaging standards and specifications—EPEP, create and detail lists of parts, subsystems and components (SSC)—CDLP, provide process flow chart—FFDP, decide to make or buy systems, subsystems and components (SSC)—DFCS, provide facility layout—FLDI, and perform production planning and preparation—EPPP.

The outputs of the development of the concept of the production process—DCP are: concept of the production process, concept of the production system, flowchart with the physical arrangement of the manufacturing process, certification of the viability of construction of the production equipment according to product design release.

The development phase of the production process—DPP is characterized by the start of the planning and development of the concept of the production process, being constituted by the following activities: plan the production process development—PDPP, plan manufacturing and assembly process—PPFM, define technology and process automation—DTAP, define the logistic concept—DOCL, design manufacturing resources—PRDF, develop suppliers—DEFO, develop detailed production process—DPPD, define process approval acceptance criteria—DCAA,
design packing—PREM, dimension and allocate resources—DEAR, create systems, subsystems, and components (SSC), configuration and documentation of product and process—CSSC, plan pilot production—PPPI, create instructions for the manufacturing process—CIPF, get manufacturing resources—OBDF, create control plan—CPCO, perform preliminary process capability study plan—EPEP, receive and install resources—REIR, and execute analysis plan of measurement systems—EPAS.

The outputs of the production process development—DPP are: the reviewed production process, availability of production documentation, acquisition and allocation of material resources and manpower for manufacturing, production of vehicles for homologation of the manufacturing process (outside the production environment), and start of operators’ training (with the physical product) who will be the multipliers for the production personnel.

The phase of test of the production process—TPP is characterized by the start of tests in the production process, with the construction of the first vehicles in the production area, being constituted by the following activities: plan performing the test of production—PRTP, perform prior training of production staff—ETTP, test facilities, equipment and means—TIEM, perform preliminary process capability study—EEPC, evaluate packaging—AVEM, evaluate measurement systems—AOSM, start preproduction series—IPSP, optimize production process—OPDP, approve vehicle manufacturing with production means—AFVM, certify product in final production process—CPPF, and homologate process—HOPR.

The outputs of test of the production process—TPP are: evaluation of production process, evaluation of equipment and means, homologation of manufacturing process in the production environment and start of operators’ training (with the physical product), and manufacturing preseries vehicles for validation of product and validation of production process.

The phase of validation of the production process—VPP is characterized by approval of release of production, being constituted by the following activities: approve phase and release production—AFLP, start serial production—IAPS, and monitor serial production—MPSE.

The outputs of validation of the production process—VPP, are vehicles that can be commercialized, thus closing the production process development.

6. Test of consistency and relevance of methodology
The test of the consistency and relevance of the reference model for implementation of new assembly processes in the automotive sector was carried out in two stages, the first stage was the practical evaluation of the proposed model and the second stage was the qualitative evaluation of the proposed model with experts in the automotive industry.

During the first stage, a practical evaluation of the proposed model is carried out, applying part of the reference model for implementation of new assembly processes in the automotive sector, in the development of a process of components assembly in the final assembly. Thus, an existing process is compared in two time points: first, with the process developed using the traditional method of the company studied, and in a second time point, with the development and implementation of this new process, using the reference model for the implementation of new assembly processes in the automotive sector.

Subsequently, during the second stage, the qualitative evaluation of the reference model for the implementation of new assembly processes in the automotive sector is performed with experts in the automotive industry. For this, a validation was developed through structured interviews with recognized experts of the automotive field, evaluating the model as a whole.
6.1. Practical evaluation of the proposed model

A theoretical background was searched in the literature on manufacturing processes for final assembly. This was performed to select the processes to be compared during the test of the consistency and relevance of the reference model for the implementation of new assembly processes in the automotive sector. DIN 8593 standard addresses assembly manufacturing processes, presenting their classifications, subdivisions, terms, and definitions (DIN, 2003).

According to Hall (2004), the stability of process depends on manpower, equipment, material, and method used, known as 4Ms (man, machine, material, and method). Thus, it can be stated that to correctly compare the process benefits to the product, isolating the other three variables of the process (man, machine, and material) is required. These have to be as similar as possible in the two processes to be compared.

In order to isolate the process variables, the comparison used vehicles produced with:

- Processes geographically situated in the same plant;
- Similar products in both processes;
- Technologically similar equipments; and
- Labor with similar level of training.

For the comparison of the results, data of similar products (vehicles of the same platform), manufactured in two assembly lines were used. It is important to mention that the two assembly lines have technologically similar processes and equipment, and trained and qualified employees who alternate their jobs in both lines, according to the need for labor.

DIN 8593 classifies nine types of assembly manufacturing processes for manufacturing processes in generic products. Weyand (2010) cites and exemplifies in his work four processes as typical in final assembly in the automotive industry.

Following the study of the four typical processes in the final assembly of the automotive segment, the process of joining together was selected among these. This process is to be used during the test of consistency and relevance of the reference model for the implementation of new assembly processes in the automotive sector.

The choice for the process of joining together is justified as this is the most critical, and consequently, presents the highest rate of defects, among the four typical processes in the final assembly in the automotive industry studied. By using a more critical process, a faster response of the indicators is obtained, which is therefore more relevant during validation.

For the definition of the production operations to be studied, joint operations were sought. These would have their manufacturing processes changed, due to the introduction of new parts and assemblies in the final assembly of the vehicles. In addition, care was taken to look for operations in which the vehicle body was not altered due to modifications of the product. Therefore, influences caused by dimensional instability due to new processes and new parts in the vehicle body were prevented.

In addition, there was a concern with the precision of the results during the test related to operators’ learning curve, caused by alteration of the parts due to the face lift of the model. In order to minimize this variable, processes with not major conceptual changes of assembly were used. Another fact was the high volume of daily production, which makes the learning curve much faster.
Main modifications of the vehicle were observed during the choice of sets for the study in the final assembly process. Processes composed mainly of injected parts were selected. These processes already had the final, dimensioned and approved, tooling, thus preventing that dimensional instabilities in the injected parts influenced the study.

The new instrument panel assembly and the new “A” pillar lining assembly were selected as the processes to be studied, meeting the abovementioned criteria.

During the execution of the process planning with the development in the traditional way, the following was noted for the chosen processes: execution or not of each activity, duration of each activity and its temporal location in the planning of production process.

The series production of the vehicles studied began in week 1 in 2016, initially for the automobile and then in week 4 in 2016, for light commercial vehicles (light commercial vehicles, per decision of the company’s board, also started production in week 1, with early manufacturing of vehicles of series production).

After the traditional process was executed and implemented in the production area, work began on the development and implementation of the new production process, using the proposed method of production process development.

The proposed model of production process development was applied only after implementation and test of the traditional planning of the production process. This was chosen to enable a comparison of the two indicators in the production process, at different time points.

During the application of the proposed model of production process development, activities that had not been carried out before were performed. Activities that had been partially carried out were performed again. Those that had not been carried out with the correct use of the model of reference for implementation of new assembly processes in the automotive sector were also performed.

It is important to mention that although the assembly lines are designed for a certain installed production capacity and these lines can be operated in several shifts, the aforementioned assembly lines have the flexibility to be operated with lower production volumes and in reduced amounts of shifts.

The company studied utilizes the production flexibility in the assembly lines, considering several aspects such as: variations of market demand, variation of available labor, additional night costs, unavailability of parts, quality actions in the assembly line, among others.

Figure 4 shows the planned production acceleration curve of vehicle facelift, the planned deceleration curve of the previous models for the two production lines, and the proposed method of production process implementation sequence.

The production test with the application of the proposed method of production process development began in March/April 2016. Follow-up of the indicators was extended until June 2016; during this period, 68,441 vehicles were produced.

The indicators used to compare the results of each process were obtained from the company’s official database. The defect indicator has its origin in an electronic database, consisting of defects observed during the production process, and during quality inspection. Table 10 presents the defect indicators of the products of the company studied.

The defect indicators are observed and recorded, taking into account the left and right sides of the vehicle. Therefore, more than one defect can be recorded per vehicle.
Figures 5 and 6 show defect indicators per vehicle of the products of the company studied.

An increase can be observed in the indicators of the processes studied: in the number of defects per vehicle from January 2016 (preexisting flaws in the vehicle of the previous model). This occurred due to introduction of vehicle facelift in the production line and the increasing volume of vehicles. Initially due to the production of the first vehicles, and subsequently due to the production acceleration curve, reaching the daily planned volume in April 2016.

After the implementation of the proposed method of production process development, a reduction in the supply of defects per vehicle was noted for the two processes studied. This occurred even considering the increment of production with additional vehicles after week 20.

Therefore, it can be stated that the process developed using the traditional method (where certain activities are not carried out, activities are carried out partially, activities are performed without using the correct methodology, or activities are carried out late, in relation to the time points defined in the reference model for the implementation of new assembly processes in the automotive sector), end up offering a higher rate of defective products, when compared to the
reference model for the implementation of new assembly processes in the automotive sector. This fact corroborates the validation and applicability of the proposed model.

### 6.2. Qualitative evaluation of the proposed model with automotive experts

For the qualitative evaluation of the reference model for the implementation of new assembly processes in the automotive sector, structured interviews were carried out with recognized experts from the automotive industry.

A questionnaire was used as the instrument to collect data from the recognized experts of the automotive field.

The interviews were developed to occur on-site. By presenting the reference model for the implementation of new assembly processes in the automotive sector, opinions, suggestions, and comments could be obtained regarding the adherence to the theme. Additionally, strengths and weaknesses were also obtained, thus capturing the authentic opinion of the interviewee.

The interviews for data collection took place in the first quarter of 2017. Five recognized experts in the automotive sector participated in the survey. Four are or were President, Vice President, and or Director in companies of the automotive field. The only exception was a Manager of an assembler appointed by his former Vice President, who considered his opinion most relevant on the subject.
The characterization of the respondents occurred according to: higher position in the automotive sector, education, higher level of education, and professional experience. The results are presented in Table 11.

After finishing the interviews, the results and comments of the respondents were tabulated and analyzed. A great agreement by the respondents was noted. All of them agreed regarding the validation of the reference model for implementation of new processes of assembly in the automotive sector.

More precisely, acceptance of 80% in terms of arithmetic mean was reached during stratification of the results. The possible answers were categorized from “I do not agree” to “I fully agree.”

A strength mentioned was that sequencing of the reference model for the implementation of new assembly processes in the automotive sector: facilitates the understanding of the interrelationship of various activities and phases of the DPPr, provides an analytical detail of the phases, establishes managerial decision-making milestones and defines the timeline based on a practical benchmark.

In addition, there was confirmation that the reference model for the implementation of new assembly processes in the automotive sector can be replicated to the auto parts area. It can also be used for training and qualification of trainees in engineering.

Only the interviewee one stated that continuous activities undergo changes, and therefore there should be a feedback. Feedback and analysis of new failure modes are considered mandatory as part of the FMEA methodology. The interviewee considers that using the current methodologies allows the development of a robust process of DPPr. The reference model for the implementation of new assembly processes in the automotive sector is not intended to replace existing methodologies, standards and studies, but rather to assist them during DPPr.

7. Conclusions and final considerations
The reference model for the development of new assembly processes in the automotive sector established the basic theoretical foundations of production process development. It describes the five phases that compose the production process development, the 52 activities that must occur in each one of the phases, the sequence in which the activities are to be performed, the department responsible for the execution of each activity, a time frame with beginning and end of activities, and six decision points, which are the respective milestones related to the phases of the model.
The application of the reference model for the implementation of new assembly processes in the automotive sector was validated through a test of consistency and relevance. For this, the proposed method of production process development was used, in a real process in an industry of the automotive sector. In addition, a qualitative evaluation was carried out through a field research with experts of notorious knowledge in the area.

Concerning the results of the validation, the model was validated in its practical evaluation. This occurred due to better performance of internal indicators regarding the amount of defect supply using the reference model for the implementation of new assembly processes in the automotive sector. Subsequently, the model was validated in its qualitative evaluation through the agreement of experts of notorious knowledge in the research area.

In this work, a reference model for the implementation of new assembly processes in the automotive sector was developed. In addition, the model can also be used in the auto parts sector.

7.1. Future research
The development of case studies using the reference model for the implementation of new assembly processes in the automotive sector is considered as a future research work. The model should be implemented during the whole DDPr phase, since more information would become available, in addition to the information already obtained in this study.

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