**Assessing maturity level of product development process in electrical-electronic industry**

Tamie Takeda Yokoyama1 – Centro Universitário UniSociesc – Programa de Pós-Graduação em Engenharia de Produção

Satie Ledoux Takeda Berger2 – Universidade Federal de Santa Catarina – Programa de Pós-Graduação em Engenharia de Produção

Marco Aurélio de Oliveira3 – Centro Universitário UniSociesc – Programa de Pós-Graduação em Engenharia de Produção

Enzo Morosini Frazzon4 – Universidade Federal de Santa Catarina – Programa de Pós-Graduação em Engenharia de Produção

André Hideto Futami5 – Centro Universitário UniSociesc – Programa de Pós-Graduação em Engenharia de Produção

**Abstract**

The achievement of a strategic, dynamic and flexible Product Development Process (PDP), allows companies to gain prominence and increase their sales. This can improve their market share, bringing them a competitive advantage. In this context, it is relevant to understand the practices, procedures and tools that compose and determine the PDP maturity level, in order to structure it to obtain a superior performance than competitors. This article aims to evaluate the PDP maturity level of an industry manufacturer of household appliances and electronic products. In view of this, a study was developed in which the questionnaire of a maturity model is applied; it considers the evaluation of 5 levels of maturity. At each level it is necessary to get 4 as median on all questions to be considered as reached level. Data analysis revealed that the industry's PDP is currently at maturity level 1, from a scale of 1 to 5. A more detailed diagnosis of the industry's PDP is provided and, from it, critical practices have been identified that by receiving greater managerial attention, can provide an increase in the maturity of the industry's PDP.

Keywords: Product development. Maturity level. CMMI. Household appliance and electronic industry.

**1. Introduction**

With a rapidly changing global economy, companies have been pressured to successfully develop products to remain competitive. Thus, in recent decades, in order to achieve this goal effectively, companies have established Product Development Processes (PDP). Since most industries base these actions on academic research, Product Development (PD) theory and methods have progressed rapidly to keep up with these changes (MIGUEL, 2005; PERSSON, 2016).

To face competition, it is critical that companies develop innovative products and reconcile product lifecycle management concepts with technology management concepts, taking advantage of their benefits (BITZER; VIELHABER; DOHR, 2014). Innovative products deliver long-term success by making a company's product portfolio healthy and sustainable. However, achieving a permanent flow of innovative products that are attractive to customers is not a simple task (COOPER, 2011). Just as important as innovations for competitive advantage are also changes in PDP processes (FLEURY; FLEURY, 2003) and the achievement of a unique performance PDP (CLARK; WHEELWRIGHT, 1993). Establishing a PDP and coordinating it while maintaining good performance has been a recurring challenge for industries and academia (GMELIN; SEURING, 2014).

Increased speed in New Product Development (NPD), as well as products that deliver value to customers – are unique and meet their needs – drive companies' competitiveness, profitability and success (COOPER, 2011). PD is a complex, multidisciplinary activity that involves the planning, development, manufacture and marketing of new products, and the improvement in the relationship between performance and cost of these new products (TYAGI et al., 2015; PERSSON, 2016). The forces that stimulate PD actions are technology, market and society (PERSSON, 2016).

Following Michael Hammer and James Champy's work about process reengineering in the early 1990s, business process concepts have spread and are considered an essential factor for competitiveness. Among the most relevant business processes for companies is PDP. Proper management and enhancement of the PDP with the intention of creating customer value can ensure market leadership. To deliver a desired product to the customer, the PDP needs to be comprehensive, ranging from market needs until the end of the product life cycle (ROZENFELD et al., 2006).

The scope of PD is wide; however, the concept of an efficient PDP is simple. The PDP efficiency can be seen in its ability to facilitate obtaining a product with better quality and low cost (TYAGI et al., 2015). Another way to examine a PDP performance and still identify what can be improved is by assessing maturity levels (JUGEND et al., 2010; PAUL et al., 2010; BOUGHZALA, 2014).

Given these considerations, studying the PDP of an electrical-electronic industry that has its products sold throughout Brazil, it was found that the industry faces problems such as customer complaints about the quality of its products and returns of finished products. Thus, this research aims to evaluate the industry's PDP maturity level. For this, the evaluation model developed by Quintella and Rocha (2006) will be used.

The research is justified by the need for a diagnosis for the industry, with subsequent design of best practices to serve the customer better and reduce rework costs. From the maturity assessment, the industry will be able to understand its PDP weaknesses to focus its improvement efforts. In addition, considering that there is not yet a specific model for maturity evaluation for electrical-electronic companies, it is relevant to investigate the applicability of the chosen tool.

The article is structured in six sections. In the first section there is the research introduction. In the second section is the theoretical referential. The third section details the research methodological procedures. In the fourth section there is the presentation of the results. The fifth section brings discussions about the results. In the last section are made the final considerations.

**2. Theoretical Referential**

This section aims to expose the main contributions in the literature about the PDP maturity theme. The first subsection will discuss maturity concepts and models. In the second subsection the chosen maturity level evaluation model will be detailed.

*2.1 PDP Maturity*

The concept of maturity can be understood as a process of evolution in which changes occur progressively, demonstrating the ability from an initial end stage to a desired end stage (METTLER, 2011). According to Torres (2014), maturity is the full development mode or condition in which an area or company seeks maturity; it is the fulfillment state in a service or product. It is a transition process from a structure, form or function to an experience position, potential development and the pursuit of the full improvement of its potential, skills, competencies and knowledge in project management. To Dooley, Subra and Anderson (2001), maturity in NPD projects can be defined as the degree to which the company establishes, manages, measures and improves its processes, being these elements essential in any quality system.

According to Patah (2010), the maturity assessment in a company can be explained as the application of a procedure and the communication of the results. The basic procedure is summarized as: a starting meeting to continue the initial assessment; the execution of the steps of data collection and analysis; and then finalize the results. Regarding the maturity models, Xavier et al. (2014) state that they represent the maturity degree that an organization has achieved in terms of project management practices. With the guide provided by the models, companies can be classified according to specific characteristics of each level, and with this tool can also check at what maturity level is the organization or a particular department. Once the maturity assessment model has been chosen, it is necessary to apply the research in order to analyze at which model level is the organization, and then work on the key points to obtain the desired maturity level.

The origin of maturity models does not yet have a consolidated understanding. There is a conception that the maturity models began to emerge in the literature from the 1970s, after the work of Nolan and Gibson (1974), being initially used to evaluate the performance of an information system (BITITCI et al., 2014; CARVALHO et al., 2017; GASTALDI et al., 2018). However, there is also a recognition that maturity models originated in quality management in the work of Crosby (1979), who created the Quality Management Maturity Matrix (QMMG) (JOKELA et al., 2006; MAIER; MOULTRIE; CLARKSON, 2012; JIN; CHAI; TAN, 2014; MOSCHIDIS; CHATZIPETROU; TSIOTRAS, 2018).

Nolan and Gibson (1974) proposed a four-stage maturity model – initiation, expansion, formalisation, and maturity – which assessed four areas of an information system function: budget, applications, personnel, and management techniques (BITITCI et al., 2014). Crosby's (1979) QMMG model identified the description of an organization's behavior as it progresses into five levels of maturity: Uncertainty, Awakening, Enlightenment, Wisdom, and Certainty. These levels considered a set of aspects for the company to achieve excellence in quality management (JOKELA et al., 2006; MAIER; MOULTRIE; CLARKSON, 2012).

In general, the maturity models developed from Crosby's (1979) foundations have several evolutionary levels, usually from 3 to 6, covering various process areas. The maturity level assessment in these models involves the inspection of key factors. The reach measurement of these key factors is based on detailed descriptions of certain subjects for each level. Processes from different areas are considered independent and can reach different maturity levels. The result allows companies to know their weaknesses and create improvements for relevant activities (JIN; CHAI; TAN, 2014).

The popularization of maturity models came from the Capability Maturity Model (CMM), developed by the Software Engineering Institute (SEI) (DOOLEY; SUBRA; ANDERSON, 2001). The model was published in 1987, presenting itself as a structure with five levels of software process maturity (PAULK, 2009), as follows: Initial, Repeatable, Defined, Managed and Optimizing (DOOLEY; SUBRA; ANDERSON, 2001). Figure 1 shows this structure. The CMM is extensive and considers several Key Process Areas (KPAs) at each maturity level, moreover each KPA has a number of key resources and practices to achieve the stated goals (BOUGHZALA, 2014). When process goals are met, a software process component is stabilized. Achieving each maturity level implies determining the stabilization of another software process component, and thus, the organization has an increase in the capacity of its process (PAULK et al., 1993).

**Figure 1 - The five maturity levels of CMM.**



Source: Paulk et al. (1993).

In 1991, the 1987 CMM model was formalized by SEI as CMM Software®, bringing the detailing of software engineering and management practices. Its success has led to the creation of several maturity models (PAULK, 2009), even in fields beyond software engineering, such as knowledge management and PD (JIN; CHAI; TAN, 2014), process management and performance measurement (BITITCI et al., 2014). In addition, the CMM model has been influencing the establishment of standards and norms for companies (PAULK, 2009).

In the PD area, the work of Hynds et al. (2014) described a model that aims to assess the companies' maturity in creating innovative and sustainable products and services. The authors state that the first feature of a maturity model is the specification of the progress of an organization's development capacity in an area. The model structure should normally cover four or five maturity levels for a given capacity, with the levels ordered by the competence degree in that area. The maturity levels are: Beginning, Improving, Succeeding, and Leading. The model use allows companies to track their progress in terms of environmental sustainability throughout the maturity cycle.

In Brazil, the work of Rozenfeld et al. (2006) presents a model as a reference for the PDP implementation or for its improvement, if the process already exists. The authors bring concepts, practices and tools that integrate the model and propose as an implementation guide the definition and evaluation of maturity levels that should compose a PDP. The PDP maturity level resulting from the assessment reveals how well a company applies PD best practices. It also specifies the skills required for employees to be able to include these practices in PD projects. These measures are fundamental for better process performance (ROZENFELD et al., 2006).

The research by Amaral and Rozenfeld (2007) presents a model for the NPD project that supports the full PD change cycle. This model is called PDPNet and integrates a business process reference model, a maturity model and a change management model. The PDPNet model maturity is measured according to 5 levels (Basic, Intermediate, Measurable, Controlled and Continuous Improvement), which represent a set of institutionalized practices. These practices are assessed by observation and classified as: not observed; ad hoc; formal and measured. The authors clarify that the model provides continuous transformation in the NPD process. This enables the best practices adoption and maintenance until the achievement of strategic goals.

The model by Ma et al. (2011) brings a combination of the Organizational Project Management Maturity Model (OPM3) published by the Project Management Institute (PMI) with the NPD project and other characteristics of an organizational environment. As a result, a three-dimensional model with five maturity levels (Initial concept level, Single method level, Entire level, Quantification control level, and Continuous improvement level) is obtained. In the first dimension (x-axis) is the NPD project life cycle; in the second dimension (y-axis) is the NPD project management knowledge system; and in the third dimension (z-axis) is the maturity level in NPD project management. The model aims to increase the success rate in the PD projects.

Rossi, Terzi and Garetti (2013) propose a maturity assessment model for NPD with 5 maturity levels: Chaos, Low, Intermediate, Mature, Best Practice. NPD is evaluated from 3 main perspectives: process, organization and knowledge management. For this, a questionnaire with 33 questions, related to 9 areas of the NPD is developed. After analyzing a sample of 30 companies, the authors found a maturity level between intermediate and mature for the group. The main shortcoming of the companies studied is low definition and communication of customer value. In addition, the authors consider the proposed model an important tool for companies to benchmark with their competitors.

Kandt et al. (2016) developed a model called RAPIDO to study the maturity of a product in the different PDP stages. According to the authors, the model is based on compatible quality methods, such as FMEA, and it is easy to use. The use of RAPIDO has been validated in a German company in the mechanical engineering sector. The model provides the product maturity degree throughout the PDP, which allows immediate interventions in the process when deviations are identified.

According to Boughzala (2014), the advantages of maturity models are their easy use and analysis, and the provision of an instant view of the organization situation and structure. As a consequence, one has the opportunity to prioritize the necessary improvements. In addition, following the authors, the application of the maturity assessment can be performed by both external auditors and internal employees, in the form of self-assessment.

For Fraser, Moultrie and Gregory (2002), the maturity assessment provides a company's behavior characterization at different maturity levels, based on studied elements. This allows classify the developed practices into good or bad, as well as to identify a possible transition position between levels.

*2.2 PDP maturity assessment by the chosen model*

The maturity analysis developed by Quintella and Rocha (2006) was constructed considering the criteria of the Capability Maturity Model Integration (CMMI) maturity model. CMMI was born from CMM. In 1997, after CMM Software® received new versions, SEI's efforts were devoted to new work, the development of CMM Integration™ (CMMI). CMMI integrated into a single model the software engineering, the systems engineering, and the product and process integrated development (PAULK, 2009). Therefore, the CMMI model, besides guiding and evaluating software development, also started to provide these actions in PDP (all CMMI models consider maturity levels in their project). Maturity levels consist of generic and specific practices that, when applied, mature certain process areas to which they relate. These practices aim to improve overall organization performance (TEAM, 2010). Through the integration of the interorganizational functions, CMMI drives companies towards constant improvement. Its use enables the follow-up of objectives and priority setting, contributing to quality processes and the establishment of a reference for processes evaluation in progress (REIS; MATHIAS; DE OLIVEIRA, 2017).

An example of a successful PDP maturity assessment conducted by the qualitative application of CMMI is the work of Jugend et al. (2010). The authors analyzed through semi-structured interviews the PDP practices in two companies, one producing high pressure boilers and the other producing turbines and power generators. The article main conclusion is the feasibility of CMMI's maturity analysis in tangible products development (JUGEND et al., 2010). Later, Albanez and Estorilio (2014) examined the association between the CMMI-DEV 1.2 maturity diagnostic model and the ISO/TS 16949 technical specification for quality management. Their results revealed that CMMI indicates which areas need to be developed and what goals need to be achieved in the PDP, while ISO/TS only encourages continuous improvement. Consequently, an ISO/TS certified organization may not even reach maturity level 2 on the CMMI 1-5 scale. Therefore, for better PDP performance it is recommended to take these and other approaches together. In the work of Estorilio et al. (2015) is stated that there is a correlation between the status of ISO certifications and the PDP maturity level based on CMMI. The conclusion is: the higher the maturity level, the longer the ISO certification has been achieved and maintained.

These different CMMI applications cases and their findings highlight the model relevance to researchers. Rossi, Terzi and Garetti (2013) share this understanding, stating that CMMI is among the most important assessment tools in the literature. In addition, they explain how the model works. CMMI consists of 5 maturity levels, and the evaluation is commonly performed through questionnaires. The answers are used to understand the critical factors in each evaluated area. CMMI's five maturity levels, as well as their characteristics are (QUINTELLA; ROCHA, 2006; TEAM, 2010):

1. Initial: At this maturity level the company has no prior planning of its processes, so its environment is unstable to support them. There is a disorder, and in this situation the organization success will depend on the competence and bold performance of employees. The developed products and services work, however to achieve this result the budget and/or schedule has been sacrificed. The company cannot repeat the processes that were successful.

2. Managed: This is a level at which processes are planned, executed, monitored, controlled and reviewed. This is ensured by projects involving skilled employees, adequate resources and working tools that meet the standards and procedures specified in the process. There is discipline in the organization, so the plans are documented, ensuring that good practices are maintained in times of crisis. Although there are a pattern and certain procedures in the processes, they can change a lot depending on each project. Managers can view the products and services status at defined points in the process and there is a commitment to stakeholders.

3. Defined: presents a set of properly defined processes, based on procedures, standards, methods and tools. Standard processes are used throughout the company, and are being improved over time. Process descriptions are more rigorous, including definitions of purpose, entry and exit criteria, roles, inputs and outputs, among other process components. The company uses training programs to ensure that its employees and managers have the knowledge and skills appropriate to their processes. Process management is more proactive, and its improvement is more intense.

4. Quantitatively managed: This is a level marked by the establishment of quantitative objectives based on the needs of the customers, process implementers and organization. These objectives should guide product quality and process performance, and should be used as criteria for project management evaluation. Processes, subprocesses and products are quantitatively evaluated and managed in terms of productivity and quality throughout the life of projects. In order to control project processes and products, statistical techniques are used, supported by quantitative measurements. The organization knows the risks of introducing a new application domain and can manage them.

5. Optimizing: At this level there are processes continuous improvement, both incrementally and technologically, being an activity developed throughout the organization. Business objectives and organizational performance requirements are quantitatively defined, and to support them, quality and process performance objectives must be constantly reviewed. New technologies and proposed improvements are measured by statistical techniques and analyzed in relation to their cost and benefit. The organization cares about its overall performance, so it collects data from its projects and disseminates learned lessons from previous projects. The collected data are analyzed to identify process deficiencies aiming their optimization. Process optimization is the result of aligning the organization's business objectives with the participation and empowerment of its employees.

The work of Quintella and Rocha (2006) groups the characteristics of each CMMI maturity level into different categories and process areas. Table 1 clarifies these concepts, to make framing an organization at a maturity level a simpler task.

**Table 1 - Practices at each maturity level.**

|  |  |  |
| --- | --- | --- |
| Categories | Process Areas | Maturity level |
| 2 | 3 | 4 | 5 |
| Process management | Focus on Organizational Process |  | x | x | x |
| Organizational Process Definition |  | x | x | x |
| Organizational Training |  | x | x | x |
| Organizational Process Performance |  |  | x | x |
| Innovation and Organizational Deployment |  |  |  | x |
| Project management | Project Planning | x | x | x | x |
| Project Monitoring and Control | x | x | x | x |
| Supplier Agreement Management | x | x | x | x |
| Integrated Management of Project |  | x | x | x |
| Risk Management |  | x | x | x |
| Team Integration |  | x | x | x |
| Integrated Management of Supplier |  | x | x | x |
| Quantitative Management of Project |  |  | x | x |
| Engineering | Requirements Development |  | x | x | x |
| Requirements Management  | x | x | x | x |
| Technical Solution |  | x | x | x |
| Product Integration |  | x | x | x |
| Verification |  | x | x | x |
| Validation |  | x | x | x |
| Support | Configuration Management | x | x | x | x |
| Assured Quality of Process and Product  | x | x | x | x |
| Measurement and Analysis | x | x | x | x |
| Organizational Environment for Integration |  | x | x | x |
| Decision Analysis and Resolution |  | x | x | x |
| Causal Analysis and Resolution  |  |  |  | x |

Source: Quintella and Rocha (2006).

 Four broad categories encompass the process areas: Process Management, Project Management, Engineering, and Support. The process areas include practices related to certain areas of the company, which, when executed, will meet specific and generic goals, contributing to the improvement of this area and the achievement of maturity levels (QUINTELLA; ROCHA, 2006).

In this research, the choice of the model of Quintella and Rocha (2006) adapted from CMMI to evaluate the maturity of an electronic PDP, can be justified for three reasons. First, from the performed literature review, it was found that this model is unique because it is available in Portuguese, is quantitative, it has a concise questionnaire, open access, simplified application and accessible language. The second reason is the prior confirmation of the model applicability in real case in Quintella and Rocha's (2006) own work, assessing the maturity of two automotive companies. The third reason is the statement in the research of Jugend et al. (2010), exposing that CMMI can be used for the maturity levels assessment in industrial PDP – tangible products. Therefore, since the chosen PDP has tangible products and the Quintella and Rocha's (2006) model has already been tested, this model was adopted to measure the maturity level.

**3. Research methodology**

The research consists in exploratory research, which adopted the technical procedures of literature review, survey and single case study. The survey involved the application of a questionnaire, unstructured interviews and direct observation in the workplace. In the case study methodological triangulation was used, comprising the results analysis and discussion under quantitative (median obtained from questionnaires) and qualitative (data from interviews and observation) approaches.

The studied industry operates in the electrical-electronic sector, selling products to the entire country. This industry was chosen due to the need to characterize the current situation of its PDP and find possible failure points that may be causing lower quality in its products, generating customer complaints and lost sales. To analyze their maturity degree, the questionnaire developed by Quintella and Rocha (2006) was applied. This questionnaire has a total of 27 questions that verify the fulfillment of the goals (generic and specific) of certain practices (process areas), based on the CMMI concepts. The alternatives to answers default to the Likert scale: 1) No/Never; 2) Rarely; 3) Sometimes; 4) Often; and 5) Always. Therefore, each answer is assigned a number that will indicate the respondent's perception of each statement. The respondent should tick only one of the alternatives. For better understanding, an example of questionnaire questions and answer alternatives is presented in Table 2.

**Table 2 - Sample questions and answer alternatives from the applied questionnaire.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  Questions | N | R | S | O | A |
| 1. Are product development projects planned with the involvement of stakeholders (including suppliers) and are such projects monitored and controlled against their plan? |   |   |   |   |   |
| 2. Are corrective actions taken when the development project is not following its plan? |   |   |   |   |   |

Source: Quintella and Rocha (2006).

Subtitle: N (No/Never); R (Rarely); S (Sometimes); O (Often); A (Always).

The link between each question in the questionnaire (given goal) and the corresponding maturity level is presented in Table 3. Details of each process area and goal by level of maturity are presented in Annex A, coming from Quintella and Rocha (2007).

**Table 3 - Key-questions and the corresponding maturity level.**

|  |  |
| --- | --- |
| **Key-questions** | **Corresponding CMMI Maturity Level** |
| 1 to 7 | Level 2 |
| 8 to 19 | Level 3 |
| 20 to 24 | Level 4 |
| 25 to 27 | Level 5 |

Source: Adapted from Quintella and Rocha (2006).

The purpose of questions 1 to 7 is to verify whether processes are measured and controlled; whether products, services and requirements are managed; whether there is a commitment to stakeholders; whether the status of products and services are visible to management. Questions 8 to 19 analyze from characterization and processes establishment to their understanding and documentation; identify whether the company knows the training needs as well as the parts and risks involved. Questions 20 to 24 look at process and product control; the ability to develop predictable processes; the reduction of performance variation and the existence of performance and quality measurements stored in repositories. Questions 25 to 27 investigate whether causes of variation are removed from processes; whether there is a permanent knowledge sharing throughout the organization and whether there is a search for continuous performance improvement, through stabilization and process management (QUINTELLA; ROCHA, 2006).

The results of the application of the questionnaires were analyzed from a quantitative approach. The used criteria to assess the maturity degree were those proposed by Quintella and Rocha (2006):

1) The company maturity degree will be the result of the highest level whose median obtained by CMMI questions is equal to or greater than 4. For this, all group responses must reach values equal to or greater than 4. If one does not, it will be considered as a level not reached. This criterion originates from the CMMI criteria, which requires that all process area goals be met to determine level attainment, if one of them is not met, the level is not met.

2) The company maturity will be level 1, if the result of the median obtained in the questions does not reach at least level 2 of maturity.

The questionnaires were printed and distributed to a sample of the studied industry. The sample was intentional non-probabilistic, i.e., a representative portion of the entire population was chosen. The chosen representatives were the department heads – manager and supervisors (three people) –, and the main staff involved in the PDP documentation (formalization) (three people).

After the six questionnaires were answered, the data were extracted, gathered and organized using Microsoft Office Excel software. Maturity analysis was performed using the median as a measure of central tendency.

**4. Presentation and analysis of results**

The studied industry has more than 4,500 employees and over 60 years of experience in the Brazilian market. It has developed a partnership and trust relationship with the Brazilian consumer and retail, which continues to strengthen. It currently produces household appliance (such as mixers) and electronics products, bringing together in its portfolio more than 200 products to serve the domestic market (without exportation). Its organizational structure is functional and does not have a formal structure for the PDP. Moreover, there is no reference model guiding your PDP. Considering the classification by Clark and Wheelwright (1993), the company's projects are mostly incremental and derivative, i.e., they come from extensions or improvements (small changes) in existing projects. These projects aim to generate new products versions with the extension of their applicability, with resources and costs reduction. To study the maturity, it was chosen the industry's product development department apply and it was applied the questionnaire according to the procedures detailed in Section 3 of the Research Methodology.

In order to find the industry PDP maturity level by the Quintella and Rocha (2006) model, the data were organized into 4 tables referring to the analysis of levels 2, 3, 4 and 5. Table 4 presents the detailed results of the level 2 analysis.

**Table 4 - Assessment results for maturity level 2.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Maturity level** | **Question number**  | **Median by question** | **Target median** |
| 2 | Question 1 | 3 | 4 |
| Question 2 | 3 | 4 |
| Question 3 | 3 | 4 |
| Question 4 | 4 | 4 |
| Question 5 | 3 | 4 |
| Question 6 | 3 | 4 |
| Question 7 | 4 | 4 |
| The lowest response of the level: | 2 |
| The highest response of the level: | 5 |
| Level median: | 3 |
| Average deviation of the level: | 0,677 |
| The lowest median of the level: | 3 |

Source: Authors (2019).

 The reached median at this level was 3. The minimum median of 4 per question was not reached, consequently the median of 4 for the level also was not reached. Thus, the industry failed to reach level 2, so its maturity level is 1, called initial. At level 2, there was no question that stood out as a critical point, with the lowest score, because all questions were rated between 3 and 4. Thus, the industry must strive to improve all practices at this level in the same way.

Despite the failure to reach level 2, the results for the other levels will be presented to clarify the most critical points to improve. Table 5 shows the result of the level 3 analysis.

**Table 5 - Assessment results for maturity level 3.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Maturity level** | **Question number** | **Median by question** | **Target median** |
| 3 | Question 8 | 3 | 4 |
| Question 9 | 3 | 4 |
| Question 10 | 2 | 4 |
| Question 11 | 3 | 4 |
| Question 12 | 2 | 4 |
| Question 13 | 3 | 4 |
| Question 14 | 4 | 4 |
| Question 15 | 3 | 4 |
| Question 16 | 4 | 4 |
| Question 17 | 2 | 4 |
| Question 18 | 4 | 4 |
| Question 19 | 2 | 4 |
| The lowest response of the level: | 1 |
| The highest response of the level: | 5 |
| Level median: | 3 |
| Average deviation of the level: | 0,958 |
| The lowest median of the level: | 3 |

Source: Authors (2019).

At level 3, it was found that some practices are already well established, because they reached the median 4, for example the practices in questions 14, 16 and 18. This means that the industry seeks to meet customer requirements, develops technical solutions. and their processes are well characterized, being prepared for further verification. However, in contrast, other goals are farther from being met, such as those in questions 10, 12, 17, and 19, which got a median 2. These goals relate to organizational training, team and customer integration, and product validation. Due to their low score, these are the practices that to be improved will require more effort from the organization to achieve greater maturity.

Only 25% of level 3 reached median 4, so there is no support for this level. In addition, the participants differed their opinion greatly on the practices of this level, varying their score from 1 to 5 in the answers, generating the second largest mean deviation. This indicates that there are significant differences in respondents' perception about PDP maturity. This can be caused by the lack of visibility and clear understanding of the PDP strategy: for some employees the goal has been met, for others not yet. This divergence could be alleviated with better transparency, communication and training. Then further evaluation should be done to investigate if the answers will be unanimous.

In Table 6, it is possible to check the results of the study for maturity level 4.

**Table 6 - Assessment results for maturity level 4.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Maturity level** | **Question number** | **Median by question** | **Target median** |
| 4 | Question 20 | 3 | 4 |
| Question 21 | 3 | 4 |
| Question 22 | 3 | 4 |
| Question 23 | 4 | 4 |
| Question 24 | 3 | 4 |
| The lowest response of the level: | 1 |
| The highest response of the level: | 5 |
| Level median: | 3 |
| Average deviation of the level: | 0,867 |
| The lowest median of the level: | 3 |

Source: Authors (2019).

 At level 4 only the goal contained in question 23 is being met, which deals with determining the cause of the problems. The others questions reached median 3, so the industry still needs to invest in them to get better PDP performance. At this level, responses were closer, with the second smallest mean deviation, meaning that employees have less divergent perceptions.

Starting with the last analysis, Table 7 contains the results for level 5.

**Table 7 - Assessment results for maturity level 5.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Maturity level** | **Question number** | **Median by question** | **Target median** |
| 5 | Question 25 | 3 | 4 |
| Question 26 | 3 | 4 |
| Question 27 | 3 | 4 |
| The lowest response of the level: | 1 |
| The highest response of the level: | 4 |
| Level median: | 3 |
| Average deviation of the level: | 0,975 |
| The lowest median of the level: | 3 |

Source: Authors (2019).

Level 5, because it involves more advanced process optimization goals – which are usually achieved after the other goals have already been consolidated – obtained the lowest scores, ranging from 1 to 4. In addition, its average deviation was the largest within low scores, which means that even if the practices are not fully followed, the understanding about them is not convergent either. As with level 2, better communication and training is required to ensure focus on goals. Despite the weaknesses, the median level was 3.

With a quantitative analysis of the maturity level evaluation tables, it was identified that the most critical level is 3, since it obtained the lowest median per question, a large mean deviation and a large variation between scores when compared to the other levels. This result is understandable because level 3 covers the PDP definition subject with the largest number of goals to be achieved.

Concluding the questionnaires analysis, the industry PDP achieved maturity level 1, as discovered in Table 4. Because it is the first model level, considering the entire process and based on the CMMI, this means that the industry does not has well-established management practices, there is a disorder in the work environment, its prior planning is not executed and the generated product or service does not meet the schedule and may harm its budget.

Parallel to the quantitative research results from the questionnaires, the analysis of qualitative data (observation and informal interviews) revealed more characteristics about the industry's PDP maturity. It was noticed that the industry develops and guides its PDP activities mainly through the employees' experience involved in these activities. There is a great appreciation of tacit knowledge. However, one neglects explicit knowledge and the establishment of management practices, which leads to unpredictable and poorly controlled processes, with much rework.

The industry has no quantitative indicators to evaluate the success of its projects, and does not work with cross-functional teams per project. PDP assessment is informal and not disclosed to employees. Although the executed projects documentation (registration) is carried out – which mainly deals with the technical subject –, before starting new projects, no meetings are held to discuss previous hits and misses. Knowledge is passed on informally from employee to employee through their experiences. The work environment is therefore unstable; when an experienced employee leaves office, valuable knowledge not yet formalized is lost. The success of industry projects depends mainly on individual skills, because management practices are not well established.

**5. Discussion**

The characteristics raised by the qualitative approach of exploratory research do not contradict the characteristics of CMMI level 1, in which the industry was classified by the quantitative approach of the research (from the questionnaires). This initial level is marked by poor planning, lack of control, and consequently unpredictable results. Therefore, the same successful results achieved cannot always be achieved. As previously explained, some of these elements were found in the studied PDP.

It should be acknowledged, however, that although questionnaires are versatile, uncomplicated and a widely used, they can cause some difficulties, such as the generation of other variables that interfere with the collected data, depending on how they were designed or applied (OMOTE; PRADO; CARRARA, 2005). Even if the questionnaires were tested by other researchers, it is noteworthy that in the present research there may have been misinterpretations by the respondent group, lack of knowledge about the question or lack of access to information in the process in which they operate. There is no way to determine how effectively each respondent understands the subject. These and other factors may have affected the found result.

Considering the most critical questions for the industry – obtained from the low medians in the questionnaire – and other weaknesses revealed in the exploratory research, some recommendations were developed based on the CMMI model to raise the level of its maturity. It is suggested that the industry invests in more efficient planning, with a greater formalization of procedures and knowledge. It is necessary to establish quantitative indicators to precisely control its processes, and to develop a functional integration, creating multifunctional teams that get involved throughout the project. Training programs are also indicated – as there are communication failures and divergences in process understanding –, and greater customer involvement in establishing design requirements and product validation. These actions will provide more stable projects, higher product quality, and prevent sales losses. Finally, it is suggested a maturity model adoption to guide the industry's PDP and to integrate all its employees to achieve the common goal of developing a product that satisfies its customers.

In summary, the carried-out research collaborates with the studied industry, promoting a greater knowledge about the characteristics of its PDP and the main faced difficulties. From this and the presented/given suggestions, the industry can improve its process, obtaining greater assertiveness in its final results, thus gaining competitive differential. In addition, the research consolidates the literature by presenting a case study that explores the PDP maturity theory, and the feasibility of applying the Quintella and Rocha's (2006) questionnaire to an electronics industry. The study tests the theory, revealing some limitations in the use of the questionnaire, such as the chosen model, sample size and misinterpretation. If the given suggestions are implemented, a future study can compare the PDP state before and after the modifications, generating new insights on the theme. In addition, the research as a case study that involves real observations, contributes to form a cumulative current of investigations that help in the theory construction and improvement (STUART et al., 2002; LØKKE; SØRENSEN, 2014).

**6. Conclusion**

The developed research aimed to identify the PDP maturity level of an electrical-electronic industry. This objective was achieved using the Quintella and Rocha's (2006) questionnaire, which provides an analysis from quantitative data (Likert scale). The analysis results classified the maturity as level 1, called initial. Based on CMMI, this means that the industry does not has well-established management practices, there is clutter in the work environment, its prior planning is not executed and the generated product or service can negatively affect the schedule and the budget.

From the qualitative-exploratory research it was verified the proof of some of these characteristics and the contestation of others. Comprehensively, it was found that PDP practices are still poorly controlled, with unpredictable processes outcome. There is a low measurement of process performance and communication failures regarding the knowledge dissemination, procedures and goals. These weaknesses corroborate CMMI level 1 definitions. However, the industry's DP processes are in place, the work environment is organized and there is process management according to industry's rules. These strengths complement the elements of the initial level, indicating that the industry's maturity may be in the process of transition to level 2. The various medians 3 obtained at level 2 show agreement with this proposition.

Regarding the use of the CMMI-based questionnaire to evaluate a PDP of tangible electronic products, it was found that its application was simple and feasible. It facilitated the identification of the main deficiencies of the studied PDP, allowing to determine actions focused on improving these weaknesses. Thus, it is an important tool for the industry and others that need to analyze and make decisions in the management of their PDP.

The contributions of this research are three. The first is to provide a clear diagnosis of the industry's PDP maturity in a quantitative and qualitative manner. The second concerns the applicability verification of the chosen assessment model, through a case study in an industry of a sector not yet explored. The third contribution involved identifying and proposing opportunities for improvement in the PDP, which the industry can use to raise its maturity level.

The research had as limitations the sample size and the difficulty of access to strategic information. As a suggestion for future research, after the implementation of improvements, it would be pertinent to expand the sample to apply a new evaluation. In addition, a complementary assessment by another maturity level model could provide different elements for PDP understanding, providing a comparison with the result found in this research.

**References**

ALBANEZ, A. U. D. A.; ESTORILIO, C. C. A. Associações entre CMMI-DEV 1.2 e ISO/TS 16949. **Revista Produção Online**, v. 14, n. 2, p. 679-702, 2014.

AMARAL, D. C.; ROZENFELD, H. **Integrating new product development process references with maturity and change management models**. A International Conference on Engineering Design, ICED’07. Paris, France**:** 1-12 p. 2007.

BITITCI, U. S.; GARENGO, P.; ATES, A.; NUDURUPATI, S. S. Value of maturity models in performance measurement. **International Journal of Production Research,** v. 53, n. 10, p. 3062-3085, 2014.

BITZER, M.; VIELHABER, M.; DOHR, F. From Product Development to Technology Development. **Procedia CIRP,** v. 21, p. 247-251, 2014.

BOUGHZALA, I. Assessing the Community Maturity from a Knowledge Management Perspective. In: POMEROL, J.; SAAD, I.*, et al* (Ed.). **Information Systems for Knowledge Management**. London: ISTE Ltd and John Wiley & Sons, Inc., 2014. p.1-31.

CARVALHO, J. V.; ROCHA, A.; VAN DE WETERING, R.; ABREU, A. A Maturity model for hospital information systems. **Journal of Business Research**, 2017.

CLARK, K. B.; WHEELWRIGHT, S. C. **Managing new product and process development: Text cases**. New York: Free Press, 1993.

COOPER, R. G. **Winning at new products: Creating value through innovation**. 4th ed. New York: Basic Books, 2011.

DOOLEY, K.; SUBRA, A.; ANDERSON, J. Maturity and its impact on new product development project performance. **Research in Engineering Design,** v. 13, n. 1, p. 23-29, 2001.

ESTORILIO, C.; VAZ, G. R. M.; DE LISBOA, F. C.; BESSA, L. D. O. F. The relationship between industrial process maturity and quality certification. **Computer Standards & Interfaces**, v. 39, p. 22-33, 2015.

FLEURY, A. C. C.; FLEURY, M. T. L. Estratégias competitivas e competências essenciais: perspectivas para a internacionalização da indústria no Brasil. **Gestão & Produção,** v. 10, p. 129-144, 2003.

FRASER, P.; MOULTRIE, J.; GREGORY, M. The use of maturity models/grids as a tool in assessing product development capability. IEEE International Engineering Management Conference, 2002. p.244-249 vol.1.

GASTALDI, L.; PIETROSI, A.; LESSANIBAHRI, S.; PAPARELLA, M.; SCACCIANOCE, A.; PROVENZALE, G.; CORSO, M.; GRIDELLI, B. Measuring the maturity of business intelligence in healthcare: Supporting the development of a roadmap toward precision medicine within ISMETT hospital. **Technological Forecasting and Social Change,** v. 128, p. 84-103, 2018.

GMELIN, H.; SEURING, S. Determinants of a sustainable new product development. **Journal of Cleaner Production,** v. 69, p. 1-9, 2014.

HYNDS, E. J.; BRANDT, V.; BUREK, S.; JAGER, W.; KNOX, P.; PARKER, J. P.; SCHWARTZ, L.; TAYLOR, J.; ZIETLOW, M. A Maturity Model for Sustainability in New Product Development. **Research-Technology Management,** v. 57, n. 1, p. 50-57, 2014.

JIN, D.; CHAI, K.-H.; TAN, K.-C. New service development maturity model. **Managing Service Quality: An International Journal,** v. 24, n. 1, p. 86-116, 2014.

JOKELA, T.; SIPONEN, M.; HIRASAWA, N.; EARTHY, J. A survey of usability capability maturity models: implications for practice and research. **Behaviour & Information Technology,** v. 25, n. 3, p. 263-282, 2006.

JUGEND, D.; SILVA, S. L.; TOLEDO, J. C.; ONOYAMA, M. M. Evaluation of maturity levels in the management of product development: case studies in the capital goods industry. **Product: Management & Development,** v. 8, n. 2, p. 183-192, 2010.

KANDT, A.; PICKSHAUS, T., FLEISCHER, K. & SCHMITT, R. A new model to ascertain product maturity in product development processes. **Procedia CIRP,** v. 50, p. 173-178, 2016.

LØKKE, A.-K.; SØRENSEN, P. D. Theory testing using case studies. **The Electronic Journal of Business Research Methods**, v. 12, n. 1, p. 66-74, 2014.

MA, Y.; CHANG, Y.; ZHU, H.; XIA, C.; CHANG, Z. Research on maturity model of enterprise NPD project management. International Conference on Advances in Education and Management, 2011, Berlin, Heidelberg. Springer Berlin Heidelberg. p.328-335.

MAIER, A. M.; MOULTRIE, J.; CLARKSON, P. J. Assessing organizational capabilities: Reviewing and guiding the development of maturity grids. **IEEE Transactions on Engineering Management,** v. 59, n. 1, p. 138-159, 2012.

METTLER, T. Maturity assessment models: a design science research approach. **International Journal of Society Systems Science,** v. 3, n. 1-2, p. 81-98, 2011.

MIGUEL, P. A. C. Evidence of QFD best practices for product development:a multiple case study. **International Journal of Quality & Reliability Management,** v. 22, n. 1, p. 72-82, 2005.

MOSCHIDIS, O.; CHATZIPETROU, E.; TSIOTRAS, G. Quality costing and quality management maturity in Greece: An exploratory multi-dimensional data analysis. **International Journal of Productivity and Performance Management,** v. 67, n. 1, p. 171-191, 2018.

OMOTE, S.; PRADO, P. S. T. D.; CARRARA, K. Versão eletrônica de questionário e o controle de erros de resposta. **Estudos de Psicologia (Natal)**, v. 10, p. 397-405, 2005.

PATAH, L. A. **Avaliação da relação do uso de método e treinamento em gerenciamento de projetos no sucesso dos projetos através de uma perspectiva contingencial:** uma análise quantitativa. 2010. Tese (Doutorado em Engenharia de Produção) – Universidade de São Paulo, São Paulo, 2010.

PAULA, I. C.; FOGLIATTO, F. S.; ECHEVESTE, M. E. S.; CRISTOFARI, C. A. Product development management maturity assessement: Proposal of a new method. DS 60: Proceedings of DESIGN 2010, the 11th International Design Conference, 2010, Dubrovnik, Croatia. May 17-20. p.391-402.

PAULK, M. C. A history of the capability maturity model for software. **ASQ Software Quality Professional,** v. 12, n. 1, p. 5-19, 2009.

PAULK, M. C.; CURTIS, B.; CHRISSIS, M. B.; WEBER, C. V. Capability maturity model, version 1.1. **IEEE Software,** v. 10, n. 4, p. 18-27, 1993.

PERSSON, J.-G. Current Trends in Product Development. **Procedia CIRP,** v. 50, p. 378-383, 2016.

QUINTELLA, H. L. M. D. M.; ROCHA, H. M. Avaliação da maturidade do processo de desenvolvimento de veículos automotivos. **Gestão & Produção,** v. 13, n. 2, p. 297-310, 2006.

\_\_\_\_\_\_. Nível de maturidade e comparação dos PDPs de produtos automotivos. **Production,** v. 17, n. 1, p. 199-215, 2007.

REIS, T. L.; MATHIAS, M. A. S.; DE OLIVEIRA, O. J. Maturity models: identifying the state-of-the-art and the scientific gaps from a bibliometric study. **Scientometrics,** v. 110, n. 2, p. 643-672, 2017.

ROSSI, M.; TERZI, S.; GARETTI, M. Proposal of an assessment model for new product development. 2013, Berlin, Heidelberg. Springer Berlin Heidelberg. p.383-390.

ROZENFELD, H.; FORCELLINI, F. A.; AMARAL, D. C.; TOLEDO, J. C.; SILVA, S. L.; ALLIPRANDINI, D. H.; SCALICE, R. K. **Gestão de desenvolvimento de produtos: Uma referência para a melhoria do processo**. São Paulo: Saraiva, 2006. 542 p.

STUART, I.; MCCUTCHEON, D.; HANDFIELD, R.; MCLACHLIN, R.; SAMSON, D. Effective case research in operations management: a process perspective. **Journal of Operations Management**, v. 20, n. 5, p. 419-433, 2002.

TEAM, C. P. **CMMI® for Development, Version 1.3, Improving processes for developing better products and services**. Carnegie Mellon University. Pittsburgh, p.482. 2010.

TORRES, L. F. **Fundamentos do gerenciamento de projetos.** Rio de Janeiro: Elsevier, 2014. 216 p.

TYAGI, S.; CHOUDHARY, A.; CAI, X.; YANG, K. Value stream mapping to reduce the lead-time of a product development process. **International Journal of Production Economics,** v. 160, p. 202-212, 2015.

XAVIER, C. M. D. S.; VIVACQUA, F. R.; MACEDO, O. S. D.; Xavier, L. F. D. S. **Metodologia de gerenciamento de projetos:** methodware abordagem prática de como iniciar, planejar, executar, monitorar, controlar e encerrar projetos. 3 ed. Rio de Janeiro: Brasport, 2014. 376 p.

Annex A – Maturity level and respective goals.

|  |  |  |
| --- | --- | --- |
| **Level** | **Process areas** | **Specific goals** |
| 2 | Project Planning | Establish estimates; |
| Develop the project plan; |
| Get commitment to the plan. |
| Project Monitoring and Control | Monitor project against plan; |
| Manage corrective actions to completion. |
| Supplier Agreement Management | Establish agreements with suppliers; |
| Satisfy agreements with suppliers. |
| Requirements Management | Manage requirements. |
| Configuration Management | Establish baselines; |
| Track and control changes; |
| Establish integrity. |
| Assured Quality of Process and Product | Objectively evaluate processes and results; |
| Provide objective understanding. |
| Measurement and Analysis | Align measurement and analysis activities; |
| Provide measurement results. |
| 3 | Focus on Organizational Process | Determine opportunities for process improvement; |
| Plan and implement process improvement activities. |
| Organizational Process Definition | Establish organizational process structure. |
| Organizational Training | Establish organizational training capability; |
| Provide necessary training. |
| Integrated Management of Project | Utilization of the process defined for the project; |
| Coordinate and collaborate with relevant stakeholders;  |
| Use of shared vision for integrated management of project. |
| Risk Management | Prepare for risk management; |
| Identify and analyze risks; |
| Mitigate risks. |
| Team Integration | Establish the team composition; |
| Manage team operation. |
| Integrated Management of Supplier | Analyze and select product sources; |
| Coordinate work with suppliers. |
| Desenvolvimento dos Requerimentos | Develop customer requirements; |
| Develop product requirements; |
| Analyze and validate requirements. |
| Technical Solution | Select product solutions and components; |
| Develop the design; |
| Implement the product design. |
| Product Integration | Prepare for product integration; |
| Ensure interface compatibility; |
| Assemble components and deliver product. |
| Verification | Prepare for verification; |
| Perform peer review; |
| Check selected job results. |
| Validation | Prepare for validation; |
| Validate product or product component. |
| Organizational Environment for Integration | Provide infrastructure for integrated management of product; |
| Manage people for integration. |
| Decision Analysis and Resolution | Evaluate alternatives. |
| 4 | Organizational Process Performance | Establish baselines and performance models. |
| Quantitative Management of Project | Quantitatively manage the project; |
| Statistically manage subprocess performance. |
| 5 | Innovation and Organizational Deployment | Select improvements; |
| Deploy improvements. |
| Causal Analysis and Resolution | Determine causes of defects; |
| Address causes of defects. |

Source: Quintella and Rocha (2007, p. 213).