

Development of a Diagnostic Tool for the Management of the Product Development Process in Metalworking Companies

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ABSTRACT: Organizations that have their Product Development Process (PDP) systematized are benefited because the structuring of the PDP Management brings significant advantages, since it improves the understanding of the client's needs in the initial phases of development, facilitating the control of costs, quality and time. Regarding companies in the metalworking sector located in Region 3 - Santa Fe Node, Argentina, through preliminary observations and analysis, it can be concluded that many companies present non-systematized practices related to the PDP, and in the cases in which observes some degree of formalization, there is no habit of registering or systematizing the PDP; as well as they present ignorance of PDP tools and Project Management. This reality causes companies to use resources inefficiently. In the present work, a PDP diagnostic tool is designed for companies belonging to the metalworking sector. For its elaboration, it was resorted, on the one hand, to a bibliographic survey in relation to PDP Management models, to definitions of Maturity Levels, as well as to the experience of the authors of this work in other productive sectors, contributing the definition of variables, subvariables and analysis categories that allow diagnosing the Maturity Level in the companies' PDP (Basic, Intermediate and Advanced). From the analyzed bibliography, the diagnostic instrument developed by the authors was adapted to the metalworking sector. Future works will address its application in metalworking companies located in Region 3 – Santa Fe Node, Argentina.

KEYWORDS metalworking companies, product development process, tool, diagnosis

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I. INTRODUCTION

The analysis of the Product Development Process (PDP) is of the utmost importance for companies, especially for organizations where development has particular characteristics (for example, metalworking companies that develop products on request).

The available bibliography presents models that guide the development, defines levels of maturity, proposes tools to improve the management of the PDP, but few works have been found that address the development of methodologies and tools that allow a diagnosis of the "state" of the PDP in companies or organizations.

The authors of this work, in previous studies, have addressed the analysis of PDP management in food producing companies. In order to have an understanding of the situation of the companies, since they did not have tools that allow an objective diagnosis to be made, they proceeded to develop a diagnosis methodology: numerous interviews were conducted with directors and managers of the PDP, applying a semi-structured questionnaire, and Starting from the systematization of the answers, variables, subvariables and analysis categories were created, which allow detecting the "state" of the PDP situation in companies. This diagnosis is used to determine the level of maturity of each company, which allows subsequent implementation of improvement actions in the PDP [1-3].

The present work is based on a bibliographical analysis of the Product Development Process in companies of the metalworking sector, and on the authors' experience in other productive sectors. In this way, the variables, subvariables and categories are reviewed and adapted to carry out the analysis of the companies in

the sector under study (metalworking). On the other hand, the concept of Maturity Levels is adapted according to the characteristics of the companies.

II. CONTEXT OF THE SECTOR

The metalworking industry comprises a diverse set of manufacturing activities that use steel products and/or their derivatives among their main inputs, applying some type of transformation, assembly or repair to them. Likewise, the electromechanical and electronic branches are part of this industry. This industry is a fundamental link in the productive fabric of a nation, not only because of its technological content and added value, but also because of its articulation with different industrial sectors. In other words, it is called "Industry of Industries" [4-6].

In Argentina, the metalworking industry brings together around 20,000 production establishments, distributed mainly in the provinces of Buenos Aires, Córdoba and Santa Fe, and in the Autonomous City of Buenos Aires. 90% of the national metalworking universe is concentrated in these four zones. This industrial sector is characterized by being a chain made up mainly of small and medium-sized companies that also coexist with large companies, particularly in the machinery and equipment manufacturing segment. The group of workers in the metal-mechanical complex comprises approximately 20% of the total number of employees in the entire manufacturing industry. Likewise, it represents 11.5% of the gross industrial added value, positioning itself as one of the industrial activities that generate the highest added value [7, 8].

Within the machinery and equipment category, attention is focused on the productive segment called engineering to order or project-type production system. In the companies that carry out their production under the project modality, the products are unique and respond to the specific requirements of each client. As not all product specifications can be standardized due to their diversity, the production process must be flexible in its characteristics and work capabilities, as well as the skills of the work group or project. Problem solving is achieved through adaptation, teamwork, and proper project management for a coordinated design. Most of the companies that base their production on projects apply innovation processes, since they must find technological solutions based on what the project demands, in order to develop a product conditioned by the specifications of their clients.

III. MANAGEMENT OF THE PRODUCT DEVELOPMENT PROCESS

In the current context, companies that have competitive advantages focus their objectives on the variables costs, time and quality, mainly in the PDP [9, 10].

The Management of the PDP implies the choice of a work methodology that begins with the identification of an unsatisfied need until obtaining a product that satisfies it in the best possible way. It entails carrying out a set of activities, in which the functional areas of the organization must intervene jointly. Basically, all theories of the product development process contemplate the following stages: a) conception and development of the idea, b) evaluation of the idea and selection of the product, c) development and engineering of the product and the process, d) evaluation and design testing, e) product production, f) launch and follow-up, and g) product withdrawal from the market and/or product innovation.

Throughout history, PDP Management theories have been integrated from technology-focused forms of product development to customer- and business-focused forms of product development. The interfunctionality between the areas of the organization that demand these new PDP approaches must be proactively managed.

There are several PDP models described in the literature. Among the most used, we can mention Ulrich and Eppinger (2007), Pahl and Beitz (2007), Kotler and Armstrong (2008) and Rozenfeld (2006). Pahl and Beitz focus on the engineering area; Ulrich and Eppinger, and Kotler and Armstrong emphasize the area of marketing, and Rozenfeld presents a unified analysis of both disciplines [11-14].

It should be noted that in the last decade tools and techniques from different areas of knowledge began to be implemented that allow speeding up the development processes of new products, among them we can mention the so-called "agile methodologies" [15, 16]. These methodologies arose from the need for companies to adapt and respond to change quickly, and therefore propose an iterative and incremental development approach that, in some sectors of activity, has replaced the traditional "cascade" development [17-19]. Among them, the following stand out: Design thinking, a design trend centered on the user/client, which allows extracting their real needs, and designing the product with their experience in mind; Agile (Scrum), which proposes a co-creation process through which the client is involved in the product development process, and Lean, a methodology for systematizing the validation process that any innovation requires, exposing the client to early to what is related to the design of the business model [20-22].

Based on the bibliography surveyed by the research group, at the moment Rozenfeld makes the most relevant contribution of the PDP in relation to the metalworking industries, presenting a referential model in which the process is separated into three macro phases: pre-development, development and post-development, and each of them, in phases, activities and tasks. The Rozenfeld model, which was developed for the automotive

sector, has been taken as a reference for studies in other industrial sectors. It is a unified model that is defined as a theoretical framework, to then develop various Reference Models according to the sector to be analyzed (reference model for the food, metallurgical, plastic, etc.). Figure 1 shows a synthetic scheme that presents the Macro-phases and Phases of the Model.

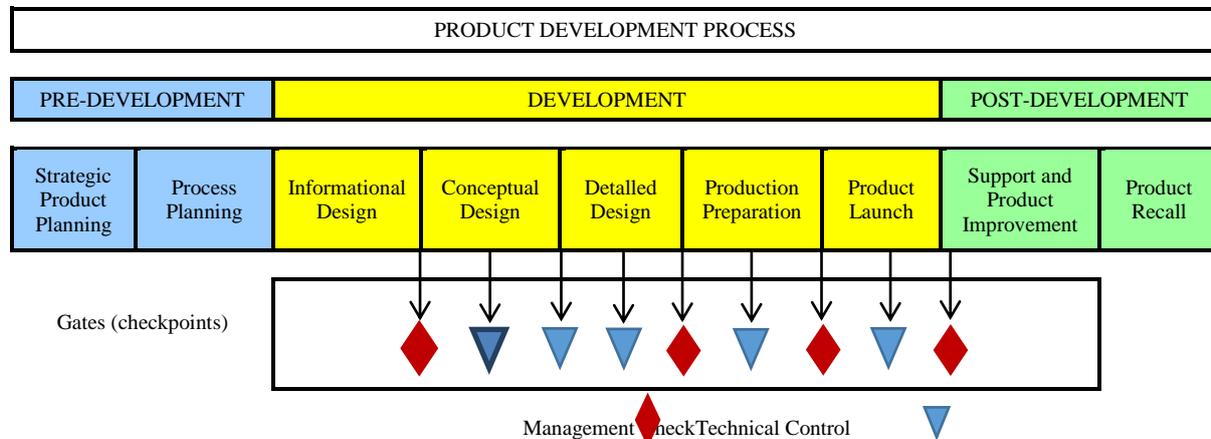


Fig. 1. Scheme of the Rozenfeld Model, showing the macrophases, phases and control points (technical and managerial)

IV. MATURITY LEVELS

The Maturity Level, following, consists of the best practices that cover the life cycle of the product, from its conception to delivery, monitoring and eventual withdrawal from the market. The study of the Levels of Maturity allows to diagnose the process of the company (current level) and guide those responsible on forms of intervention to achieve superior performance [23-25]. There are maturity models proposed by authors and organizations, which present different classification scales. This work considers the Rozenfeld Models and proposes the following classification of PDP Maturity Levels:

Elementary: Only some essential activities of the PDP are carried out. The product requirements are defined intuitively, and a product outline is made in relation to those characteristics. There is an initial integration between the strategic planning of the company and the product, although it is informal and through dialogue, taking into account the experience of those responsible. The delivery of the product is carried out with little planning and the follow-up of the product is limited to receiving possible claims. Many of the activities are aimed at complying with current legislation, and product development is not conceived as a business process.

Intermediate: The most relevant activities of each phase of the process are carried out, and repetitively. In addition to defining product requirements, prototypes are developed and evaluated (technical, commercial and financial analyses), although not systematically. The company thinks of a portfolio of products, analyzing each project in a relative way. The company begins to apply the concepts of phase approval (gates). Delivery planning is more elaborated, and some accompanying activities are carried out (comparison of predicted and actual values). The PDP begins to be conceived as a business process, and simple initiatives are carried out to improve the process, without a systematic approach.

Advanced: Most of the activities of a structured process are carried out. Product requirements are defined based on detailed studies of the client and the environment, prototypes and pilot/in-plant tests are carried out, which are evaluated in detail (technical analysis). Economic, financial, commercial and legal analyzes are also added systematically. A planning of the process is carried out and all the actions are scheduled in detail. Portfolio management is carried out in an integrated manner with the company's strategic planning. Delivery strategies are planned and follow-up activities in the market are formally carried out, appointing those responsible for product follow-up who constantly monitor key variables. The PDP is considered a core business process.

V. DIAGNOSTIC TOOL

Based on the aforementioned reference models and the concept of maturity levels, as well as taking into account the experience of the authors in other productive sectors; a diagnostic tool is developed that, defining variables, subvariables and categories, will allow determining the current situation of the companies in

relation to the PDP [1, 2, 10]. Tables 1, 2, 3, 4 and 5 show the variables and subvariables selected to carry out said diagnostic instrument, which are numbered from 1 to 18.

Table 1 presents the variable "Development Structure" and its subvariables. This variable shows the relevance that the organization grants to the PDP in terms of material structures.

Table 1. Variable "Development Structure" and subvariables for diagnosis

Variable	Sub-variable
Development Structure. Relevance that the organization grants to the PDP in terms of material structures.	1. Formalization of the Area. Existence in the organization chart of a specific area usually linked to the activities of the Development phase
	2. Composition of the Area. People involved and how the process is carried out

Table 2. Variable "Pre-Development" and subvariables for diagnosis

Variable	Subvariables
Pre-Development	3. Strategic and Product Planning. Activities related to aligning the planning of the pdp with the strategic planning of the company
	4. Analysis of the Environment. Activities related to market and company analysis to detect development opportunities.
	5. Process of Generation and Selection of Ideas. Activities related to collecting information, generating ideas for new products (or modifying existing ones) and making a selection of them.
	6. Evaluation and Approval of the Ideas. Activities related to analyzing the opportunity of the selected ideas, and their technical and commercial viability, and once approved, moving towards the development phase.

Table 3. Variable "Development" and subvariables for the diagnosis

Variable	Subvariables
Development	7. Development of the Concept and Evaluation. Activities related to the task of translating the idea into product specifications. It includes a detailed analysis of the needs of the clients and the requirements of the product, advancing in the conception of the product (including research of raw materials, supplies, manufacturing process, maintenance, preparation and use). Then, develop formulation alternatives, manufacturing processes, process parameters, and proceed to their evaluation, and finally develop the prototype.
	8. Realization and Evaluation of the Prototype. Activities related to experimentation or testing on a reduced scale (units) in workshops and their subsequent evaluation, which includes physical-chemical analysis, climatic resistance and useful life. It is done with one or several prototypes.
	9. Feasibility Analysis. From the prototype, activities are carried out that involve a more precise commercial, financial and technical analysis. Regarding costs, suppliers, distributors, customers, internal processes, among others.
	10. Prototype Evaluation and Production Preparation. Activities aimed at evaluating the useful life and stability of the product and, subsequently, standardizing and registering the product and the process, to give rise to the release of production (if applicable).
	11. Product Delivery. Activities related to the development and execution of distribution, sales, advertising and promotion strategies, among others.

Tables 2, 3 and 4 present the variables constructed from the activities carried out in relation to the PDP, which are those carried out by the company specifically related to the product development process. In this case, each activity is taken as a subvariable, and for the purposes of ordering the analysis, they are presented

according to the three macrophases in which they are usually grouped by the authors (Pre-development, Development and Post-development activities).

Table 4. Variable "Post-Development" and subvariables for the diagnosis

Variable	Subvariables
Post-Development	12. Evaluation of Customer Satisfaction. Activities related to knowing and analyzing customer satisfaction, in order to introduce improvements or optimize the product/process.
	13. Product Performance. Monitoring activities on commercial, productive aspects and complementary services, in order to introduce improvements or optimize the product/process.

Table 5. Other variables and their subvariables for diagnosis

Variable	Subvariable
Communication Internal information exchange mechanisms.	14. Gates. They are the "decision points" positioned between the critical stages of the PDP, whose objective is, after some type of evaluation, to decide whether to continue the project, introduce modifications or abort the project.
	15. Schedule. It includes the list of the terminal elements of the project with their expected start and end dates.
Communication Internal information exchange mechanisms.	16. Meetings. Grouping of people in a given time and space, with a common purpose.
	17. Information Flow. How internal information circulates in the organization. It refers to the channel used (oral or written) and the way in which the records are used (individual or shared).
	18. Documentation. Types of documents that the company prepares and uses for the PDP, including their level of standardization and their storage.

In Table 5, other variables and their subvariables are presented, which are also taken into account, to carry out the diagnostic instrument, with respect to the PDP. These variables are defined based on the activities associated with the Product Development Process.

It should be noted that each of the 18 variables and subvariables can be presented in three categories (Basic, Informal and Formal). The categories of each of the variables and subvariables defined above are presented below. Table 6 presents the variables/subvariables with the description of their respective categories.

Table 6. Variables/subvariables and their Categories

Variable/Subvariables	Categories
1. Formalization of the Area	Basic: There are no development/engineering areas or departments.
	Informal: it exists in the organization chart, secondary level: there is a development/engineering area or department (third or fourth hierarchical level).
	Formal: it exists in the organizational chart, priority level: there is a development/engineering area or department (second or third hierarchical level).
2. Composition of the Area	Basic: Unipersonal. The process rests with one person.
	Informal: There is a group of people who manage new product ideas. However, the people involved vary throughout the process.
	Formal: There is a work team that is responsible for developing, approving and managing new product ideas. The equipment is stable throughout the process.
3. Strategic and Product Planning	Basic: The company's overall strategy focuses on the experience/intuition of managers, and product development follows the same logic.
	Informal: The company has some strategic goals and tries to guide the PDP towards those goals by reviewing and updating the product portfolio.
	Formal: The strategic planning of the company considers the planning of the PDP, which allows meeting corporate objectives through product development.
4. Analysis of the Environment	Basic: There are no systematic reviews; the possibilities that the environment or the company can offer the pdp arise from experience or intuition or suggestions.
	Informal: Every certain period of time, information is collected about the environment and about the technical possibilities of the company, seeking to detect opportunities.

Formal: There is a structured analysis of environment variables (customers/users, competitors, suppliers, patents) and of the company's processes.

Table 6. Variables/subvariables and their Categories (continuation)

Variable/Subvariables	Categories
5. Process of Generation and Selection of Ideas	Basic: The generation and selection of ideas occurs spontaneously (during a meeting or sending them to the person(s) in charge).
	Informal: Meetings are held to generate ideas, and the selection occurs after relieving some general conditions (technical feasibility and commercial possibility).
	Formal: Techniques are used to generate ideas (Brainstorming, SWOT Analysis, Benchmarking) and patent research/scientific-technological advances. The selection of the ideas to be developed requires a quantitative and qualitative analysis.
6. Evaluation and Approval of the Ideas	Basic: After the selection of the idea(s), the approval is given by a voting process, based on the experience of the participants, without too many evaluations.
	Informal: Ideas are approved according to certain pre-established criteria (technical capacity, demand to meet, competing products).
	Formal: There is a standardized procedure to evaluate ideas from strategic, commercial, financial and technical aspects. The approval of the ideas is given after the analysis of the information and has a series of formalized steps.
7. Development of the Concept and Evaluation	Basic: There are no activities that link business opportunities/needs with product specifications. Once the idea has been approved, the process continues with preliminary proposals for possible solutions, to go on to the development of prototypes or directly to the production line.
	Informal: There are activities oriented both to the investigation of the needs and requirements of the product, and to the design of solutions, although they vary between each product idea and do not follow a structured sequence.
	Formal: There is a standardized procedure to advance the development of the product concept. Approval is given after a detailed analysis of the information and also includes a series of formalized steps.
8. Realization and Evaluation of the Prototype.	Basic: Some basic tests are carried out in metallurgical workshops/pilot plants and others are outsourced. Evaluation is fundamentally about observing whether results are achieved.
	Informal: Tests are mostly carried out in their own workshops/pilot plants, and they are evaluated based on a series of established analyses, but they do not follow a structured sequence. The prototype or prototypes that continue the process are fundamentally chosen based on the experience of those in charge of development.
	Formal: There are numerous standardized steps for the tests, which must be documented and developed in their own workshops/pilot plants (except for complex analyses, where the counterpart is evaluated in detail), given the emphasis on confidentiality. Experts evaluate the physical and mechanical properties of the products, counting on steps and documentation for the evaluation. Based on these evaluations, the prototype is chosen to continue the process.
9. Feasibility Analysis.	Basic: The analysis is fundamentally based on setting some costs to assess whether the final price is competitive with respect to similar products.
	Informal: There are analyzes that provide more information to decide on the continuity of development, where managers from different areas participate (commercial, production, finance) but they vary between each product and are not structured.
	Formal: There are standardized steps to evaluate ideas from strategic, commercial, financial and technical aspects.
10. Prototype Evaluation and Production Preparation	Basic: The evaluation basically consists of observing if acceptable results are achieved, and it concludes with the approval of the product by the corresponding organisms. Depending on the industry, production begins for delivery.
	Informal: Analyzes are performed, but vary between each product and do not

follow a structured sequence. In addition to complying with the regulations, other reports are prepared (registration of the product and the process, quality specifications for suppliers, etc.).

Table 6. Variables/subvariables and their Categories (continuation)

Variable/Subvariables	Categories
10. Prototype Evaluation and Production Preparation	Formal: There are numerous standardized steps for evaluation activities that must be properly documented. The experts continue the evaluation to verify that the quality of the products is maintained, and the steps and documentation involved are structured. There are standards for the approval and registration of the process and the product.
11. Product Delivery	Basic: The strategy is based on offering the product from distributors or points of sale with which the company works regularly.
	Informal: There is an analysis of the points of sale, some sales strategies (eg, advertising material and testing at points of sale) but it varies in each product. Formal: A detailed analysis of the distribution and marketing channels is carried out, and the delivery strategy corresponding to each of them is detailed.
12. Evaluation of Customer Satisfaction.	Basic: Passively. Eventually, customer complaints are received and solutions are sought, but the learning does not always turn into improvements in the process.
	Informal: In addition to receiving and dealing with complaints, information is sought through conversations with vendors or distributors, but they are informal.
	Formal: There are channels and mechanisms to assess customer satisfaction that must be completed as part of the PDP. The information is collected in a standardized way and serves to provide feedback to the process.
13. Product Performance.	Basic: Only the level of sales of the product is analyzed to decide its continuity.
	Informal: Commercial and technical analyzes are carried out comparing what was planned with the performance, but without a specific pattern or systematization.
	Formal: The product is monitored in commercial, productive and after-sales service aspects in a structured and systematized manner. Emphasis on detecting opportunities.
14. Gates	Basic: There are basically two gates, which arise out of the need to direct the pdp, without systematization: advance with the testing of ideas, and approve the delivery of the product.
	Intermediate: The process has some decision points established from experience, and although in each new development the approval criteria are enriched, there are no steps planned for its formalization.
	Formal: The decision points are standardized: there are guidelines so that they can be carried out (meetings and deliveries with planned and known dates based on the activities, necessary participants, required reports, etc.). The Gateses feed back the evaluation criteria based on each new development.
15. Schedule	Basic: There are no schedules and, on occasions, tentative dates are agreed upon; the pdp advances according to the availability of those in charge.
	Informal: A tentative schedule is agreed, but it is not documented or strictly monitored.
	Formal: The preparation of the schedule is a fundamental step of the PDP, and is usually carried out from a Work Breakdown Structure (WBS). Once established, there are people in charge of monitoring the progress of the project.
16. Meetings.	Basic: Although there may be some scheduled meetings, people meet spontaneously to resolve issues related to the pdp, usually in the course of their daily work.
	Informal: Meetings between those involved in the PDP are convened well in advance and have preparation, but are held as necessary.
	Formal: The PDP has standardized meetings at different moments of the process, they are foreseen in the schedule.
17. Information Flow	Basic: Information circulates mainly orally; records are used individually and eventually shared via email.
	Informal: Although the information circulates orally, there is a tendency to use

written channels. The records are used individually and shared (via e-mail).

Formal: Mainly written channels are used. Records are shared over the network (via intranet or cloud services).

Table 6. Variables/subvariables and their Categories (continuation)

Variable/Subvariables	Categories
18. Documentation	Basic: Only the mandatory documentation is prepared by the corresponding bodies. The documents are not standardized and there are no information storage guidelines.
	Informal: Other documents are added, in different phases (Planning, Reports of results and specific to the Analyzes carried out) that do not follow standardized patterns. The relevant documents are stored, in charge of those in charge of the process, depending on them the possibility of retrieving information in the future.
	Formal: Documents exist for most PDP activities and decisions. The formats are standardized. A relevant aspect of the PDP is the storage of information, which facilitates its subsequent consultation.

It should be noted that this research is of an exploratory-descriptive nature, and therefore, the construction of the diagnostic tool has as its main purpose, to carry out an analysis of the usual practices related to the Management of the Product Development Process, in companies of the metalworking sector located in Region 3 – Santa Fe Node, Argentina.

Once variables, subvariables and categories have been defined that will allow determining the current situation of the companies in relation to the PDP, the diagnostic instrument is elaborated. Said instrument, basically, is a questionnaire that is divided into two parts: (i) general information on the company (size, structure, type of product they manufacture, market they supply) and (ii) information on the activities related to PDP Management (grouped according to the macro-phases of the Reference Model: Pre-Development, Development and Post-Development). This questionnaire is then used to carry out semi-structured interviews and on-site observation in companies in the metalworking sector, which comply with the condition that their production is developed through projects. It should be noted that the personnel linked to product development (PDP) and the management of the company are interviewed. In this way, it is possible to fulfill the objective of knowing in depth the way in which companies carry out PDP Management (activities, information, resources and organization).

On the other hand, it should be noted that in the different stages of the product development process, companies in the metalworking sector could be applying "agile methodologies" to carry out some or all of the activities of the PDP. For this reason, at the time the presented diagnostic instrument is applied, through the semi-structured questionnaire, questions specifically associated with the use of agile methodologies are included, in order to detect which stages are developed using this type of practice, and how advanced the sector is in understanding them.

VI. CONCLUSION

The objective of this work was to propose a tool that allows analyzing and diagnosing the Product Development Process (PDP) in companies in the metalworking sector. To select the most relevant variables, subvariables and categories, to develop the diagnostic tool, the bibliographic survey, the level of maturity and the experience of the research group were taken into account. Said variables, subvariables and categories present enough breadth to reflect the current situation of the PDP in the companies under study. Then, the diagnostic tool is built, which consists of a semi-structured questionnaire, which will be applied to companies in the metalworking sector that work for projects and are located in Region 3 - Santa Fe Node, Argentina. The main conclusions are detailed below:

- A bibliographic search has been carried out regarding the state of the art in relation to the PDP in companies in the metalworking sector, as well as the levels of maturity and agile methodologies, which allowed determining the variables, subvariables and categories, which must be contemplated for the elaboration of the diagnostic tool.
- From the analyzed bibliography, it can be deduced that the use of a referential model for the PDP helps, organizes and directs the development of new products, allowing to contextualize the importance and application of the tools and methodologies linked to the Management of the PDP.
- The selected variables, subvariables and categories contribute to making the diagnosis, since they are broad enough to reflect the current situation of the PDP in companies in the metalworking sector.

- The application of the diagnostic tool will allow knowing the current situation of the companies in the sector under study, determining the different levels of maturity that they present with respect to the PDP, as well as the practices that they carry out for the development of products, tools that apply for project management and knowledge of agile methodologies.

Then, based on the diagnosis that would be obtained by applying the developed tool, it will be possible to determine the improvements to be implemented in the Management of the Product Development Process (PDP) in the companies of the metalworking sector that work by projects, defining methodologies and practices that can be internalized for systematic application. This will bring significant benefits, such as improving understanding of customer needs in the early stages of development, reducing duplication of work in the actual development stages, and making it easier to control cost, quality, and schedule during development. This would allow companies to make efficient use of their resources, as well as achieve a higher degree of work quality within the organization. On the other hand, it should be noted that the larger the organization, the greater the degree of systematization of the PDP will need.

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