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# Integrating Manufacturing in Product Development Process

## A Propose of a Method Based in Lean Startup Approach

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**Abstract.** Integrate and involve manufacturing during the product design phase brings benefits to the product development process (PDP). Although this is an old subject of studies, it continues to be a challenge in the practice of industries, and the new agile methodologies can be crucial to facilitate and reach the integration of manufacturing in PDP in an effective way. Thus, the present work proposes a method to integrate the manufacturing in the PDP, based on the practices of the Lean Startup approach. To do this, structured bibliography research was carried out, and based on the findings the method was proposed. The method is compound by two main stages. The first refers to project planning, using a visual management tool called deliverable roadmap, while the second refers to the development and evaluation of what was developed of the product. This second stage is based on the build-measure-learn cycle of the Lean Startup approach and is the heart of the method. The proposed method can fill some gaps in the traditional methods of product development, while works the two faces of integration (interaction and collaboration) between manufacturing and the project team, in a more effective and anticipated way. With the proposed method, working in short cycles is possible to reduce uncertainties during development and the need for rework, improving the development process as a whole, as well as propitiate to work with a focus on valuing and developing people.

**Keywords:** Manufacturing Integration, Product Development Process, Lean Startup.

## 1 Introduction

Design products focused on quality – functional, easy to manufacture and to assembly, reliable, environmentally friendly, etc. – is essential to guarantee the operational success of a company and your competitiveness in the current market [1]. Also, integrate and involve the others departments of the company during the product design phase, in addition to the external customers, enables the prevention and early resolution of problems, better reliability of the final product, and also better manufacturability [2].

However, what still can be perceived in practice is certain difficulty to involve internal customers in the value definition process, identification of needs, and in making decisions during the entire development. According to Morgan and Liker [3], this inability to involve and integrate the different areas in the development process makes it difficult to deliver the value defined by the external customer, creates delays, generates extra costs, and affects the final quality of the product.

Looking especially to the integration of the manufacturing sector in the product development process (PDP), according to Simões Junior [4], is essential not just to take into account the needs and limits of this sector, but also to analyze and treat these aspects as soon as possible in the PDP. And, although this integration is foreseen in the traditional development methodologies and reference models, and literature emphasizes the importance of this interaction already in the early stages of the PDP, this old theme remains a challenge in the practice of industries [5][6][7].

Despite being widely used, the traditional development methodologies and reference models used in PDP, generally have limitations because they work with very bureaucratic processes and verifications in long cycles, and nowadays has been considered not very flexible and even rigid when applied in dynamic markets [8], like the actual. As a counterpoint of these methodologies, the agile movement appeared, and its arise can be crucial to facilitate and reach the integration of the manufacturing sector in PDP in an effective way.

One of the new approaches based on agile development, which works with the promotion of early and continued client participation (external and internal clients) in the product development process is the Lean Startup. Developed by Ries [9], the Lean Startup approach has roots in Lean Manufacturing, proposed by Taiichi Ohno and Shigeo Shingo in Toyota, and can work in companies of any size, sector, or activity.

However, what can be perceived in practice is a difficulty in using the Lean Startup approach in non-software companies – despite the bibliography mention this possibility – as well as is not known how can occur the integration of an important internal client in manufactured product development - the manufacturing sector itself – in the PDP using the Lean Startup approach. Thus, the present work has as objective to propose a method to integrate the manufacturing sector already in the initial stages in the product development process, based on the practices of the Lean Startup approach.

## **2 Methodology**

The article was realized in two main stages. In the first stage, structured bibliography research was carried out in four different databases, following the Systematic Search Flow method [10]. The focus of the bibliography research was the practices and approaches used to integrate manufacturing in PDP. The found studies were analyzed, searching to evidence important aspects about the theme.

In the second stage, the proposed method was developed, based on the aspects identified in bibliography research, combined with the fundamentals and practices of the Lean Startup approach and other pertinent subjects.

### 3 The Integration of Manufacturing in PDP

Integrate manufacturing in PDP is a theme of research for a long time, being possible to find many studies, with different focuses. From the analysis of these, was possible to identify important aspects of the theme.

The definition of integration most used in found studies about integrating different sectors during the PDP, including manufacturing, is the one proposed by Kahn [11], in which integration can be split into two aspects, interaction and collaboration. The aspect of interaction refers to the structural nature of interdepartmental activities and the information sharing (phone calls, meetings, exchange of e-mails, reports, etc.), while the aspect of collaboration refers to the non-structural nature, activities related to the interdepartmental biases (collective objectives, mutual understanding, sharing of resources, etc.). Most studies focus on integration only from the point of view of information sharing, not collaboration, and in this regard, it is highlighted that collaboration represents the biggest success factor in product development and management, and not the interaction [11].

The practices most used in PDP to integrate the manufacturing in the product development process, among other things, are the creation of multifunctional teams, the use of manufacturing guidelines, overlapping activities, job rotation, simulation tools, and CAD/CAM systems [12][13][14].

Related to multifunctional teams, was found that increase the functional diversity in high levels has no effect [15] and that this increase of inter functionality may also increase the difficulties of communication and interaction between the team [16]. Thus, it is known that inter functionality can bring benefits to product development, however, it is important to highlight that the increase in inter functionality requires greater care and attention to the management and organization of the project team and the development process itself.

The use of practices linked to manufacturing guidelines, like Design for Assembly (DFA) and Design for Manufacturing (DFM), show positive interactions with the increase in performance of the PDP, but if used isolated they are not able to portray the different realities of the industrial shop floor [17][18].

About the overlapping of activities in the PDP was noted that a development process executed in an overlap way and not sequential provides better performance in quality, development of new products, and deliveries fastness [12], but also demands more careful management. Concerning the practice of job rotation between design and manufacturing, it is negative and significantly related to the effectiveness of the development process [17] and the use of simulation and CAD/CAM tools does not bring benefits in development as a way to promote integration [19].

It is important to highlight that currently different simulation and CAD/CAM tools can be found that can help to promote the integration between different actors, even allowing the joint work of people in different locations, working on the same project at the same time. However, the single-use of these tools is not capable of covering and supporting the various faces of integration.

Although the participation of manufacturing in PDP be predicted in traditional development methodologies, it generally occurs after the concept of the product was already elaborated. It means that the needs and limitations of manufacturing usually do not present in the earlier phases of the development process, to help the generation itself of the product's concept, as well as this integration also does not follow continuously in the other stages of development. The most common situation is the integration happening only at the moment of concept selection or at the end of a development phase, not in a cadenced way, but punctually. Still, few studies focus on the changes of behavior of the people involved in the project and manufacturing when facing the integration of these two sectors.

Another important aspect related to the integration of design and manufacturing, besides the stage in which the integration occurs, is related to the actors involved in this integrative process. Commonly, manufacturing integration is seen only through the presence of a manufacturing engineer in the product development process, or through the interaction of the team with this engineer in search of feedbacks, as shown in Nafisi, Wiktorsson, and Rösiö [20] and Ettlé and Reifeis [21]. However, the direct participation of the design team in the shop floor environment or its relationship with other people in manufacturing than the engineer is not usually addressed. Another point that must be highlighted is related to the learning concept, which, despite being considered an important aspect during the PDP [12], usually is not taken into consideration.

The way of planning the PDP also can influence product development. In a study to improve the integration between manufacturing and design, Carbone [22] uses planning that is not made based on activities but on deliverables. They compose the planning so that it is possible to know and visualize the interdependence between the deliverables, and the planning is presented through a visual management tool.

Analyzing the findings, it was noticed that they are mostly old studies, but that they portray practices that are still used by companies today. However, it is important to highlight that there are still other product development practices and tools used in modern companies, although they were not found in the review as a way to promote integration between the manufacturing and design sectors.

Thus, from the findings obtained through the literature review, important aspects were identified that will guide the method proposal. The use of manufacturing guidelines appeared as an important aspect for PDP, and the DFA and DFM are very useful tools. Thus, the DFA and DFM (or DFMA) concepts can be used together with other practices, as a way to assist in the integration between manufacturing and design.

It is very important that the different people involved in the project development feel safe in sharing ideas and creating a sense of understanding. Therefore, it is necessary to provide a space, in which the people of the design and the manufacturing can share and discuss their ideas, seeking to help to promote a mutual understanding, resource sharing, and the achievement of common goals.

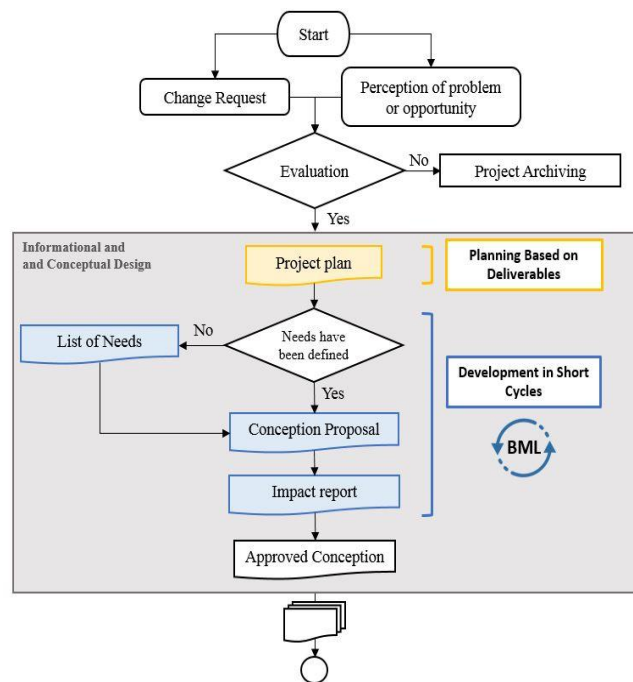
Regarding some barriers found in the promotion of integration, such as the idea of society by department, language differences among those involved, and the difficulty in the release and use of information, it was identified as helpers the use of communication mechanisms and execution of feedback cycles [20][23] and constant meetings (or interactions) among those involved [24]. Thus, it is appropriate that the method in

question foresees the participation of manufacturing during the development process in an anticipated manner, i.e., not only in the evaluation stages or in the gates between the PDP phases. Moreover, the method must continuously predict this integration, with frequent feedback cycles that promote interaction and collaboration among the different actors involved in the development. One way to work on these aspects can be with the use of the practices of the Lean Startup approach, which focuses on interaction and validation through frequent feedback cycles performed between the development team and the real customers.

Finally, another aspect to be highlighted in the elaboration of the method is related to planning, which will be based on deliverables, not activities, making use of a visual management tool. Moreover, the concept of learning will also be present in the use of the method.

#### 4 The Proposed Method

The pillars of the method developed in this work were chosen based on the aspects identified during the literature review stage, as follows: use of the manufacturing guidelines (through DFMA principles and philosophy), promotion of an integrative space aimed at developing and valuing people, work in short and frequent cycles, learning, and planning based on responsibility.



**Fig. 1.** Integration of the main steps of the proposed method (rectangles on the right, in bold) to the steps of the generic model of improvement project development.

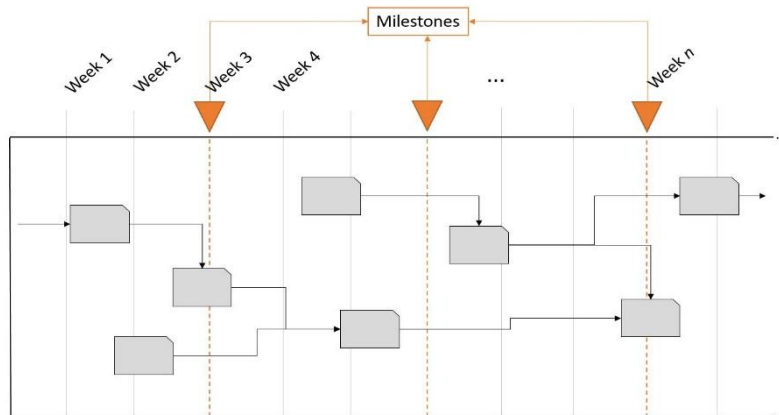
The proposed method can be divided into two main stages. The first refers to project planning, while the second refers to the development and evaluation of what was developed of the product. The structure of the method is presented in Fig. 1, in which the method is inserted in a generic model of improvement projects, created based on the traditional project development model proposed by Rozenfeld et al. [2]. This generic model served as a base to situate the stages of the developed method and to help to understand how occurs the insertion of aspects of the agile method in the traditional development methods, as well as occur the integration of manufacturing in an anticipated way during the PDP.

The first stage of the method, called "Planning Based on Deliverables", coincides with the traditional project planning stage, in which the project plan is elaborated. This step aims to adapt the traditional planning commonly used, composed of tasks and schedules, into planning based on deliverables. Besides working with deliverables and not activities, this planning should be done by the project team itself, which will define and execute the necessary actions to achieve the planned deliverables. This way of elaborate the planning creates a sense of responsibility by the project team for the plan.

To accomplish this step it is proposed to use an adaptation of the tool called deliverable roadmap (DR), which is a visual management tool for planning based on deliverables.

The main elements of a DR are project milestones, timelines of development, time lanes, learning cycles, responsibility lanes, and deliverables [25]. In the proposed method, the learning cycle was suppressed, since this aspect will be worked with the use of the practices of the Lean Startup, as well as the responsibility lanes were also removed, since the present work deals with the development being carried out by an only project team.

Fig. 2 shows the DR model used in this paper.



**Fig. 2.** Deliverable roadmap model (Adapted from OLIVEIRA et al. [25]).

The upper triangles represent the project milestones, which correspond to the main events that must happen during the project, such as meetings between teams or with



clients, management decisions, and others. Based on these milestones the main required deliverables will be determined.

The time lanes determine regular time intervals that can vary from days to years, and are represented by the vertical lines. The total timeline, which portrays the entire project development time, is represented by the horizontal line, which is formed by the  $n$  time lanes.

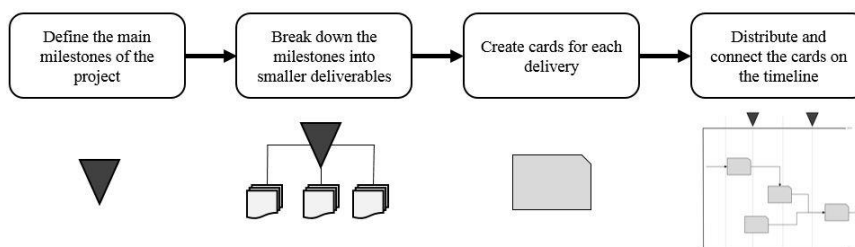
The deliverables are represented using cards consisting of three main sections: the date of the delivery, its description, and the person responsible for it. A model of the delivery card is shown in Fig. 3.



**Fig. 3.** Template of the delivery card (Adapted from OLIVEIRA et al. [25]).

The starting point for the elaboration of the DR is the definition of the main deliveries and known events, which, at first, may contain only the minimum details, to facilitate their visualization, and be detailed later [26].

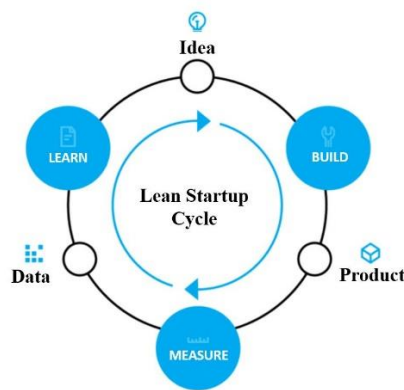
After defining the main milestones of the project, the cards should be broken down into derived deliverables, seeking to work with smaller work packages. According to Attolico [27], is necessary that these packages represent simple things, since very complex work packages, no matter how small, can difficult the work of the team in adding real value to what is being developed. Then, after analyzing the defined deliverables, the cards for each deliverable are drawn up. At this moment, the deliveries are detailed with the information on the card [25]. After the cards are elaborated, they are arranged on the project timeline, it is necessary to determine the interdependence relations between them. Fig. 4 presents the steps described for the creation of the deliverable roadmap.



**Fig. 4.** Scheme for development of the deliverable roadmap.

The second stage of the method, called "Development in Short Cycles", coincides with the traditional stages of identification and definition of needs, development of the solution concept, and evaluation of the impact and effectiveness of the changes. This stage is the heart of the proposed method concerning the objective of integrating manufacturing in the project; in this stage its try to advance and accelerate the feedback process, working with short cycles for the identification and validation of the manufacturing needs, as well as for the validation of the solution proposals. For this, we will use the build-measure-learn (BML) cycle, also known as the feedback cycle, of the Lean Startup approach.

The BML cycle is the central part of the Lean Startup approach and should be performed in such a way as to minimize the total time spent in learning [9]. The cycle can be seen in Fig. 5.



**Fig. 5.** The feedback cycle of the lean startup method (Adapted from PEREIRA [28]).

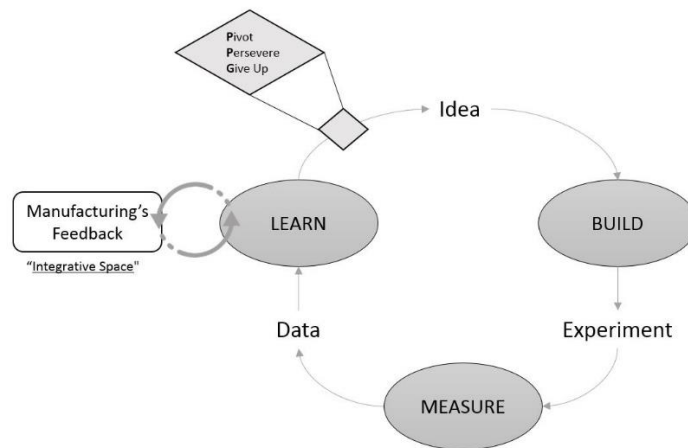
The first phase of the cycle is called "building" and begins with an idea. This idea is closely linked to the concept of hypotheses - assumptions are made and hypotheses are created, based on a vision, which needs to be "build" and tested. This construction is often related to the idea of a minimum viable product (MVP), which is the minimum version of the product, bringing the basic ideas of operation, and that can be tested in some way, allowing a complete turn in the feedback cycle, with the lowest level of effort and development time [9]. However, although the output of this phase of the cycle is called "product" and is often associated with an MVP, it is not only related to the construction of physical objects. The concept used is to build experiments, by which is possible to discover which hypotheses are true and which are not, as quickly as possible [29].

Experiments must not be performed just "to see what happens", but must have a clear and verifiable vision (an expected result), and lead to a subsequent action - a new cycle. Also, experiments should be conducted to test assumptions, so should be possible to link what is being measured in the experiment with at least one hypothesis, which means that a cause and effect relationship needs to be established [29].

The second phase of the BML cycle, the measurement phase, is related to the application of the built experiment in a real environment. Furthermore, this experiment must be monitored and measured based on metrics established during its formulation [29].

Finally, there is the validated learning phase of the cycle. In this phase, the obtained data are evaluated to find out which hypotheses are true and which are not. Depending on the results obtained, the team must decide if it must pivot or persevere on the previous idea, starting the creation of new hypotheses and restarting the feedback cycle [9][29].

The BML cycle model developed in this work is shown in Fig. 6 and will be detailed in sequence.



**Fig. 6.** BML cycle model developed for the proposed method.

The first phase of the cycle is the construction of the hypotheses and the experiment. The cycle starts with an idea (about a problem, a solution, etc.) which is based on the knowledge that the team already has, on the learnings that they have already obtained, but that can also be based on external information and knowledge, for example, opinion or needs of customers, management requests, methodological principles, philosophies, among others. In this phase, the manufacturing guidelines are used, in this case, defined by the DFMA principles and philosophies, as a way to help in the process of hypotheses building for the experiment.

The hypotheses can refer to different elements within product development, depending on what the team doesn't know yet and what it needs to learn; therefore, hypotheses can be created both to identify and validate customer needs and to evaluate possible solutions and product concepts. After the hypotheses are created, an experiment is built to verify which of them are true or not. In this phase, the integration between the design and the manufacturing sectors happens indirectly, and it is related to the use of manufacturing and product assembly guidelines, as well as the already identified needs of this sector, for the creation of the hypotheses and the experiment.

The measurement phase involves the application and monitoring of the experiment in the manufacturing environment, which should be executed in short cycles. The objective is to verify the reaction of those involved in the proposed experiment, which must be executed and measured in a way that allows the team to learn as much as possible. The integration between manufacturing and design in this phase happens mainly due to the real application of the experiment with the clients (in this case the manufacturing). This allows the involved people to have early contact with what is being thought for the product and to help through feedback in the generation of data that will be used for the creation of learning and future hypotheses.

In the third phase of the cycle, called learning, the data obtained from the application of the experiment is evaluated to find out which hypotheses are true and which are not, and from there new knowledge is obtained to restart the BML cycle. The integration between the design and manufacturing sectors in this phase happens directly. The concept is that both sectors participate in the validation of the learning, providing a kind of integrative space, where manufacturing can bring its suggestions, check or take part in the analysis of the experiment learning together with the design team. However, it differs from the idea of creating consensus for decision-making - this space seeks to help in the correct understanding of the information and the transformation of knowledge, being a way to support learning and knowledge management in the company.

After the execution of the three phases of the cycle and before the beginning of the next one, the project team must evaluate, based on the learnings validated with the manufacturing and other information and requirements of the product, the next action to be taken. At this point the project team will decide whether to pivot (change the direction either from the needs that are being identified or from the proposed concepts), to persevere (continue to develop the product and run the cycles on the same or subsequent hypotheses), or to quit (if it is confirmed that the change in question is not possible to be made at the moment). Here too the project plan can be revised, and planning changes can be made as new knowledge is gained.

## 5 Conclusions

With the development of the method in question, it was sought to fill some gaps in the traditional methods of product development, such as the difficulty to achieve an effective and anticipated integration between the manufacturing and the design team during the whole PDP, the lack of flexibility and time to respond to changes during the development.

The integration sought by this method is said to be anticipated because it engages to integrate manufacturing into the PDP in a proactive way, not reactive. It means that it seeks to anticipate the perception of problems or limitations of manufacturing in the PDP still in the early stages of the development, during the needs identification phase and before the generation of the product concept, and not only at the end, to give the final approval on what has been developed. To work like this can help to reduce uncertainties during development and the need for rework, improving the development pro-

cess as a whole. It is also important that this integration be continuous during the development phases, so the feedback cycles must be performed frequently and successively.

Furthermore, this integration is also called effective, because with the method in question the goal is to overcome the boundaries of the project team during development, making it interact and participate in the shop floor environment, with different people than the manufacturing engineer, encouraging collaboration among the different actors. This way of integrating also seeks to go beyond the mere sharing of information. It can provide the design team and the manufacturing with the opportunity to overcome the barriers of the departmental society, working with a focus on valuing and developing people, helping to find mutual understanding, sharing resources, and establishing common goals among them.

Make use of responsibility-based planning, combined with the use of a visual management tool, enables the project team to work with a focus on delivering real value, both to the external customer and to others involved in the project development, which helps the team to visualize the interdependence of deliverables and eliminate unnecessary work and deliveries. Furthermore, because the project team itself develops it, this type of planning brings a greater sense of responsibility to the members.

During the project plan elaboration stage based on deliverables, is also possible that the team can focus on other important aspects, such as the fractioning of deliverables into smaller work packages, which improves the flow and progress of the project, as well as also brings positive effects for the team, being these impacts supported by Atolico [27]. In addition, it is observed that from the use of this planning is possible to draw up a project plan based on the idea of pulled and cadenced work, as well as is possible to evaluate the aspect of workload leveling throughout the project development.

In the stage of the method related to the use of short cycles to development is also possible to highlight some relevant topics. In traditional product development the evaluation of what was developed occurs only at the end of each development phase, being characterized as work in long cycles, and many times this evaluation is validated taking into consideration only the point of view of the project team itself. In the proposed method, on the other hand, the idea is that evaluations about what is being developed are carried out constantly, with real clients, and that the validation of learning goes beyond the frontiers of the project team.

In general, it can be seen that with the method developed it is possible to work the two faces of integration proposed by Kahn [11], interaction and collaboration. More, with its use, the integration foreseen goes beyond the contact of the design team only with the manufacturing engineer, bringing interaction and collaboration among different agents of the manufacturing sector and the design team. Furthermore, by using the proposed method it is also possible to pay attention to the aspects of behavioral change of the individuals in face of the integration and of the development of people within the work environment, being these issues little addressed in the analyzed bibliography, despite being important.

From the analyses performed is possible to conclude that the proposed method can help industries to achieve the integration of manufacturing in the product development

process with the use of an agile methodology. Moreover, not only integrating manufacturing early in the PDP but also continuously, making it possible in the future to extend the execution of BML cycles to the other product development phases, until its launch. Besides this possibility, the method can also be used to integrate different sectors than manufacturing to the PDP.

Moreover, the proposed method can also help in the understanding of the application of the Lean Startup approach for the development of manufactured products, as well as provide a way to help traditional industries to start the process of transitioning their development methods towards agile. Gradually include small parts of agile development in traditional companies, like a hybrid way of work, can reduce resistance and help them to make use of other agile practices and tools more easily in the future.

Finally, it is emphasized that the proposed method is part of a larger study. The method continues in development, and it is being prepared to be applied in a real industry environment to verify and evaluate the perceived and highlighted potentials.

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