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Product development methodology "scalability"

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Abstract

In industrial manufacturing environments, where production requires a detailed product development, delivery times to customer are highly affected by the time required for development. Usually, product development takes long before arriving to the final solution Therefore, an improvement of the product development process can imply a very high potential in reducing the product delivery time to customer. This paper outlines a new product development methodology, based on the foundations of collaborative design and lean and agile methodologies. For that, we analyze and optimize the value stream of the product engineering process flow in a company of the sector of design, manufacturing, and commercialization of equipment in retail, through lean tools, to implement the "product scalability" concept. The case study shows a reduction of the product development lead time around 10-20%, regarding the present process, in the pilot tests conducted. Consequently, product development methodology "scalability" could have an enormous potential in reducing lead time and product development cost, in sectors with similar characteristics in terms of number of product variants and life cycles than the development of furniture and equipment for retail sector.

Keywords: Scalability; Product Development; Methodology; Collaborative Design; Agile; Time to Market; Retail

1. Introduction

A huge number of approaches to the effective management of product engineering have emerged, but most of them have been instigated in high-volume industries, such as automotive manufacturers. Moreover, product engineering is a complex undertaking and characteristics of low-volume industries make difficult the implementation of these approaches in their own context [1]. In addition, the average age of the product engineering models as stated in [2] is of 24 years.

Collaborative design and Lean methodologies have been researched during decades. Although the Lean culture can be applied in many business areas, it has scarce success outside the production and logistics processes, where deep research has been made and it is clearly understood by the market. However, applications in product engineering processes are not so obvious. This is because product development has been always referred as a creative activity, which was traditionally considered not measurable and in which improvements are thought related to the talent of the engineer.

In addition, product engineering differs, at least, in two ways from manufacturing. First, the input and output of the process is not a product itself, but information. Secondly, variability and uncertainty is higher in product engineering than in manufacturing [3].

Despite this paradigm, when Lean principles are separated from its productive aspect, its application allows to create methodologies which make possible disruptive improvements in product engineering processes.

On the other hand, the recurring term "collaborative product design" usually refers to a product design created by the collaborative contribution of industrial design and engineering design. In corporate contexts, collaborative product design involves a series of design activities [4]. This methodology is usually utilized in brainstorming processes or new products generation, where several professionals, from different organizational areas or organizations, work closely during the briefing and definition of a new product.

Nowadays, market situation asks for an intensive use of engineering resources and time due to the complexity of

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materials and processes involved in the type of products. The huge variety of materials and processes to manage, makes not possible that the product engineer responsible for the engineering process possess the full knowledge and all the expertise required to develop the most optimal product [5].

A great range of functions are involved in the formulation of the specifications, but the production departments are frequently not involved [1]. In this sense, the principles of collaborative design could be used to optimize the demand of resources to engineer a product, due to the cooperation with other areas, such as manufacturing area or quality area.

This new paradigm implies collaboratively engineering the product and the required documentation for manufacturing. Communication may cause problems in collaborative design as participants have different backgrounds and, therefore, different perspectives. Moreover, participants come from different areas within the company, which may lead to contradictory responsibilities. [6]

The increased demand of engineering resources in some sectors is especially true in the shopfitting of retail sector (furniture and equipment), mainly due to three factors. First, customers are attracted by the design of the shop. Second, client brand identity is also built through the appearance of their shops. And third, retail sector requires a continuous adaptation of stores to the changes in the needs of final consumers [7]. In the past, shopfitting was much less important and consisted mainly of installing shelves, counters and other basic fixtures that were necessary to store and display the retailers' goods. So that, standard product could be used for it. Nowadays, most retailers require smart, creative, modern, fresh, and attractive presentations for their products.

Above characteristics lead to a very short cycle life for furniture in shops; to an enormous customization of the equipment according to client brand identity; to an increase of complexity of the equipment; and to a wide range of product variants. In addition, as design is becoming a critical issue in retail sector, most of the time in projects is spent in concept decision, leaving much less time for the phases after, and, therefore, product engineering delivery times must be reduced.

All these reasons make the shopfitting in retail sector a very interesting environment in which to develop and test a new methodology to reduce lead time of product engineering.

This paper introduces a methodology based on scalability which pursues expending just the required effort and time in engineering to get what the customer needs and is ready to pay, reducing as consequence the lead time to develop the product. This methodology lies on the application of added-value and waste reduction principles, which are specific to Lean, to the product engineering processes and on the principles of collaborative product design. This paper also provides a pilot test for each scalability level, results and conclusions, that shows a clear reduction of the total time invested by product engineering and, therefore, of the final lead time of the product development.

2. Scalability Methodology

2.1. Scope for this methodology

The initiation stages of projects are frequently cited as an area which is unsatisfactorily managed by companies. The research has shown that combination of a wide variety of variables influences the most appropriate project approach in each case, for instance, in terms of the degree of integration required between functions and disciplines. [1]

Product engineering can be hardly explained from a mono-disciplinary perspective. In Figure 1, the process flow for the delivery of a new product from customer specifications is shown.

During these phases, different sub processes, which are led by the different functions of the organization, take place. This methodology rethinks the way functions intervene. This process flow is not considered anymore a linear flow [4] in which the output of one process is given to the next function to be used in next process. Instead, functions contribute to the sub processes according to the added-value brought to the output.

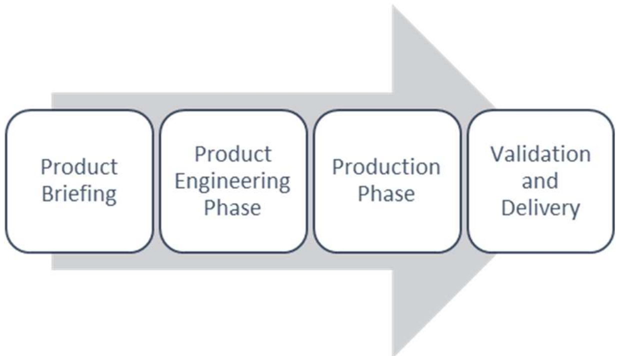

Fig. 1. Process Flow for the delivery of a new product.

Even though scalability has no generally accepted definition, this term usually transmits the feeling of efficiency [8]. A possible definition of scalability, in this context, is the "capacity for adding or removing resources in a cost-effective manner, in order to adjust the capacity on a system in steps or stages" [9]. These are the main reasons why this term fits perfectly to this new product engineering methodology.

2.2. Scalability levels (SL)

The methodology described in this paper is founded in two prerequisites for manufacturing. First, the information must be enough to define completely the product and to fabricate the product. And second, all the organization must be aware of the scalability level, to engineer and fabricate the product following the correct process in each case.

The base is the definition of scalability levels (SL). This paper standardizes 3 SLs according to the level of detail in the definition of a new product before production launch, and the type of documentation released to the manufacturing area.

The aim is not avoiding the definition of the product by the Product Engineering Area, but to balance by whom the decisions about the design will be taken: product engineering area (PEA) or manufacturing area (MA). This balance will rely on some parameters of the product and the project, and on the added-value contribution of each area. As several studies in product engineering processes reveal, involving the right people in the process from the start, after clarifying their roles, responsibilities, and ownership, improves the result [10], [11]. Another good practice is to eliminate the need of releasing information that is not needed. [12].

The level of detail for design, as referred at the beginning of this section, is related to how deep the constructive solutions of the product are defined and which restrictions to the design are established for the decision taking in MA [13]. For instance, for a table, if low level of detail was chosen, PEA should define general dimensions, number and general shape of the legs (central leg with circular shape), and the materials for top and legs. All decisions not limited by previous specifications (for instance, diameter of the central leg or the way it is fixed to the top) will be left to MA, which will apply its experience and knowledge. In the case of high level of detail, PEA should define every single detail of the table, and MA would receive all the drawings and specifications clearly defined, with no freedom for decision.

From the information processing perspective, product engineering can be considered as a process for information collection, creation, interpretation, transformation, and transfer [5]. Depending on the level of detail decided, the type of documentation will vary. In the first case, a simple sketch with comments will suffice. In the second case, it is required a CAD-CAM file, a comprehensive BOM, manufacturing drawings fully dimensioned with tolerances, and the list of manufacturing operations. As a result, under scalability methodology, documentation to be able to produce the product with sufficient level of quality, is linked to the SL applied.

In addition, SLs are incremental [1] and cumulative, meaning that level of definition is increased as SL is higher, and that the documentation released in each level is accumulated to the one generated in the previous SL, supplementing and broadening it.

As a conclusion, the scalability methodology for product engineering process can be explained as though we were building a scalable machine tool. This scalable machine tool is a kind of modular machine, where the equipment modules (additional definitions of the product and documentation) can be added to a base machine structure (SL1), and latter rearranged or replaced as required, providing the machine scalability (SL2 and 3). [9].

2.3. Decision Matrix for SL

The criteria to apply to select the level of scalability are four:

- Level of maturity of the product, related to the level of definition of design. Some new developments are just a change in an existing product (dimensions, materials…). In others, customers know that they want a new product but not exactly with which specifications. Therefore, they require a prototype to touch and feel and take decisions about most of the aspects of the design. In this case, the target is to fabricate quickly a first unit to take these decisions, and later, adjust the design and engineering of the product.
- Degree of complexity: the complexity of the product engineering process correlates with the complexity of the product being developed [5]. This criterion refers to the complexity of the constructive solutions required in the product, to the complexity of the solutions to satisfy the required function, to the number of subcomponents that interact in the design, and to the number of different materials involved in the design, among others. There are two main approaches to measure complexity. One is to consider the perception of complexity of the workers involved. The other is to measure objective complexity using objective process factors that are independent from the people involved [14]. Regarding complexity, in this methodology is used a combination of both approaches. On one hand, complexity for the decision matrix is considered through number of subcomponents and elements. On the other hand, the final decision on the degree of complexity lays on the product engineer because the humans involved, and their perception of complexity cannot be neglected.
- Level of repeatability expected for the project: this is related to the number of times that this product is going to be ordered in different projects. In the case this product will be used in a unique project or in maximum three projects, it is considered as low repeatability. On the contrary, if the project is going to be used in more than three projects, it is considered as high repeatability.
- Batch size: this refers to the size of the production batch or number of units per project. It is considered as small batch size when the number of units per the project is less than 10, and a large batch size when it is over 10.

Given these four criteria, the decision matrix of Table 1 is used to define the SL to apply to the product. Once the SL for a single product is decided, a specific methodology is applied depending on the SL.

Table 1. Scalability Level (SL) Decision Matrix.

		High Complexity		Low Complexity	
	Repeatability / Batch size	Large	Small	Large	Small
HIGH MATURITY	HIGH	SL3	SL3	SL3	SL2
	LOW	SL3	SL2	SL2	SL1
LOW MATURITY	HIGH	SL2	SL2	SL2	SL2
	LOW	SL2	SL2	SL1	SL1

2.4. Methodology for SL1.

Figure 2 displays the main sub processes which take place during the two main phases of Figure 1. The leader of these subprocesses and the way they are conducted is the innovative contribution of this methodology.

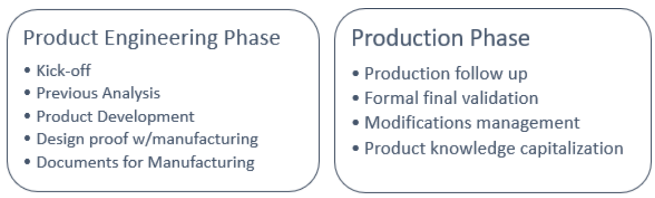

Fig. 2 Main subprocesses in product development and production phases

Despite the level of scalability, activities are the same; differences lay in the roles of each area and the specific output in each sub process.

In scalability level 1 (SL1), PEA defines the main dimensions, materials, and finishing of the product. If additional restrictions to the design shall be included, it would be possible, without increasing the SL, through the product file. The minimum documentation in this SL is:

- 2D, schemes or photographs with dimensions, materials, and finishing. Neither tolerances, nor welding indications are usually included.
- Product file: it includes all the fixed specifications defined by PEA which cannot be modified by MA.

Additionally, in SL1, subprocesses of Figure 2 are deployed as follows:

- Kick-off with MA is a key subprocess, in which PEA explains a briefing about the product to MA. PEA sets the level of definition that MA is going to receive, and all decisions are formalized. When using SL1, Kick-off and previous analysis subprocesses merge in only one.
- Design validation with MA is also highly critical because MA will take decisions about design. In this way, MA is responsible for the constructive solutions for the degrees of freedom assigned in the kick-off and PEA is responsible for validating the solutions.
- During daily review in production, PEA solves blocking points emerging during production phase, through a no-wait inquiry solving system and also validates the decisions about design taken by MA during the production phase.
- Final formal validation subprocess by PEA is crucial to assure that all constructive solutions are valid for the customer and fulfill functional requirements.
- Design modifications management is not managed through the standard procedure but carried out directly between the product engineer and the production team assigned to the product.
- During know-how documentation, PEA must invest more time than in other SLs. The aim is to compile all the know-how generated during product engineering and production phases.

Indeed, this SL oblige a close cooperation between PEA and MA and represents a clear collaborative engineering example. Design decisions are shared between PEA and MA, which may result in reduced product engineering lead time.

2.5. Methodology for SL2

In scalability level 2 (SL2), PEA engineers the product in more detail. Therefore, when the product is launched to production there are very little degrees of freedom. All the constructive solutions to fulfill functional and geometrical requirements are defined and a complete 3D with all the details is produced. The time and complexity reduction in PEA in SL2 are based on the use of a basic drawing or 2D, a simple BOM and an elemental manufacturing operations routing. The information included in the 3D is enough for production and it is used during all the production phase.

The minimum documentation in SL2 is the following:

- Full 3D with all details for constructive solutions.
- CAM manufacturing files.
- Basic 2D, to give a general idea and facilitate the access to the rest of the information in the 3D. It also includes list of materials and tolerances of critical dimensions.
- Basic BOM: only purchased components and basic raw materials are included, in order to enable supply.
- Full operations routing, with estimated times.
- Comprehensive product file, which is more exhaustive than in SL1 as the product is defined in a higher level of detail. It includes the specifications from the PEA in issues relating materials, types of welding, constructive solutions, type of finishing, ironwork.
- General control plan resulting from the risk analysis of the product.

If SL must be risen from SL1 to SL2, most of the product definition and documentation made for SL1, will be reused. Therefore, SLs are incremental and accumulative.

Main differences between SL1 and SL2 are based in the way the subprocesses are conducted. The main differences are:

- Previous analysis subprocess between PEA, MA and experts lead to agree the constructive solutions to be applied in the design. All decisions will be implemented in the 3D and in the product file. So that degrees of freedom for decisions in MA are drastically reduced.
- Design validation with MA has a different function than in SL1. Decisions about design has been taken by PEA after previous analysis and, hence, design validation with MA is used to validate feasibility of the solutions.
- Production review subprocess is made under demand of MA and there is no periodical follow-up. MA leads intermediate validations using 3D information, product file and standards already defined.
- Final formalized validation is only made in first production to formalize know-how for further batches.
- Design modifications are managed through the standard process.
- Know-how documentation subprocess requires much less dedication of PEA. The aim for this phase is to register improvements identified during the production.

In SL2, a narrow cooperation between PEA and MA is kept, however, PEA is who takes most of the decisions about the design. Time saving in PEA is translated in an increase of the required time of MA for understanding the documentation. However, the implementation of new technologies in MA, such as 3D visualization devices, compensates enormously this increase in time. As a whole, there are important savings.

2.6. Methodology for SL3

SL3 is the traditional way of working, but with some improvements. Product is fully defined by PEA and, consequently, MA becomes extremely efficient. PEA releases a 3D with all its elements and subcomponents, a very detailed 2D, a tolerances analysis, a comprehensive bill of material and routing, a validation plan for prototypes and a control plan per subcomponent. As a result, quality will be uniform for all the units produced of that product

To maintain cooperation between PEA and MA, some subprocesses have been redefined. Therefore, main particularities of SL3 regarding SL1 and SL2 are the following:

- Kick-off, previous analysis, and design validations with MA subprocesses are preserved so the best product in all senses is engineered. The leading and responsibility lays on PEA, but the result takes the advantage of counting on the experience and know-how of the MA.
- Concerning intermediate and final production validations, control plans defined by PEA must be used. Nevertheless, an open line with PEA is still kept open.
- SL3 should not require know-how documentation. However, it is maintained to assure that any improvement found during production is integrated in design.

Lead time for product engineering phase in SL3 raises considerably and, therefore, this level of scalability should be used only in real necessary cases in which quality among parts and batches must be assured and production efficiency due to size of batches and repeatability is key to be cost effective.

3. Pilot test

This methodology is being tested in an organization dedicated to design and manufacturing of equipment for retail, where number of product variants is really high, and life cycles are extremely short. This organization will be referred to as ABC throughout this paper due to non-disclosure requirements.

ABC develops over 10.000 selling references per year. In addition, ABC employed in 2019 more than 150.000 hours of engineering in new products, with a lead time of 25 days, in product engineering phase, and 15 days, in production phase.

The prerequisites to sustain successfully in tough competitive marketplace in shopfitting of retail sector is higher product quality, lower cost and, overall, lower lead times. Therefore, reducing the lead time to 10 days for both phases and reducing the total hours dedicated to engineering and manufacturing of products are among the main targets of ABC. This target requires a disruptive improvement through the application of a new methodology.

In ABC, in 2019 and 2020, nearly 50% of the references are only produced for one project, 55% of them can be classified as low complexity, and more than 50% are produced in small batches (1 or 2 pieces per batch). Therefore, the references of ABC are particularly suitable for SL1 and SL2.

The standard product engineering process for all references is the complete one: every detail is defined by PEA and the full documentation is made. MA receives no information about the new product until prototype or final production is launched. In conclusion, there is no interdepartmental interaction between PEA and MA. As revealed by many authors, this is the standard in most of the companies [15].

Under these boundary conditions, the scalability methodology has been tested and section 4.1. presents the results of one pilot test in SL1 and another one in SL2.

3.1. Pilot tests applying scalability methodology

This section presents the results of one pilot tests made in SL1 and one pilot test made in SL1.

Time dedicated by PEA and MA in product engineering process has been measured during the test, and then, compared times in SL3. Whereas times indicated for PEA is total time (as the whole time is dedicated to engineering activities), times indicated for MA are the increase of time due to additional tasks related to SL1 or SL2.

3.1.1. Pilot test 1: SL1 – Low complexity, low maturity, small batch size, low repeatability.

This test was applied on the drawer unit shown in Figure 3. This product has low complexity and low maturity (customer did not know how he wanted to solve the main design issues). In addition, this drawer unit was a one-piece batch with no repeatability. According to decision matrix, SL1 was applied. Times measurements during the test are shown in Table 2.

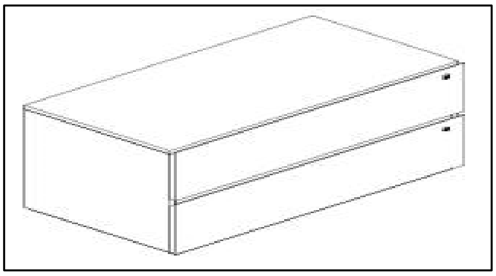

Fig. 3. SL1 Pilot Test: Simple Drawer Unit

Table 2. Engineering times per phase for LS1 Pilot Test: Simple Drawer Unit.

	DEVELOPMENT PHASE (hours)		PRODUCTION PHASE (hours)		TOTAL TIME (hours)		
	PEA	MA	PEA	MA	PEA	MA	TOTAL
LS1	3	0	1	4	4	4	8
LS3	10	0	0	0	10	0	10
Delta	-7	0	+1	+4	-6	+4	-2 **(-20%)**

3.1.2. Pilot test 2:SL2 – Low complexity, high maturity, small batch size, high repeatability.

This test was made on a simple wall unit with doors, as shown in Figure 4. It is a product with low complexity, high maturity, one-piece batch but, in this case, high repeatability, as it is part of a rollout. According to decision matrix, SL2 was applied. The study of times made for this test is shown in Table 3.

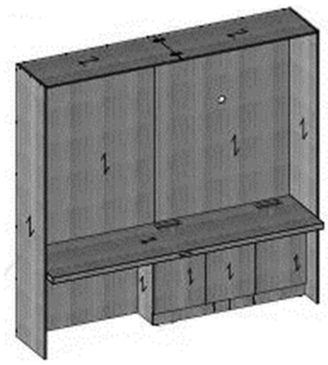

Fig. 4. SL2 Pilot Test: Simple wall unit with doors

Table 3. Engineering times per phase for SL2 Pilot Test: Wall unit w/ doors.

	DEVELOPMENT PHASE		PRODUCTION PHASE		TOTAL TIMES		
	PEA	MA	PEA	MA	PEA	MA	TOTAL
LS2	21	0	2	1	23	1	24
LS3	26	0	1	0	27	0	27
DIFF	-5	0	+1	+1	-4	1	-3 **(-11%)**

4. Conclusions

Both pilot tests show a significant reduction in the total time for product engineering compared to traditional methodology. Whereas test of SL2 shows a reduction around 10%; SL1 test shows a reduction of about 20%. In both cases, the rise of MA's time due to the new responsibilities assigned has been considered in these data and is clearly compensated by the reduction of time in PEA.

Therefore, both engineering costs and lead time in product engineering process and, consequently, in the whole process, could be reduced significantly thanks to the application of scalability methodology for product engineering in sectors with similar characteristics to the one of the pilot test.

On another level, both tests revealed that the implementation of this methodology requires a cultural change on the whole, and not only in the areas involved. An initial total rejection in PEA, MA and other satellite areas was detected despite the good results. Mentality change for implementing this new methodology requires the reassessment of the distribution of responsibilities of the processes, which must flexibly change from one area to another, depending on the type of project / product. This means an evolution from "departmental behavior" to "global improvement".

Equally important is the finding that the implementation of this new methodology also requires a digital transformation in MA. Among other examples, for instance, SL2 requires that production workers access to 3D information in digital format. That requires that MA has means and training to access this information and manipulate it correctly.

Finally, to apply this methodology efficiently, professional profiles in both MA and PEA must evolve. On one hand, even if the drawing capacity will continue being necessary in PEA, the importance of the ability to define the product and the ability of communication is dramatically increased for product engineers. On the other hand, MA requires workers with the ability to take decisions about product engineering issues.

This methodology shatters many paradigms regarding product engineering. For instance, product engineering process has always been considered a role to be played by PEA, which delivers all the required documentation for manufacturing a product to MA. Scalability blurs the limits of the roles played by PEA and MA in product engineering. Pilot tests show that this new assignment of responsibilities in subprocesses is translated into a better utilization of the knowledge and abilities of each area, and into a reduction of wastes and waiting time in the product engineering process.

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