INCLUSION OF LEAN CONCEPTS AT INITIAL PHASES OF PRODUCT DEVELOPMENT PROCESS

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Abstract. *Globalization demanded products to achieve better quality, accessible costs, and at the same moment, to fulfill customer´s higher expectations. Due to this situation, product development faced a crucial demand to be more effective in terms of design and economically, complying with shorter product lifecycle. "Lean Design" is a new approach to Integrated Product Development that proposes simplification and reduction of process bureoucracy by considering concepts of value streamming, team working, delaying of key decisions and also experimentation and learning. This paper proposes an application of Lean Concepts derived from "Lean Design" to an appropriate systematization and a well-known methodology to update Product Development Process (PDP). The first part of this work introduces Lean Design concepts. In the next part, a PDP review with inclusion of Lean Concepts is presented.*

Keywords*: Lean design, product development process, integrated product development.*

1. INTRODUCTION

Globalization resulted into higher competitivity between enterprises, demanding products to achieve better quality, accessible costs, and at the same moment, to fulfill customer's higher expectations. As a result, one new approach to integrated product development (IPD) known as "lean design" (LD) appeared recently. Although it considers practices very close to the traditional IPD, it differs by proposing simplification and reduction of process bureaucracy, by considering concepts as value streaming, team working, experimentation and learning, and delay of key decisions until the last possible moment to comply with shorter product lifecycle, avoid raw material waste, unnecessary work in assembly line and project changes after start of production.

Being a new and not so much explored approach, makes lean development very useful to update PDP, fitting it to customer's new requirements through a review of state-of–the-art methodologies for IPD and also by applying these "lean" concepts (LC) in the early stages of PDP.

LD in its actual stage requires a systematic approach, as it is mainly described in a philosophical way, without an appropriate systematization and a well-known methodology, leaving a gap in this field of knowledge that must be filled to update PDP in terms of market's recent changes in social and economic affairs due to globalization.

To achieve this update, it is extremely important to consider Lean´s five main principles in a review of a reference model of PD, to simplify this methodology process and also to promote continuous improvement according to LC.

Along with these objectives some tools originally designed to Lean Manufacturing (LM) should be adapted to PD and also be part of the methodology review proposal in order to provide new techniques to guide PD into a new level.

In a PD environment, LC could be interpreted in a slightly different manner of manufacturing interpretation. Although LC are fully consolidated at manufacturing, these concepts still have less influence in PD. That makes a practical application of tools essential to enable the inclusion of LC at early stages of PDP. According to this proposal, its objective is to consolidate "lean" in PD so that IPD gets update to the latest requirements generated during globalization - by redesigning LC and "lean" tools into a state-of-the-art methodology for IPD and also through a process review of the chosen state-of-the-art methodology according to Lean Principles, driving product design to a logical process of incentive to research requirements, resulting into customer requirements integrated to a higher-quality, lower-cost product.

2. LEAN DESIGN

In order to understand and acquire deep concepts about lean, a brief theory of LD philosophy will be presented. According to Mascitelli (2004), lean has a specific connotation: the act of eliminating non-value-added waste throughout an organization to enable higher productivity, increase profits, and improve overall competitiveness.

Machado (2006) contributes with lean definition stating that besides eliminating waste, lean also focus on value creation. According to him, both waste elimination and value creation are essential elements that lean thinking must have. Focusing only at waste elimination is not enough and may not result in sales revenues forecast.

Lean's theories and activities targets at flow of activities that adds value, at the same time that it tries to eliminate waste to achieve customer's requirements accurately, with better quality, lower cost and before deadline. Murman, et al.

(2002) defines lean thinking as a dynamic process - guided by knowledge and focused on customers – which helps all employees of a company to eliminate waste to cre ate value.

As a dynamic process, these concepts are in constant evolution. The word kaisen, or development upgrade based on all employees acknowledgeme nts, from managers to laborers, and not limited to specialists, evolves learning through practice, using process thinking to achieve a continuous flow of improvements.

According to Womack et al.(1990) five main prin ciples are essential as a guide to lean enterprise:

- Specify value: Define exactly customer's problem and identify functions that should be done to solve it.
- Identify value stream: Identify the quickest process to integrate functions defined to solve customer's problem into a high quality, low cost product .
- Flow: focus on the effort to reduce unnecessary or even recurrent items or features to optimize a product.
- Pull: means to enable customer to get his opinion heard frequently along the entire PDP.
- Strive perfection: is the action to include tools and methods to reduce cost in business practices and even on life style to open a possibility of a continuous cost reduction.

Specify value

This is crucial to get a clear understanding of what customer needs really are - at a specific price and also at a specific time – providing improvements that solve each barrier to achieve customer needs. This principle is a way to establish good opportunities of improvements at initial phases of product development. For example, under this principle the redesign of some procedures of a reference model of PDP or tolls adapted from LM can promote reduction of waste on information, as will be described at Set -Based Concurrent Engineering tool.

Another useful tool is Value Engineering, which helps to achieve this principle because it emphasizes the focus at the search for converting customer's desires into produc t features with the right price and quality. And this tool also helps to separate all conflicts of requirements for a new development that exists between shareholders and managers that may diverge from customers.

Identify value stream

When customer's requirements are identified, a process must be done to release these requirements to market in the form of a new product . Time to market is the main thing at PDP, so that a lean and efficient process is critical to sustain competitivity. Achieve these lean an d efficient process demands continuous effort to improve it , that´s the reason to use an adapted Value Stream Mapping (VSM) to PD.

To help improving this process of key requirements conversion to a successful product, Womack and Jones (199 6) classified tasks as three major fields that can be applied to any business.

- Problem-solving task: From concept through design and engineering to production launch;
- Information management task: From order -taking through detailed s cheduling to delivery;
- Physical transfor mation task: From raw materials to the finished product of the customers;

The key to a value stream analysis is to focus the entire value stream for each product or product family, beginning from the first supplier in t he chain up to the ultimate customer. For this process, synergy and transparency between suppliers are key elements to synchronize value stream activities between companies.

During value stream analysis, all activities are classified according to one of the three categories proposed by Moden (1993). These are Value Adding (VA), Non Value Adding (NVA) and Necessary but Non Value Adding (NNVA). The latter two categories identify all the waste in the system. But as Monden's categories were originally developed for the manufacturing shop floor, these definitions have limited applicability within the PDP domain. So the following interpretation proposed to administrative domain by Francis (2004), was therefore applied.

Value Adding (VA)

This type of activity directly results in the accrual of va lue in the eyes of the final customer. In a car production , VA activity is that considered essential with regard to the quality of paint. It is that activity which is unthinkable not to be conducted in any future state scenario.

Non Value Adding (NVA)

It is any activity that clearly creates no value and probably adds cost. NVA can be removed immediately with minimum or no capital investment and with no detrimental impact on end value. It is also characteri zed as having a minimum impact effect if removed. Th is is classified as "Type Two Muda" by Womack & Jones (1996). It is pure waste and should be targeted for immediate elimination. For example, documents in a departmental intray awaiting attention.

Necessary but Non Value Adding (NNVA)

Any activity which creates no value but is unavoidable given the current operating constraints of technology, production assets and operating procedures of the system under examination. This is 'Type One Muda' according to Womack & Jones (1996). For example, the physical movement of documents between departments. This activity will ideally be eliminated in the long-run but it is envisaged that this will require capital investment and/or reengineering activity.

Flow

According to Bauch (2004), after specifying value, mapping value stream and eliminating non-value adding activities, the next step in lean thinking consists in making the value-creating activities flow.

At manufacturing, Flow principle is stated by Lean Enterprise Institute as "Producing and moving one item at a time (or a small and consistent batch of items) through a series of processing steps as continuously as possible, with each step making just what is requested by the next step".

According to Womack & Jones (1996), the target of the flow principle consists in redefining the work of functions, departments and companies in a way that they positively contribute to value creation and to meet the real needs of the process participants at every point along the value stream so it is actually in their interest to make the value flow.

Make value-creating flow in a lean design context means to focus on a profitable and efficient PDP. Considering manufacturing process while designing is vital to reduce waste and cost. Tools like Seven-Alternatives process, proposed by Mascitelli (2004), are a useful way to improve this principle at PDP, as it proposes to generate alternatives to manufacture high-cost design element along with PDP activities. Another opportunity of application of this principle is the adoption of a general book of tolerances for each process made by Process Engineering to guide Product Engineering teams during new PD, initial tasks of a new PD developed under the same room with many of the stakeholders, and also intensive utilization of prototypes not to check solutions, but to choose different sub-systems and check their integration.

Pull

Get customer's opinion heard can improve significantly a project, by achieving higher performance or revealing ways to reduce costs. This principle is essential in product development.

At manufacturing Pull principle is a method of production control in which downstream activities signal their needs to upstream activities. Originally it strives to eliminate overproduction as a downstream operation provides information to the upstream operation about what part or material is needed, the quantity needed, and when and where it is needed. Nothing is produced by the upstream supplier process until the downstream customer process signals a need. This is the opposite of push production.

Battaglia, et al. (2005) stated that also at PDP there must be a guarantee to flow information and knowledge with Takt time. Takt time in a PDP context means to deliver information and knowledge at the precise moment that it is required or synchronized with demand.

Pull principle at PDP is a way to guarantee that the correct information could be delivered at the right moment, on the right place and at the precise amount needed. Besides, in a customer-enterprise environment, it also guarantee that a product will deliver only features that customer requires - and pay for.

Strive perfection

Finally this last principle states that despite of all importance of tools at PDP, they are not enough and requires a conscious cost reduction culture at the enterprise. Process and policy do not substitute initiative and team work, besides, there is no process shortcut to reduce cost.

Lean is not a one-time movement, it requires continuous improvement so that all process becomes constantly outstanding. As a consequence of improving constantly these principles, the design team will begin to identify new ways to interact with customers.

These principles identified by Womack are excellent to understand what is LD and all the philosophy behind it. Anyway, it is necessary to apply these principles at PDP.

According to Battaglia (2005), most part of success of TPS (or lean manufacturing) begins at phases that precedes production. Although lean is consolidated at manufacturing, these concepts are slowly migrating to offices, without too much influence at projects.

Mascitelli (2004) makes a proposal to product design that includes lean principles. It consists into a series of tools organized to be applied according to three stages of maturity. This author highlights that these tools should be used as soon as project begins and presents as benefits of LD cost reduction at PDP and at product final cost. Anyway, besides cost reduction, it is important to say that lean development opens more possibilities to get benefits as shorter development time, higher quality levels and higher competitivity.

Practices are very close between IPD and LD, but lean proposes to simplify and reduce process without value and give emphasis at experimentation and learning. In addition, there is also more concern to use team working, intense use

of prototypes and tests, interaction between conceived models and manufacturing models - including tools to evaluate this interaction that contributes to reduce errors at project's advanced phases.

To demonstrate with more clarity the chances of update in the IPD using LC, two of the tools cited for Mascitelli (2004) will be presented. The first one was proposed by Toyota and described by Sobeck, et al.(1999), where concurrent concepts in some phases of the PDP are created, but before choosing the best solution these conceptions are taken to Detailed Design to get more information that reduce the uncertainties in the decision taking process. Known as SBCE, the tool stimulates discarding of concepts after the phase where traditional processes of PDP normally choose the best concept. In some cases, the refinement of these concepts is left under the responsibility of some suppliers.

Once refined the main concepts, the subsystems and the components are processed in the same way, according to model described at figure 1, resulting in higher level project solutions without sacrificing time to market.

According to Sobeck, et al.(1999), SBCE assumes that communication and argument on sets of ideas generate more robust systems, optimized and generally more efficient. Moreover, according to author, the focus in convergence, instead of adjustments in the best idea to improve it, can drastically reduce the amount of re work in the process.

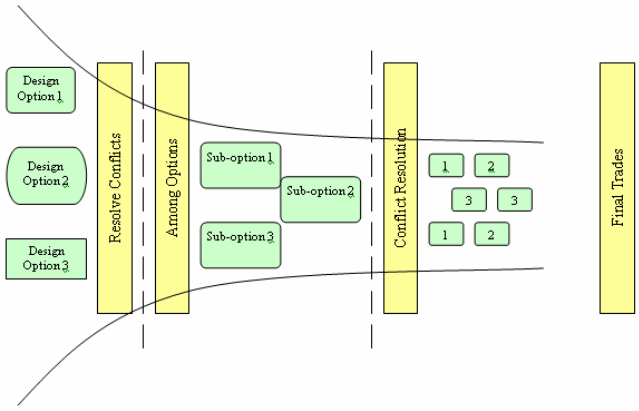

Figure 1. SBCE tool representation.

Another proposal presented that has as a goal time development reduction is described as being the processes of seven possibilities. The idea is to use Brainstorm to list a matrix of seven alternatives of manufacturing process for each part with high cost, or that can have hard manufacturing, or with possibility of quality increase, or with possibility of waste reduction, or others chances of improvement. Using multidisciplinary teams, alternatives are classified and evaluated in accordance with election factors and the most promising are selected for a detailed analysis of costs and the results are compared between them to determine optimum process for the part in study.

These proposals of application of tools by Mascitelli (2004) look for integration of manufacturing process with PDP, however the author does not relate the tools with a reference model of PDP which opens a gap between LC and the state-of-the-art models of PDP presented later, such as important factors to design process as a systematic of decision taking, clear distinction and definition of the phases of design process and chronological logic of use of tools do not become evident in the proposal presented by the author.

The lack of a reference model duly associated to the presented tools creates the possibility of these tools to be used in a inefficient way, as a logical process of incentive to requirements does not occur, leaving the "lean" principle identified by Womack, et al.(1990): to identify the value stream.

3. INCLUSION OF LC AT PRODUCT DEVELOPMENT PROCESS

PD is a very complex activity, beyond technical solutions, also many other aspects as, for example, the necessity to stimulate the participation of teams with diversified knowledge to get more efficient ways to reach goals established in the project, preventing problems of communication and organization during work, guarantee learning and the dissemination of the generated knowledge, among others aspects.

However, market's high competitiveness leaves enterprises to search the development of products quickly, with higher quality, minor development cost and customers total satisfaction.

Face to the changes in the market due to fall of protectionist barriers, increase of the competitiveness of international competitors, reduction of product's life cycle, increase of need for innovation in products and greater availability of information and products to customers, demands an update in project processes. Next, some models of reference of PDP presented in this revision will show that it is evident that they do not consider "lean" concepts in the systematic of product development.

It is understood that using LC in the initial phases of product development provides an adjustment so that product development results in innovative solutions, with higher quality, through processes that answer quic kly to market's requirements. Despite the structure and tools used on descriptions of the following models of PDP being related to LC - in the direction of assisting a more efficient process of PD - these had not been defined inside of "lean" philosophy, in such a way that an adaptation becomes necessary so that the benefits of "lean" can be totally achieved.

There are many proposals of structures for procedures or methodol ogies of PD. From 1980, t he complexity of the products increased and new necessities in product development appeared, stimulating the development of new methodologies of development in environments of simultaneous engineering or integrated teams.

The Process of PD according to Rozenfeld, et al. (2006), can be represented by three macro-phases defined as the Previous-development, Development and Post-development. In the beginning of the project, Strategical Product Planning occurs to define products portfolio that interests for the enterprise to be developed and sold to market, considering the business-oriented strategy.

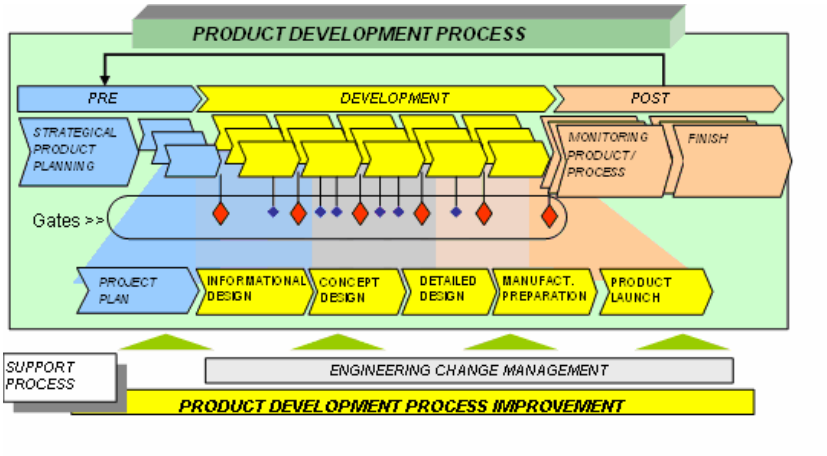

Figure 2. Rozenfeld, et al (2006) PDP Reference Model.

In this first macro-phase, research occurs to get market, customers and technologies information to verify possibilities of great business opportunit ies that results good profits through new products.

In the sequence of the model, concepts of project management are applied, from the product definition. According to Rozenfeld, et al (2006) "the project planning phase deals particularly with portfolio product development, where target of product and project, necessary resources, time, cost, responsibilities, etc., are defined in details. I f this planning gets approval, project begins in the following macro-phase".

From this point, product development occurs in three definite phases described as Informational, Conceptual and Detailed Design. The methodology looks for development time reduction and provides development of the conception of an ideal product, that is, th e one that better attends the identified requirements at the beginning of the project.

According to Rozenfeld, et al (2006), no matter how you try to take hard decisions and to make right definitions in the beginning of the development, changes will always occur in the project throughout the development, as the de cision taking process involves many uncertainti es. In this way, it is understood that "lean" differs with the reference model of PDP presented, when considering delaying critical decisions and projects concepts until the latest moment that development schedule allows, so that a bigger understanding of the project occurs and consequently the correct decision taking process happen.

In such a way, delay ing critical decisions reduces the influence of additional expenses due to changes of previous decisions constraints in project budget since, according to Rozenfeld, et al (2006), changes cost of a previous decision increases throughout the development cycle, as to the accomplish ment of a change, decisions already taken and following actions can be invalidated.

Another divergent aspect between presented reference model and lean development is the prominence use of tools to evaluate process of manufacturing conceptions during the conceptual design at "lean". The result of this interaction i s a reduction of reworks due to discovery of serious errors in advanced stages of design process. As a result, there is also time reduction on PDP schedule, therefore project teams can dedicate more to concepts, instead of wo rrying and wasting time on reworks and adjustments. In turn, this focus on concepts generates greater view to convergence of conceptions - despite of the reference model systematics that nail s the adjustment in the best conception to optimiz e it.

Analyzing another PDP reference model presented by Forcellini (2003), a descriptive brief is presented in this work, with major emphasis on the phase of product development, specifically to conceptual design.

The presented model encloses the phases of definition of the product design, production, launching and maturity of the product.

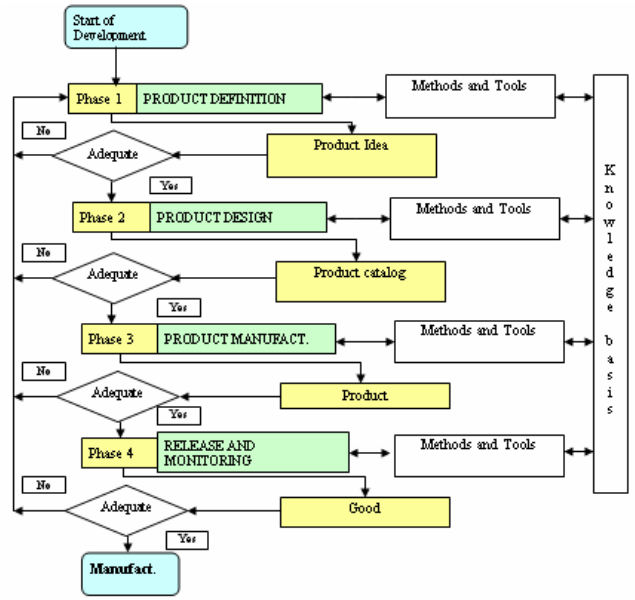

Figure 3. Forcellini (2003) PDPReference Model

In the reference model, product design displays the flow of information between each stage, results in each one of them and some decision taking moments. It is presented in four stages: Informational, Conceptual, Preliminary and Detailed design. The same model was called by Ferreira (1997) and Ogliari (1999), as "Consensual Model".

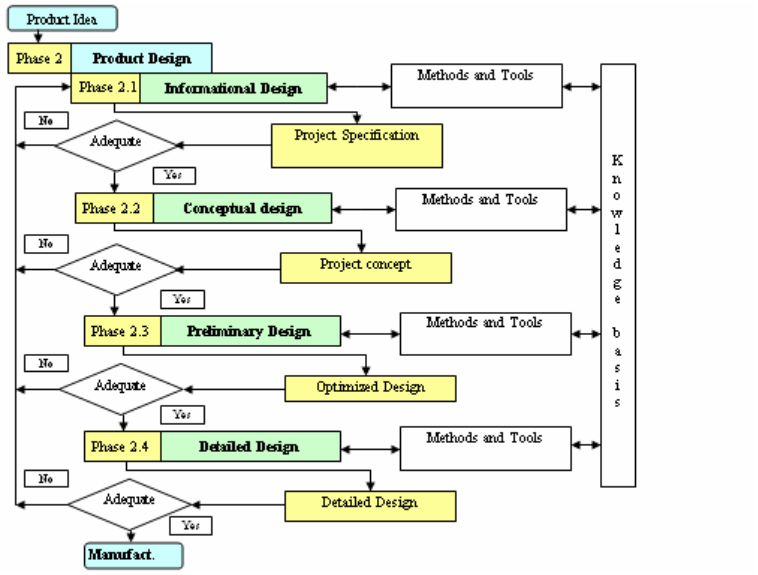

Figure 4. Consensual model

Conceptual design is the most important phase in the process of a product design, as in this phase many decisions influence the final result of PDP. Systematization of search for the conception of a product from requirements detected at the phase of Informational Design assists the process of creation while organizing, evaluating in accordance with customer and structuring information. Moreover, use of tools that stimulate team creativity for the proposal of solution principles from requirements reduces the conception time and provides a list of solutions adjusted to the final concept of the product, as following.

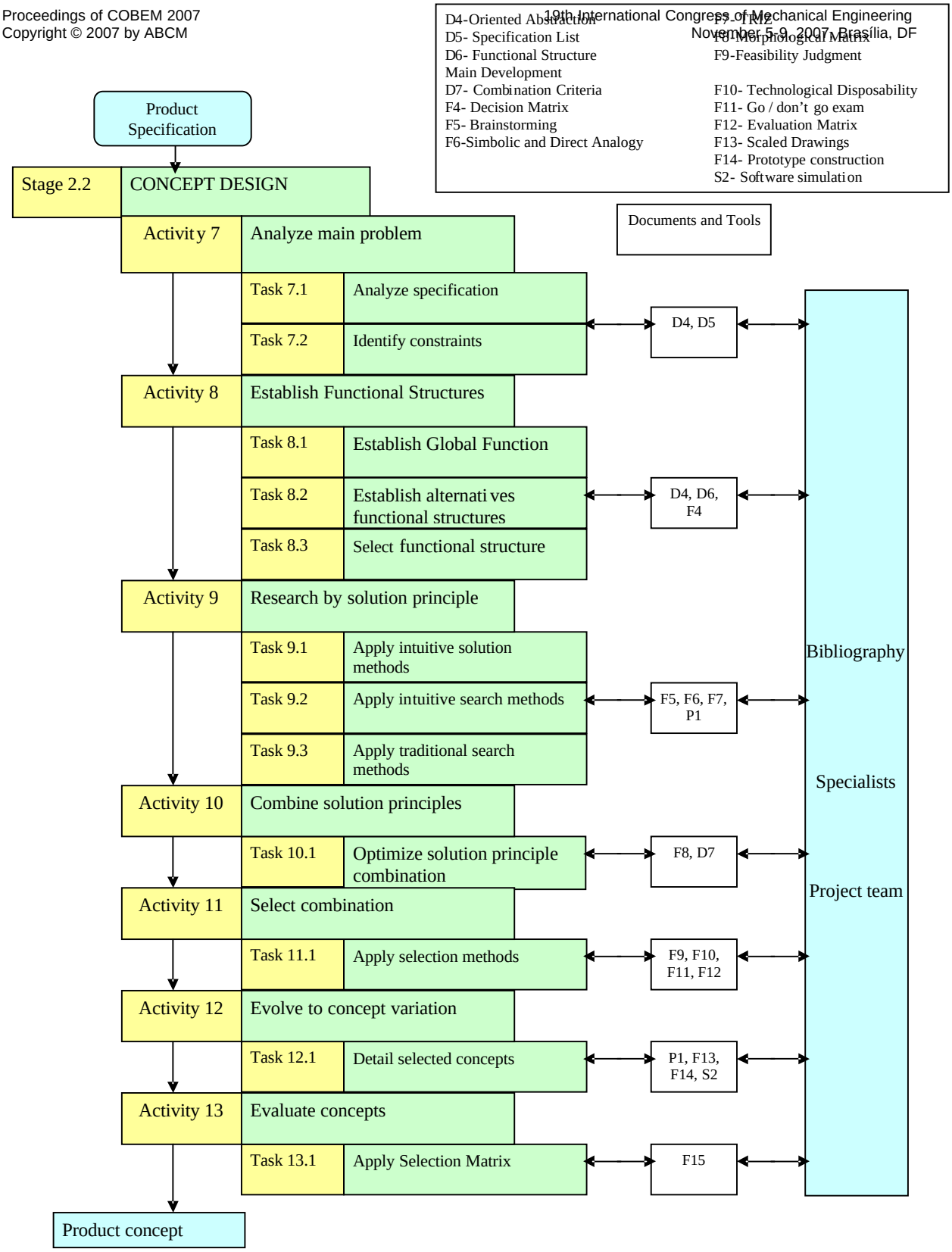

Figure 5. Conceptual Design Flowchart

In this model presented in "Fig. 5", the use of tools to help product design is very useful in each one of the activities that are part of the product development. It is interesting to notice that lean development uses many tools in common to the presented reference model, however it is distinguished the occurrence of small changes in some tools due to "lean"

proposal for simplifying and reducing process, mainly to optimize activities that adds value to product, that is, with these tools the goal is to get results consistent to product or customers requirements, in lesser time, with bigger quality and greater profit.

On the other hand, tools and the structure of the reference model in question are not totally capable of benefiting of "lean" philosophy, as they were conceived under a concept that differs from the new proposal, establishing the objective to get the best concept of the product in the end of the flowchart. "Lean" in turn, considers more than a conception in the end of the phase of conceptual design to guarantee that other evaluations in following phases, to guarantee effectively the development of the solution with higher attendance to customer requirements.

Another difference between the reference model in question and lean development is that the last one gives much emphasis to the construction of prototypes. Despite the extra expenses with construction of prototypes at lean development, they results in a satisfactory reduction of reworks needed.

About schedule attendance, "lean" differs from the reference model of this topic because it uses evaluation of manufacturing processes of solution alternatives simultaneously with its conception. This procedure aims at problem reduction of manufacturing process when developing new concepts, besides it provides more discussion over concepts and promotes more solution integration.

Others reference models that guides product designs are under development since the 60´s. These models consists of four phases and can be found, under some small variations, in works of diverse authors as French (1985) and Pahl and Beitz (1988) among others, presented in figures 7 and 8.

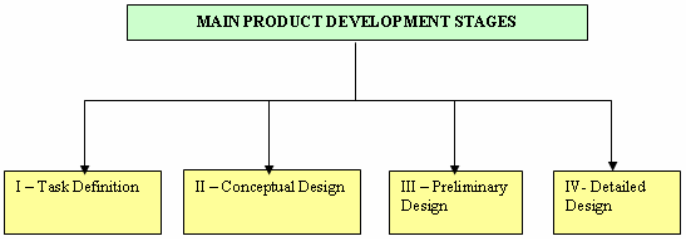

Figure 6. Main Product Development Stages

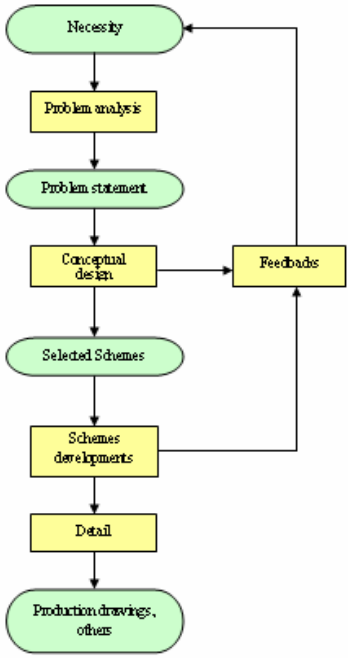

Figure 7. French (1985) PDP Reference Model

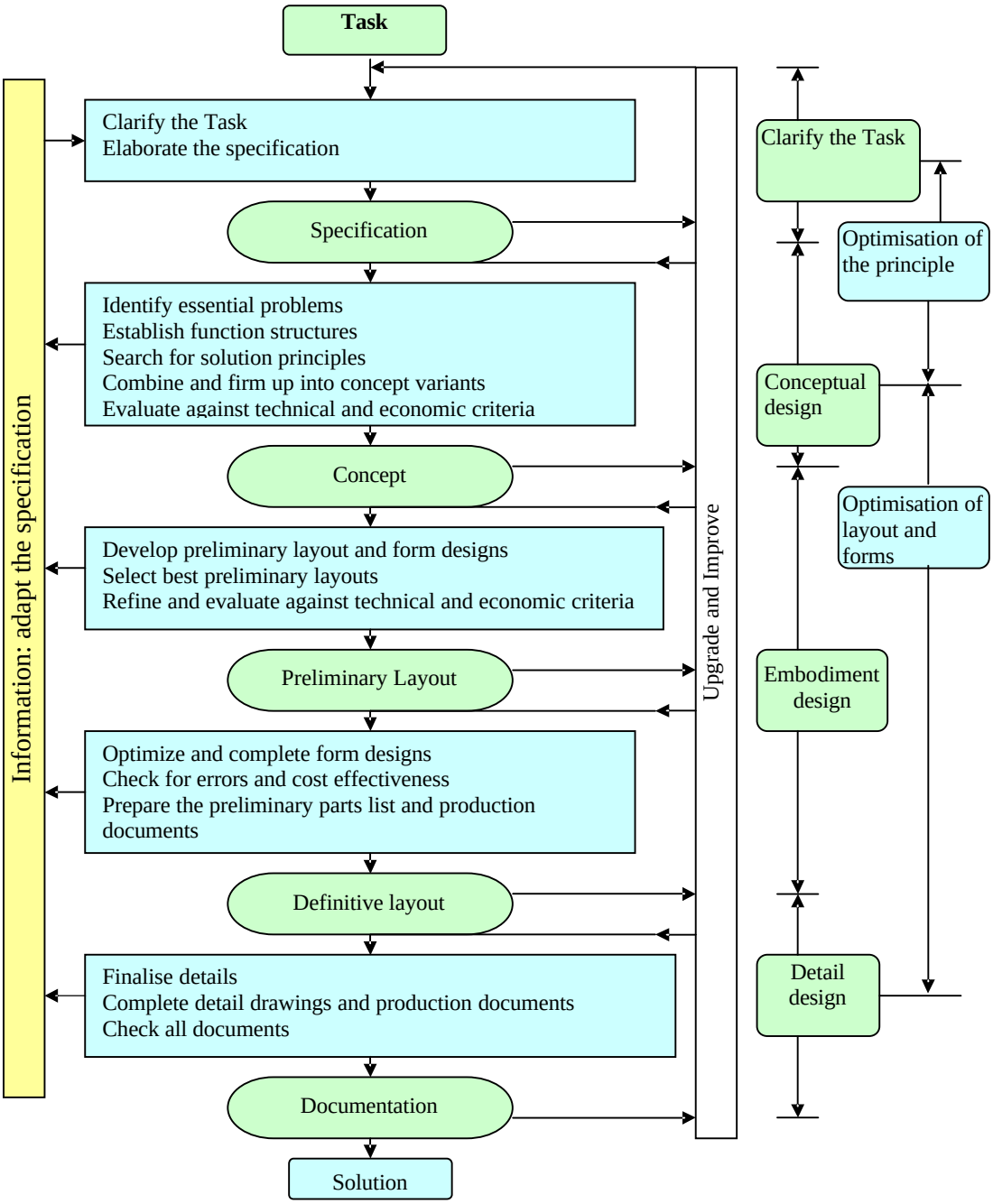

Figure 8. Pahl & Beitz (1988) PDP Reference Model

Conceptual design in the model of Pahl & Beitz (1988), which is one of the most popular, has the same characteristics of Rozenfeld´s et, al (2006) model, starting the phase from the understanding of necessities through a list of requirements and following for the establishment of structured functions and search of solution principles and its combinations to get a product concept.

Pahl & Beitz´s (1988) reference model of PDP determines that in the end of each phase a decision must be taken to evaluate if results are satisfactory to advance for the next phase or if works in the previous phase must be done again. In accordance with this model´s authors, continue the process towards to the end only to find out a serious mistake in the initial phases must be avoided at all cost.

In this aspect of redoing works of previous phase, “lean” concepts are slightly different from the reference models in question, as at lean development rework is considered a type of activity that must be avoided because it spends the available time for product development or do not add value to customer. The way to prevent them and improve products

according to "lean" concepts is to spend more time in the initial phases of the process, stimulating the work and interactions of project teams and, in the case of finding out a serious problem, stop all activities and request every team to solve the project problem.

4. CONCLUSION

Lean definitely changed manufacturing after Toyota´s successful production system. Anyway at PDP these concepts did not result in a breakthrough instantly. Project is defined as a unique event, with beginning and finish well established. As a unique event, its characteristics are completely different from manufacturing because its concepts do not repeat from one project to another.

First it seemed that Lean principles were useful only at manufacturing, but as seen on various methodologies, tasks and activities in PD occurs in the same way from one project to another and are grouped into Reference Models. So LC can improve these models, eliminating waste and adding value to its final results through an IPD process review under Lean Principles and also by offering new tools to PD. Information is the main driver of IPD, as it gives the initial requirements to the PD, and it is also the result of the whole process, as a guidance to manufacture the final product. In this way, LD emerges as a proposal to improve PDP, reduce development time, improve customer requirements attendance and achieve higher quality by reducing waste at process that handle information, promoting continuous improvement at these process and simplifying the methodology.

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