Design for Lean Systematization Applied in Detailed and Conceptual Phases

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Abstract. *Lean Manufacturing philosophy resulted from the best practice combinations used in identifying and eliminating wastes along the manufacturing process, aiming simultaneously at high quality, low cost, shorter lead-time and higher flexibility. First-rate industries have its utilization as a pre-requisite, its implementation level being the differential among them.*
When targeting full Lean Manufacturing implementation, product concept plays an important role on its efficacy. On the other hand, there is a lack of elements to support a most efficient product development while focusing Lean Manufacturing philosophy implementation.
Concern regarding product development aiming at optimization of specific characteristics was responsible for the appearance of DFX tools such as manufacturability (DFM). Until now, no DFX tool has offered enough subsidies to help the development team in creating products which will contribute to full Lean Manufacturing implementation.
This article intends to bring forward, in the form of guideline collections called Design for Lean, a systematization of the best practices for product development that will support focus on Lean Manufacturing implementation. These guidelines were gathered through the identification of product requirements pertaining to implementation of Lean. Proposed systematization focuses on conceptual and detailed design phases of Product Development Process.

Keywords*: lean manufacturing, design for lean, DFX, systematization, product development*

1. INTRODUCTION

Speed to develop a new product, competition for a more accessible price, growing quality of competitors and low profit margins have led manufacturers to pursue a growing productivity of their production lines through identification and elimination of losses.

Lean Manufacturing has been developed in order to help in the task of identifying and eliminating losses in the production phases.

According to Smalley (2004), Lean Manufacturing concept is presented as a form of specifying value, aligning in the best sequence the actions that create value, executing these activities without interruption whenever they are demanded and performing them in an ever more effective way. In short, a lean way of thinking is lean because it is a way of making more with less – less human effort, less equipment, less time and less room – and, at the same time, get increasingly closer to offering the customers exactly what they want. However one still perceives a great amount of losses during the manufacturing phase, also as a result of product concept.

Lean Manufacturing tool has been implemented by way of changes in the productive chain itself and its scope has remained restricted to the manufacturing process. It is however known that manufacturing productivity is impacted by product design, and many times Lean Manufacturing implementation is limited by restrictions of the product itself.

What concerns product development process, DFM (Design for Manufacturability) has an important role, either to render feasible the manufacturing process or to improve its productivity.

DFM tools offer specific benefits to the product manufacturing process. Perhaps due to the fact that product development teams are not so well acquainted with the Lean Manufacturing tool, these teams have found difficulties to develop products in a way to effectively contribute with it. In order for Lean Manufacturing to reach its full scope, it is required that product development process contributes in a scale larger than the present, and yet today available tools do not allow this to happen.

Considering this scenario, where large losses are observed in manufacturing even with the use of lean guidelines, there is a need for action in the initial design steps, aiming at an improvement of existing concepts in product design for lean manufacture.

High competitiveness has triggered a wide usage of Lean in production. As its application has been so far generally restricted to manufacturing, losses still occur, mainly due to the fact that product concept has not been in line with that philosophy.

It is otherwise known that DFM has an important role in product design, to impact on the feasibility and the productivity of the manufacturing process.

Perhaps due to the fact that design teams are not so well acquainted with Lean, they have met difficulties in developing products that will effectively contribute with it.

In order to help enable a full implementation of Lean philosophy all the way from product design through its final delivery out of production, present tool is presented. This tool comes in a form of guidelines, or wastes to be avoided, as in the stamping case which resulted from interviews with experts of the main automotive industry processes: stamping, welding and assembly. These guidelines are related to one or the other of the seven main wastes encountered in running production.

2. LEAN MANUFACTURING

It is understood by Lean Manufacturing everything which refers to having the right things at the right place at the right moment and in the right quantities thus eliminating wastes in a flexible and open to changes manner.

According to Womack and Jones (1996), Lean thinking is a way of specifying value, establishing the best sequence of actions which add value and developing these activities continually every time it is so required and ever more effectively. So, according to the author, Lean thinking is a way of doing more with less, increasing efficiency. Liker (2004) lists seven wastes identified through Lean thinking:

- Overproduction: manufacture of items not yet demanded, creating the need of storage and transport more often than necessary.
- Wait: workers merely watching automated machines or waiting for the next step of a process, requests for parts in delay, production bottlenecks, etc.
- Unnecessary transportation: need of long distance moving of a product in process between one step and the next or between unnecessary steps.
- Over or incorrect processing: unnecessary manufacturing steps - inefficient process due to poor tools and production design requiring unnecessary movements which may cause low quality. Wastes when excess quality demanded.
- Excess inventory: excess of raw material, product in process or finished product, causing long delivery times, obsolescence, damaged items, storage and transportation cost.
- Unnecessary movements: whatever movements made by workers, be it to search or reach for parts.
- Defects: production of bad parts. Any kind of rework, loss of products, inspection, does nor add value.

3. THE ROLE OF PRODUCT DEVELOPMENT IN THE IMPLEMENTATION OF LEAN MANUFACTURING

3.1. Product Development Process (PDP)

Once the purpose of this study is to propose a DFX tool to be inserted in the product development environment, it is necessary to choose a PDP model among the various available. Figure 1 shows the Rozenfeld, *et al.* model, which will serve as a base to have us understand in which development Phases the tool will be applied.

With DFX, proposed tool will have its application in Conceptual and Detailed Design Phases evidenced in Fig. 1, with its requisites already defined in the Informative Phase.

During the Conceptual Phase the best products architecture is chosen and pattern components can be defined in order to create a large variety of products. This architecture concept is better known as modular design, where parts are developed and tested independently.

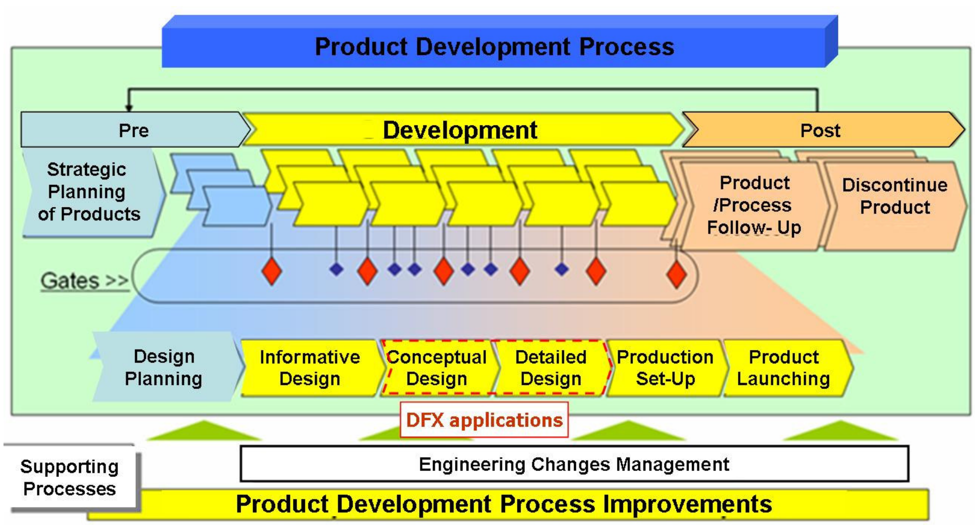

Figure 1. Model PDP adapted from Rozenfeld et al. (2006)

At the Conceptual Phase adequate previsions enable the development team to create superior products with satisfactory performance at all aspects, reducing redesign interactions, development and manufacturing time, improving also the client's perception.

During Detailed Phase the best architecture is chosen and the entire product specs are to be defined utilizing proposed guidelines exposed later on.

For better results, this tool must be used the earliest possible in the PDP process, within Simultaneous Engineering environment.

3.2. Design for Manufacturing

Product concept has a considerable impact on final cost. It is during the production Phase that design change costs are highest. To help the designer evaluate the impact of his decisions on the product's life cycle, auxiliary methods for design decisions called DFX (Design for X) were developed. Among most applied DFX tool, there is Design for Manufacturability.

3.3. Design for Lean Manufacturing – A New DFX Tool

At present the guidelines contained in DFM tool have supplied subsidies so that product development teams contribute, although modestly, with the implementation of Lean Manufacturing philosophy, mainly in what regards standardization. There is to be noticed, however, a strong absence of tools to support product development teams specifically in the task of contributing with the implementation of Lean Manufacturing in its entirety.

According to Rozenfeld et al. (2006 apud Womack, 1996), in order to promote opportunities that will cause impact on manufacturing efficiency, cost and product quality, Lean Production must be aligned with product not only in its manufacture, but also in its concept in PDP.

But, then, what new approach would this tool bring with regards to the already known DFM? The answer is a set of specific guidelines for the development of products that is focused on the implementation of Lean Manufacturing philosophy in the manufacturing Phase.

The development of products with focus on Lean Manufacturing must intrinsically think not just in the product manufacturing Phase, but yes in all the concept cycle. According to Womack and Jones (1990), one must search to utilize value engineering techniques in order to break down the costs of each production step, identifying every possible factor to reduce cost of each part. Afterwards, value analysis techniques are applied in order to reduce additional costs. In this Phase, each step of the manufacturing process is analyzed in order to identify critical points which will get more attention so as to reduce costs even more.

Womack and Jones (1990) make an analogy between *mass versus lean product development*, in which, among other differences, resources needed for the *lean development* of the design are temporarily placed under a *Design Manager*, with no ties to their routine, or series, activities for the entire duration of the design, as well as all the resources needed for the project. Whereas in *mass production*, resources needed for the design are placed in simultaneous development programs and under a functional department, so that, the team is not detached from its routine tasks. As in the Lean system the available resources dedicate exclusively to their design and do not report to other departments during its lifetime, design duration is consequently shorter than in mass concept.

Beyond the resource allocations, the focus of the design team is also very important. Following the strategy utilized for the DFM and DFMA techniques, the *Design for Lean Production* must have above all the concepts that support *Lean Production*:

The first step is the determination of the value to be delivered to the client, in this case, the manufacturer which desires a leaner production. Under this sight, design teams must have a clear understanding of the production process of the developed product in order to identify manufacturing operations that do not add value.

The second step is the determination and optimization of the value flow through the definition of activities needed to transform the value. As closer the total amount of time spent from the beginning to the end of the manufacturing process gets towards effective transformation time, less time is being wasted along intermediary operations which do not necessarily add value. This narrowing gap can be achieved by avoiding the specification of components that are difficult to achieve. Example would be a specific component that needs a special transportation from a distant place, or then parts designed with a complexity hardly achievable and maintainable along the process, requiring too many check points during its transformation flow, thus increasing its lead time.

The third step is related to the identification and elimination of waiting times and stocks, sometimes called buffers between operations. A synergic approach has the advantage of interacting directly with peripheral areas towards an optimization of the development process, thus eliminating the time spent waiting "in line" for the next development step. This can be achieved through concurrent engineering concepts, where some activities are performed at the same time when dependent on each other (see chapter 4).

The fourth step is the *pulling* effect. If the design team does not have in mind the meaning of value for its costumers, there is a chance of delivering a product that will not be consumed. This philosophy is not only applied for the final customer but also for the internal clients of the process. A bad dimensioned product or part can cause a bad balance of existing production systems, compelling to produce more than the capacity of the next step. This concept is easily observed in a process with high scrap rates. When the next production step needs more quality than the preceding step can deliver, there can be an amount of production wasted or waiting for rework.

The sum of above listed concepts leads to perfection, meaning the client will be pulling value.

Through this development technique products can be produced quicker, with less work and fewer errors, which significantly contribute to Lean manufacturing. Following prerequisites have been identified to enable this concept:

- a team leader, responsible for design and engineering;
- a synergic work team under one single design leader;
- Simultaneous engineering – as the engineering department can not have enough knowledge of all relevant design areas, experts from other areas are to be brought in. Full benefits from simultaneous engineering to be harvested.

4. SIMULTANEOUS ENGINEERING

The term simultaneous engineering can denote both a parallel cooperation and work discipline towards a set of common objectives in the development step or a form of design time reduction through the accomplishment of independent activities which can be made simultaneously.

According to Rozenfeld et al. (2006), one of the first attempts was to increase the degree of parallelism among development activities, seeking the simultaneous accomplishment of design and process planning activities. In this way, activities that were previously started after the former activity had been finished and approved, can be made in parallel.

Following benefits can be attained through simultaneous engineering:

- reduction of time for development of new products
- reduction of cost in the development of new products
- better quality of new products as per customer needs

So, through Simultaneous Engineering, one can make the product concept changes in the initial development process steps.

Our objective is not exactly the reduction of product development time, but yes the assurance that the developed product meets essential requisites for the implementation of Lean Manufacturing philosophy. For that purpose it is necessary to determine what is its application that exactly corresponds to the goal market, which in our case is Lean manufacture.

Many authors like Bralla (1996), defend that DFX tools can be implemented without the help of Simultaneous Engineering, once good designers should be able to consult their direct and indirect customers and apply design guidelines by themselves. That may be one reason why even today there is so much difficulty developing products focused on their internal customers and not just on the expectations of the final customer.

In order to assure the good result of its application, Simultaneous Engineering must be backed up by product development supporting tools, such as QFD, DFX, among others which are not exactly the focus of this work.

In the same way it is utilized to process and translate the needs of the final customer, QFD should be used as a coordination element of the information process, dictating the rhythm of product development and the sequence of activities of this process. This means that each Phase of the development process should have the elaboration of the respective QFD matrix as its conductive element.

To our interest, Simultaneous Engineering is an important tool in what concerns bringing the customer needs to the implementation of Lean Manufacturing philosophy. In other words, through Simultaneous Engineering the product development teams work together with Lean Manufacturing implementation teams.

In order to render the utilization of Simultaneous Engineering effective in the Phase of product development, of importance is the support given by the Informational Phase supported by the QFD tool, to ensure consensus of the different definitions on the product. Through QFD, translation is made of the Lean Manufacturing goal specifications into product requisites, so that they do not negatively interfere with other important product requisites. This is easy to observe as Lean Manufacturing philosophy asks, among other things, less robust products and whenever possible with not so tight tolerances. Well, this requisite may very well work against some of the final customer's requisites, as for example efficiency, or product quality, or even against Lean principles themselves, once a stamped part with loose tolerance may generate the need of further adjusting operations in the welding steps.

5. RECOMMENDATIONS TO THE PRODUCT DEVELOPMENT TEAM

Once the environment of this study is mainly the automotive industry it is only natural that study focus will be on it.

As explained in the initial stages, this work's objective is to supply directives which will enable a wider penetration of Lean Manufacturing philosophy through strong contribution of the product development team as well as other DFX tools. Therefore it has been decided to stratify the main steps of automotive production so as to supply orientation to each of them. Whenever possible, these orientations will be directly related to the seven main wastes mentioned in the Lean Manufacturing definition.

First step – stamping: If a manufacturing process of an automobile is analyzed as a whole we will notice that, as for the product development process, the higher the quality of a stamped component, the lower the investments necessary for following steps. Higher productivity gained in stamping have been obtained through manufacturing steps utilizing high flexibility equipment. Of course less complex geometry, choice of raw material and adequate thickness will allow following benefits shown in Tab. 1, according to the seven main wastes previously cited:

Table 1. Relation between benefit and avoided waste during stamping process

Benefit	Waste
Less complex geometry bringing lower tool adjusting time;	Over and incorrect processing;
Adequate raw material and thickness, bringing lower template numbers;	Defects;
Less complex geometry meaning less time spent on measuring and rework;	Over and incorrect processing;
Adequate raw material and thickness reducing stamping stages;	Over processing;

It has been established, however, that a stamped part of higher degree of complexity due to the robustness of the stamping process is to be preferred over a stamped part of lower complexity. That is so because stamped parts must be welded and assemble giving form to the vehicle. Therefore, the design of a stamped part indeed gives great contribution to the reduction of following manufacturing steps.

Second step – welding: Table 2 relates the main potential wastes encountered in the welding process as well as its consequences when they are not avoided, according do the seven main wastes previously cited:

Table 2. Relation between waste causes and consequences during welding process

Causes	Waste
Necessary process checkings to ensure good product quality to be delivered to assembly due to low design robustness;	Over and incorrect processing;
Amount/complexity of gadgets to ensure welding geometry;	Over and incorrect processing;
Number of welding spots to ensure product rigidity;	Over and incorrect processing;
Part degradation in storage due to high degree of ductibility and thickness;	Defects; over production;

Welding is the direct client of stamping; therefore quality of stamped product has a direct impact on the requirements of a robust welding process.

The environment in which the study was carried out is responsible for the production of two distinctive vehicle brands, to be called brand A and brand B. Each of them demands a specific production line, which allows a direct comparison as to the robustness of both processes involved.

Brand A, due to its more robust part design, needs a leaner manufacturing process. As an example, a hinge to be welded to the car body has a rather complex design, thus requiring a more complex stamping tool. Stamping time as well as number of tools and their stages are however not necessarily higher and the welding operation to the car body can be performed through a simple gadget as it was designed so to have its positioning on the body ensured.

Brand B on the other hand has a simpler design, but demands a much more robust and complex assembling process as it not capable to ensure needed positioning by itself.

Third step – painting: Not to be dealt with in this study as it is a distinct process from the others.

Fourth step – final assembly: Table 3 shows the relation between waste causes and their consequences in final assembly, according to the seven main wastes mentioned earlier.

As is the case with the internal supplier body welding, final assembly spends even more with the attempt to position geometrically large components, mainly the mobile parts (doors). They can not present many rigid points for its assembly must have a flexible positioning due to the low robustness of the design of their primary components, in this case the stamped parts. In addition to this factor there are the process variations. In order to facilitate the parts design and absorb variations along the process due to the addition of tolerances, it is a practice that the designer resorts to "fitting facilitators", commonly known as oblongs and keyways. These artifices have an enormous contribution for us to have an unstable process, therefore creating a dependency on operator sensitivity (which so far cannot be measured) and on devices, patterns that eliminate this variable, creating tools and operations that do not add value, swelling the process and the amount of documentation to register them. It is desirable an effort from the designer so that any and every subjective operation which depends on "the common sense of the operator" be brought to a minimum, for there is no way to standardize this requisite.

Contrary to the Japanese concept, there has been noted an intention to assure the fixation of some parts with screws, nuts and washers as well as with oblongs, when in fact all these components could be replaced by simple fittings.

Another point observed was the amount of similar items, in special screws which in many cases could have their usage unified, therefore reducing the number of inventoried items, number of screws and also the amount of assembly failures by means of mistakes.

Specified raw material can represent a sizable reduction in the cost of a final product, mainly if we consider the thickness of the steel sheets utilized in the automobile industry, which in turn also reduce the number of stamping steps. Otherwise, the designer, when specifying tolerances for the stamped parts must also take into consideration the deformation they will undergo during the various manufacturing steps and intermediate storings (even with the leanest processes), this in order to avoid unnecessary adjustments to make parts match and still assure that the product will meet the final design tolerance specifications.

It was noted that the higher the design robustness of the stamped components in the initial Phase of the production chain, the leaner is the manufacturing process of their client parts. The manufacturing cost of a stamped part with a higher degree of complexity and robustness has been amortized by the following steps, as the number of checkings, fixation devices and assembly time are considerably reduced, as shown in Fig. 2. Figure 2 shows the relation between quality of the stamped parts and the quality costs. As the quality of stamped parts increases assembly quality costs decrease.

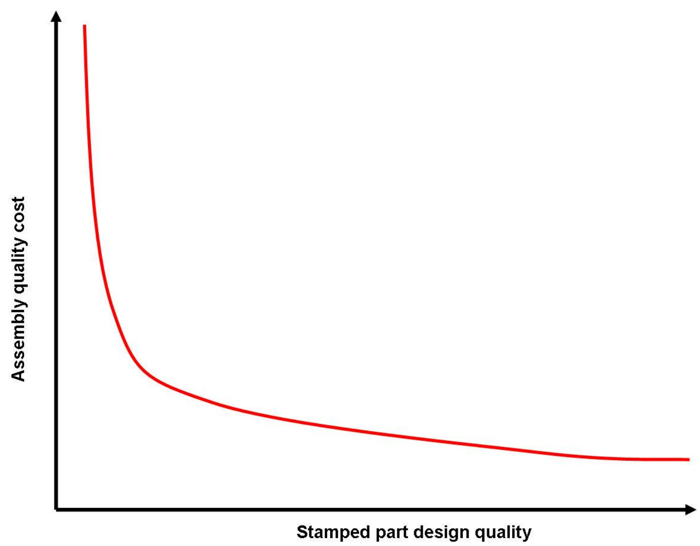

Figure 2. Assembly quality cost versus stamped part design quality

An important point to be considered when designing a stamped part is that it should come with tolerances such that when added to the tolerances of the other components there is no further difficulty put to the final assembly process.

Table 3. Relation between waste causes and its consequences during final assembly process

Causes	Wastes
Components with geometric variations received from internal suppliers;	Waiting time; over and incorrect processing; unnecessary moving;
Component with undefined positions in assembly operation (oblongs, keyways), requiring many adjustments at assembly;	Over and incorrect processing; unnecessary moving;
Parts that could have their assembly through fitting instead of screws, decreasing number of components, inventory, number of components and operations;	Unnecessary moving, excess inventory; defects; over and incorrect processing;
Lack of standardization of components that have very similar functions (screws, nuts), meaning high inventory, process faults, excessive equipment needed;	Unnecessary moving, excess inventory; defects; over and incorrect processing;
Inadequate raw material which deforms during process, requiring adjustments steps;	Defects; excess inventory; over and incorrect processing; unnecessary moving;

Figure 3 illustrates an assembly line where the recommendations previously mentioned were not applied. Figure 3 also exemplifies some examples of waste, like rework, causing the need of returning one ore more production steps as well as additional time spent to control the process quality.

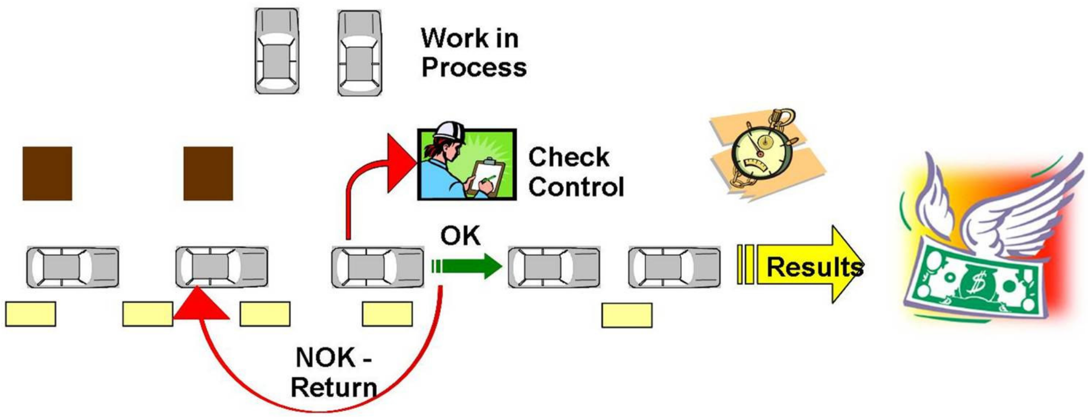

Figure 3. Process losses due to product design

6. CONCLUSION

Through this study we can observe that the integrated development of products has an important contribution for the implementation of Lean Manufacturing philosophy in its entirety. The DFX tools available to this date like DFM are not sufficient, there being room for the creation of a new tool – DFL.

Simultaneous Engineering has an important role in the search for the development of products with focus on Lean Manufacturing, still underutilized, not only in the reduction of product development time, but mainly in the development teams interaction with their client areas.

Much has been done in the search for a Lean manufacturing, with contributions from product in a punctual manner and in isolated steps of the manufacturing process. Isolated changes of the product in search of cost reductions in the production process can bring as a consequence an excess of operations that do not add value along the production chain.

Present study has shown that the product development can present a positive contribution for the implementation of Lean Manufacturing philosophy, mainly if the guidelines here outlined are applied in the initial steps of the manufacturing process.

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