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FORGING LEAN DESIGN: MULTIPLE CASE STUDY IN AUTO PARTS

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Abstract*. An increasing number of companies have sought high standards of productivity. Thus, our aim is to present the application of Lean Design near Net Shape associated with near net or final form in forming forging process. This presentation demonstrates the reduction in waste and in time- to-market (time to market new products) and lead time (lead-time in the productive sector), which occurs in the development and deployment of a forged product. The work is supported by a multiple case study into an automotive parts manufacturer and its suppliers. The results show cost reductions throughout the supply chain of this process.*

Keywords*: Lean Design, Near Net Shape, Forging, DFMA*

1. INTRODUCTION

Excellence is currently a constant search in companies and also in forging. To this end, they seek to achieve better productivity and quality indicators. This excellence can be supported by various methodologies; such as Lean Manufacturing (LM) and Six Sigma (SS) applied to metal forming projects (Silva et al., 2011).

The emergence of such methodologies in the forge shops shows substantial changes in their product design and process. These changes lead the forging technologies to some new achievements that shall be highlighted, however it is recognized the need of a continuous improvement.

The LM methodology principles gained notoriety in a research project led by MIT-USA, which studied the practices of improvement programs adopted by leading companies in the automotive supply chain and found that the adoption of these principles has contributed to increase competitiveness (Womack et al., 2004).

The SS methodology was introduced in Motorola, in order to increase the quality level from three to six sigmas, by applying statistical tools oriented to productive process improvements (Harry, 1998).

The LM and SS methodologies can be included into the projects through Lean Design (LD) and Design For Six Sigma (DFSS). The techniques of these methodologies lead the forging to develop Near Net Shape (NNS) products with excellence.

Near Net Shape is a lean production methodology that adds value and demand always the replacement of subsequent operations. Figure 1 shows examples of near net gear forgings with finished teeth. This technology is one of the ways to achieve the development of this millennium in the user industries of these types of forging, adding more value to forging, as well as to their customers (Dean, 2000; Hu et al, 2009).

Figure 1. Near net formed gears: final form with finished teeth. (Dean, 2000)

Taking as an object of study the application of technical Lean Design (LD) and DFSS (Design For Six Sigma), through the Near Net Shape (NNS) in cold extrusion, this paper presents information on how to conduct this through a multiple case study in Japanese forging and an auto parts manufacturer in Brazil, which belongs to an American company.

In section 2, we present the literature review; in item 3, the method and the case study are presented; in item 4, the results are presented and discussed. Finally, section 5 presents the conclusions.

2. LITERATURE REVIEW

2.1. Cold forging

Cold forging is the process in which the designed shape is obtained in one piece by means of mechanical or hydraulic presses (Bresciani Filho et al, 2011). The cold extrusion, as part of the cold forging, began with metals such as lead, tin, zinc, copper, brass, bronze, aluminum, among others. Only in the 1930s was cold extrusion applied to steel parts possible in Germany (Silva, 2013).

Cold extrusion is currently applied, for example, to the automotive industry, to manufacturing axles and gears for gearboxes; screws, pins and power steering bearings industry; engine components and other products (Silva, 2013).

The metal in cold extrusion is at a temperature below recrystallization; as a rule, at room temperature. This metal (phosphated and soaped billet) plastically flowing through an extrusion die, predominantly, if the compressive forces, yielding designed shapes that constitute the final product (Batalha, 2007).

The cold steel extrusion process has the following operations:

- Cut the bar (forming the billet);
- Anneal billet (by lowering its hardness);
- Mechanically blast billet (surface cleaning);
- Lubricate the billet (solid soap application with zinc phosphate or molybdenum disulfide);
- Forging (mechanical or hydraulic press);
- Evaluate the forged product with ultrasound.

2.2. Near Net Shape (NNS)

Near Net Shape is a Lean Design process that adds value and demand always replace subsequent operations. It can be seen in Figure 2, such helical gear near net forgings and finished with teeth. This technology is one of the ways to achieve the competitiveness of user industries of these types of forged (Dean, 2000; Hu et al, 2009).

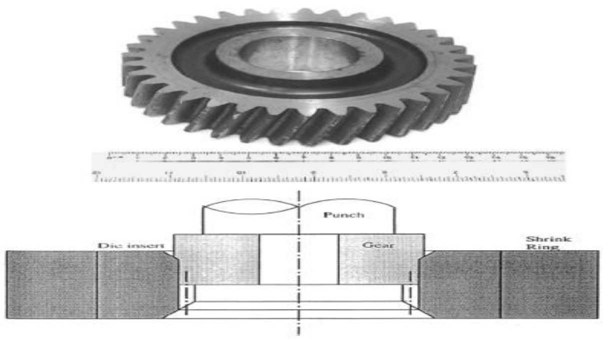


Figure 2. Helical gear near net forgings (Dean, 2000)

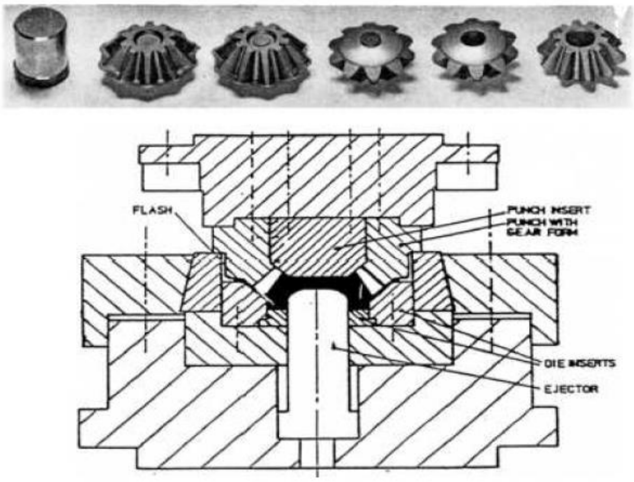
Another study forging the gear cold with spurs with new technologies in closed dies (see Figure 3) is described by Hu et al. (2007). In this experiment apply the finite element method, which simulates forging conditions in the analysis model of an asymmetric radial stresses. Also prepares a three-dimensional simulation of the shape of the teeth. At the end performs an experimental procedure to validate your project.

Figure 3. Cold Forged Spur Gear (Hu et al., 2007)

A study on die flashless system which describes the material reduction of the order of 10 to 15% in raw material is made by Doege and Bohnsak (2000). This application can be extended to a straight, helical and bevel gear, rod and a camshaft joint (see Figure 4).

Figure 4. Spur, helical, bevel and worm gears, connecting rod and overhead camshafts joints - NNS forged (Doege and Bohnsak (2000)

Dean (2000) in the article Net-Shape forming gears describes a study (see Figure 5) demonstrates the possibility of bevel gear forging production system in the cold (or warm) with NNS application.



Figuea 5. Bevel gear forged by NNS (Dean, 2000)

In precision hot forging is described in (Douglas and Kuhlmann, 2000) the demand for maximum reliability and good mechanical metal property in forged. Examples of hot forged products may accurately be seen in Figure 6. The article reports that the cost is composed of a forged raw material at 50% and 50% of earnings /expense. When considering a savings of 15 to 20% of material with precision forged application, it will have a reduction of about 10% in the final cost of fabrication.

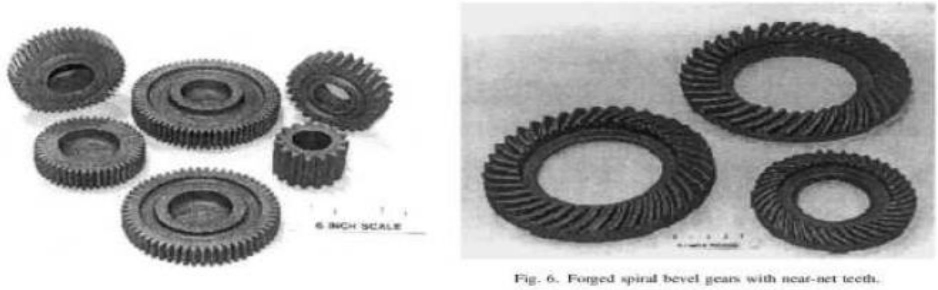


Figure 6. Precision gears by hot forging (Douglas e Kulmann, 2000)

The growing need for NNS products with quality and low cost made the forging towards to integration and automation. Therefore, it requires creativity first, and then invests. The CIM supports the business strategy, which, in turn, studying the market behavior and how to forge must market NNS product.

2.3. Computer Integrated Manufacturing (CIM)

In the product development and process design on NNS dies through CIM (Computer Integrated Manufacturing), such that (Dean, 2000; Silva et al., 2009):

- (C) Computer: plans, organizes and simplifies the decisions at all levels of an organization;
- (I) Integrated: on all computers and systems within a communication plan;
- (M) Manufacturing: establishes a production organization regarding its enhanced and whole form.

The "drawn" necessity by the client to the product and process design can be aided by the QFD (Quality Function Deployment), which is a technique used to transmit customer needs for product engineering with the aim of facilitate the planning of engineering and manufacturing.

Also, in this direction, we present the DFM (Design for Manufacturing), which seeks to integrate communication between product engineering, quality, marketing and customer service. He is known as SE (Simultaneous Engineering - Concurrent Engineering) (Silva et al, 2009), which is the concurrent development of design functions of the product and the process, which aims to reduce costs and time to launch the product NNS.

In helping to care for critical customer needs, quality point of view (CTQ's) to seek NNS products are used complementary techniques such as:

- CAD (Computer Aided Design);
- CAM (Computer Aided Manufacturing);
- CAE (Computer Aided Engineering);
- CAPP (Computer Aided Process Planning);
- FEM (Finite Element of Method), among others.

In addition to the techniques outlined above, is added to them the question sustainability.

2.4. Design for sustainability

Sustainability has been present, more and more in projects and market definitions. The forging begin to understand that the interest cost of the environmental liability is higher than the investment in the environment, as they influence the opinion of their current and future customers about the company, making the implementation of new projects and renovation contracts.

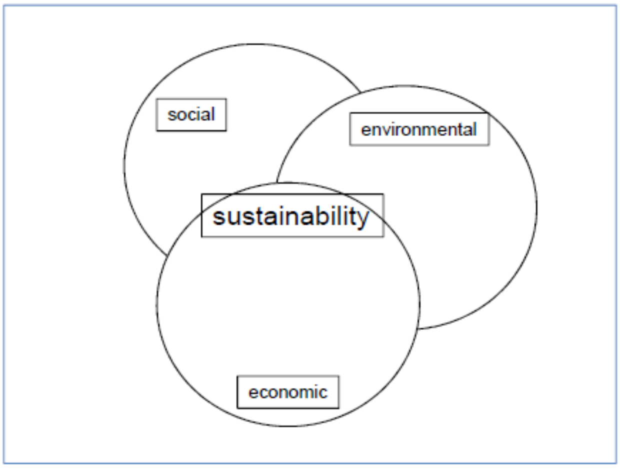


Figure 7. Triple Bottom Line

Thus, taking as a basis the situation, large forging, are concerned about the Design for Sustainability (DFS), aligning the strategic planning for sustainability, especially the possibility of having its shattered reputation (Spangenberg et al., 2010)

2.5. Lean Six Sigma

At present, forging rely on a combined effort of the methodologies Lean Manufacturing (LM) and Six Sigma (SS) turning them in Lean Six Sigma (LSS) (Shah et al., 2008 and Aboelmaged, 2010).

Forging, which had adopted only one of these methods have sought to broaden its scope, incorporating elements proposed by the other (Bendell, 2006).

The union of these methodologies is beneficial, because the important points of a methodology can compensate for certain gaps of the other, according to George (2002) and Andersson et al., (2006). As an example, cases of its effective implementation, such as the Xerox (Fornari and Mazle, 2004) and Caterpillar (Byrne et al., 2007).

In the environment of forging, there may be organizational obstacles and changes to the consolidation of the implementation of LSS. And even if it is well planned, there are still clear standards that serve as a reference for how to drive and sustain new projects; as well as improving their performance (Jing, 2009; Pepper and Spending, 2010 and Snee, 2010).

To plan the implementation of LM practices (Rother and Shook, 1999), in forging, presents the application of Value Stream Mapping (VSM), which is a form of the flow of information and materials display (see Figure 8).

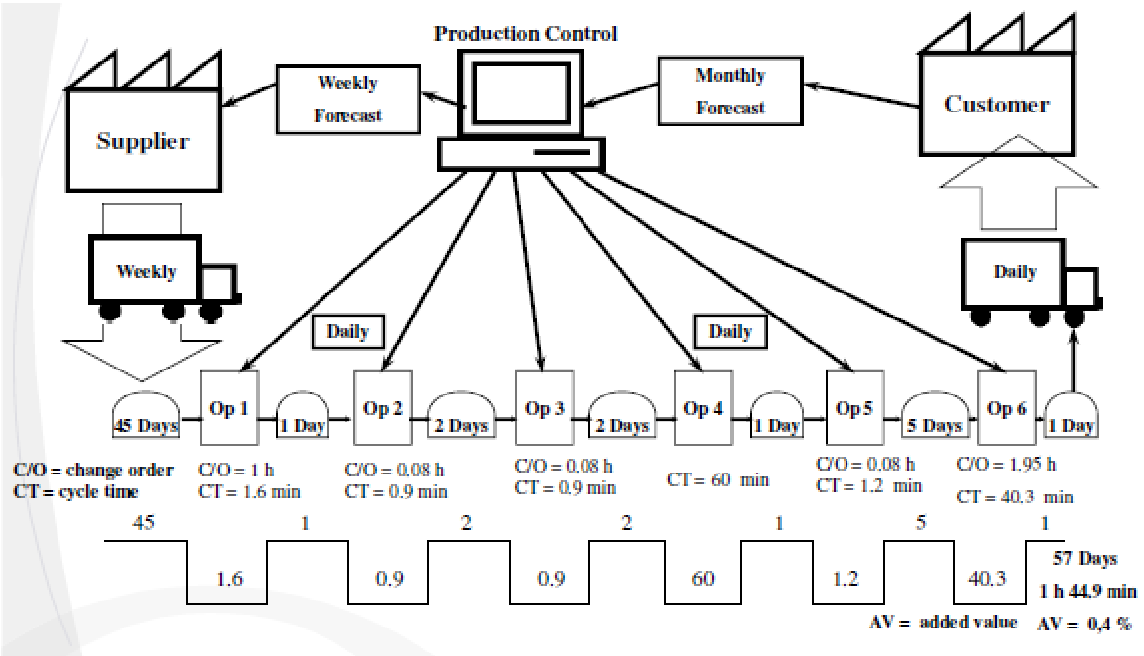


Figure 8. Value stream mapping (adapted Rother, M.; Shook, J., 1999)

The LM tools that are most commonly applied in production systems are listed below (see Table 1).

Table 1. LM tools (Silva et al., 2011)

Item	Description
Five Esses	Constitute a practice, which is important both, to motivate change, as to establish discipline in forging
Poka Yoke	They are simple devices that interrupt the operation in forging processes to prevent defects occur
Just in Time (JIT)	It is a technique that aims to enable the production of forged to make "all forged, all the time" and thus give more flexibility to forge and reduce inventory
Continuous Flow	Search the physical organization of the value stream so that the material can be moved from a process that adds value to other streaming (NNS)
Standardized work	It is the best combination of features such as operators, presses and dies, to ensure that a task is always performed in the same way in forging
SMED	It is the application of streamlining setup techniques such as Single Minute Exchange of Dies (SMED) which enables rapid-exchange deploy in shorter times, which in turn enable the production of smaller batches
Total Maintenance Productive (TPM)	Organizes the maintenance function in order to improve efficiency and effectiveness in the use of presses, relying on a combination of practices such as autonomous maintenance and planned maintenance

One of the ways to deploy the LM is by conducting Kaizen events and the results achieved must be accompanied on a daily basis through visual control (Silva et al., 2011).

When a project aimed at improving an existing process, the sequence is adopted DMAIC whose phases are described in Table 2

Table 2. DMAIC (adapted from Perez-Wilson, 2000)

Symbol	Meaning	Description
D	Define	Problem of establishing from the data base looking to relate it to the client (hear the Customer Voice - CVo)
M	Measure	Measurement of what is being studied, through the QFD, evaluating the appropriateness of the measure used, preparation of process map, finding opportunity to apply NNS
A	Analyze	Assessment and identification of root causes through the FMEA and application of statistical tools in forging
I	Improve	Determining the best way to reduce the identified variation in inputs, solution deployment and confirm the improvement of forging
C	Control	Controls property to be sure that the problem was solved

When the project involves the development of a new product and / or new process becomes a case of DFSS (Design For Six Sigma), which implies the adoption of a derived sequence known as DMADV (See Table 3).

Table 3. DMADV (adapted from Rowlands, 2003)

Symbol	Meaning	Description
D	Define	Definition of the objectives of NNS project in association with customer requirements
M	Measure	Measurement of customer specifications forged accuracy
A	Analyze	Analysis of alternatives to meet customer needs
D	Design	Detailing the process to meet the alternatives NNS forged
V	Verify	Check the performance of the designed NNS solution satisfies the customer

The expansion of continuous improvement deployment in forging can be induced by the increase of maturity, i.e. their ability to recognize the value of new knowledge such as application of NNS. Second (Shah and Ward, 2003), this causes, for example, learning established with the implementation of LM can stimulate interest in SS and the LSS.

2.6. Design For Lean Six Sigma (DFLSS)

The LD begins with the five steps (Gremyr and Fouquet, 2012):

- Specify value;
- Identify the value stream (VSM);
- Make the value stream;
- Create a project pull system;
- Seek perfection.

It also includes group technology (GT) concepts, concurrent engineering (SE-DFM), integration of functional aspects of each project. Considers the development supported by the project development chain: supplier; manufacturing, engineering (product features) client.

The DFLSS is a new design strategy. Its focus is also cost reduction; however, the DMAIC focuses on continuous improvement and the DMADV is directed to projects. Thus, DFLSS strategy NNS project is to hear the Customer Voice (CVo) to meet the critical need of quality (CTQ's) with application of QFD and FMEA creating robustness in the forged product design and process.

Finally, the combination LD / DFSS coupled CIM technique, sustainability, NNS matrices improves the competitiveness of forging. This combination develops the project quickly, reducing their costs, i.e., optimize time to market.

3. METHODOLOGY AND CASE STUDY

Taking as object of study the Near Net Shape application in cold extrusion techniques with LM and SS in an integrated way, this work aims to raise directions of how to conduct such an initiative.

Thus, the article aims to provide greater familiarity with this research approach that, according to the classification criteria provided by (Gil, 1991), can be framed as exploratory.

Prepared a case study, which is a form of empirical research to investigate a contemporary phenomenon in its real context, especially when the boundaries between phenomenon and context are not clearly defined (Yin, 1994).

The study multiple cases present two companies. The first is a Japanese company, called the supplier. The second company in the auto parts segment, the machining area; it is an American company with subsidiary in Brazil, calling client.

The supplier - forger (Japanese) and developer of NNS highlights the importance of following approach:

- Develop a VSM manufacturing roadmap;
- Develop a DMAIC for forged project management, dies, try-out (see Figure 9);
- Design (develop the design of the product);
- Forming (develop the design process);
- NNS (incorporate subsequent operations from earlier - Precision forged the project) and;
- It also recommends the use of computational techniques CIM.

Also the water company adopts includes group technology concepts, concurrent engineering (SE-DFM), integration of functional aspects of each project.

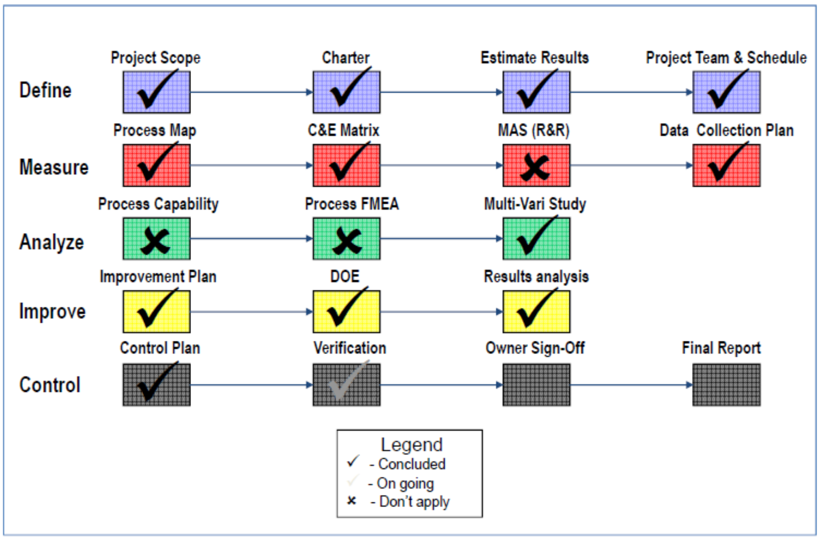


Figure 9. DMAIC for management NNS project

Already the company case, client (machining) of NNS system, in its strategic plan an innovation system, incorporates up new NNS products as family presented in Figure 8, which contains a synchronizer cone ring, cold forged, finished with teeth.

Figure 8. Synchronizer cone ring: cold forging steps.

Companies, provider (forging) and client (machining), adopted in the design techniques of Lean Design (LD) derived from Lean Manufacturing and Design For Six Sigma (DFSS) derived from Six Sigma; that way, you can say that is an application of Lean Six Sigma (LSS) in NNS projects or DFLSS.

After application of LD / DFSS companies involved in the project developed a VSM of NNS proposal for synchronizer cone ring.

Figure 9 shows the simplified VSM, the current state and future state. In VSM current state in forging (supplier), are (four operations): cut billet; hot forging; heat treatment; cleaning.

In the future state VSM, in forging, are (six operations): cut billet; hot forging of the blank of the synchronized cone; heat treatment (annealing); cleaning the blank; phosphating and lubricating the blank; cold forging of synchronizer cone ring (forming teeth and back tapering).

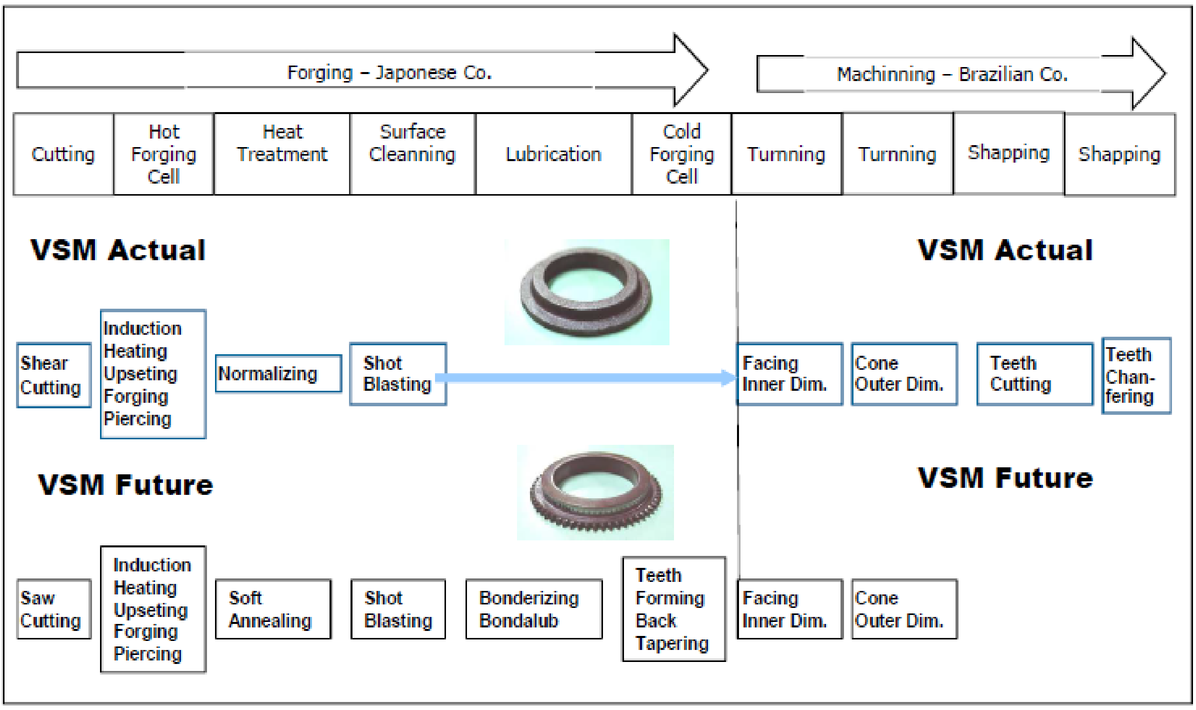


Figure 9. Synchronizer cone ring: Present and future Value Stream Method (VSM)

In the machining (client), the VSM current state, are shown (seven operations): turning a face and bore; turning the other face and outer diameter; toothed cutting; chamfering the teeth; heat treatment (carburizing, quenching and tempering) and; grinding face / hole; grinding face / external (see Figure 9).

In the machining, the VSM future, are shown (five operations): turning a face and the bore; turning the other cheek and outer diameter; heat treatment and; grinding face / hole; grinding face / external (see Figure 9).

In Figure 9, are not included the heat treatment operations as well as the grinding operation (face / hole and face / external); because they remain in both VSM (current and future).

Table 4. Forging manufacturing route - The Company case – forger

	Present VSM Conventional Forging		Future VSM Future NNS Forging	
	Description	**Detailing**	**Description**	**Detailing**
Operation	billet cutting	Blanking Shearing machine	Cut billet	Saw or precision sharing machine (Weight control billet)
	Hot forging (forging and trimming)	Eccentric press	Hot forging (forging and piercing)	Eccentric press
	Normalizing (forged)	Heat treatment	Annealing (forged blank)	Heat treatment
	Shot blast	"Wheelabrator" Wheel blast	Shot blast	"Wheelabrator' Wheel blast
			Phosphate & lubricate	Forged blank
			Cold forging	Mechanical press (cold forging synchronized cone) (teeth forming and back tapering)

Table 5. Machining manufacturing route – The Company B – Auto part

	VSM Actual Conventional Machining		VSM Future NNS Forged with machining	
	Description	**Detailing**	**Description**	**Detailing**
Operation	Turning (CNC Lathe)	Turning a face and bore (internal diameter)	Turning (CNC Lathe)	Turning a face and bore (internal diameter)
	Turning (CNC Lathe)	Turning the other face and outer diameter	Turning (CNC Lathe)	Turning the other face and outer diameter
	Shaping	Teeth cutting		
	Chamfering machine	Back tapering		
	Carburizing, quenching and tempering	Heat treatment	Carburizing, quenching and tempering	Heat treatment
	Cylindrical grinding machine	Grinding face / hole	Cylindrical grinding machine	Grinding face / hole
	Cylindrical grinding machine	Grinding face / external	Cylindrical grinding machine	Grinding face / external

4. RESULTS AND DISCUSSION

Next we analyze the results found in VSM current state and the future. In the VSM future demonstrates the need to add the product cold forged Near Net Shape, two (2) operations (see Figure 9): lubrication and cold forging of the teeth (see Table 6).

This addition converts the stream: four (4) to six (6) forging operations; up resulting in an increase of 50% (6 operations divided by 4 operations) the cost of forged; which in turn changes the value of 10% to 15% of the final product (see Table 6).

However, the machining is reduced to two (2) "bottlenecks" operations, which are cutting the dentate; chamfering the teeth (back tapering) (see Table 6).

Table 6. Results achieved in the future VSM, with the multiple case studies

VSM Future	
Forged (Company A)	**Machining (Company B)**
Addition of operations: lubrication and forging toothed cold transforming the cost of forged from 10% to 15% of the final product	Reduction of two (2) operations called "bottlenecks" (elimination of shaping and chamfering steps)
Change in manufacturing forged route: four (4) to six (6) operations (increase of 50%)	Reduction of 29% (2 operations divided by 7 operations) of the cost of the total machining, when considering the entire flow of machining operations

In the present VSM is showed that the cost of forged represents 10% of the final product; while the machining cost is 90% of the final product (see Table 7). The final cost of the product has: a (10 + 90 = 100 %) for (15 + 64 = 79 %); ie. a total gain of 21%.

Considering the cost of synchronized cone like US$ 2.00 each and 800,000 parts per year, the gain is US$ 0.42 per unit or US$ 336,000 per year

Still, if you can stand, in case company (machining), additional, tangible and intangible gains, such as: reducing the total lead-time; reduction in process inventory (WIP); reduction of investment in a shaping machine (see Table 7).

Table 7. Final Results achieved with the multiple case study

<table>
<tr><th>Present VSM Actual</th><th colspan="2">Future VSM : final product</th></tr>
<tr><th>Cost</th><th>Cost</th><th>Considerations</th></tr>
<tr><td rowspan="6">Forged part
Company A
Cost of the current forged represents 10% of final product

Machined part
Company B
Cost of the current machined represents 90% of final product</td><td rowspan="6">Forged + Machined
Final cost of the product: (10 + 90 = 100) % for (15 + 64 = 79) %; i.e. a total gain of 21%

Considering the cost of the synchronizer cone ring as US$ 2.00 each part and 800,000 parts per year, thus the gain is US$ 0.42 per unit or US$ 336,000 per year</td><td>Reducing the total lead-time</td></tr>
<tr><td>Elimination of two jobs (direct hand and machine work)</td></tr>
<tr><td>Area reduction</td></tr>
<tr><td>Reduction the WIP (inventory)</td></tr>
<tr><td>Reduction two (2) shaping machine</td></tr>
<tr><td>Reduced investment in one shaping machine (US$ 1.5 MM)</td></tr>
</table>

The case study also shows as a result, the LM methodology and / or LD seek to reduce the time between the application of machining and delivery of forging, through the elimination of waste.

The LM / LD identifies, which adds value in the customer's perspective; thus connects the steps necessary to produce goods in worthless waste flow.

As a challenge, it is also worth noting that there is to explore how to keep the implementation of LM in forging in cold extrusion, through working groups committed to change.

The SS and / or DFSS, is a program to improve the capacity of forging processes using statistical tools to identify and reduce or eliminate the variation of forging processes. It is disciplined program that uses data and statistical analysis to measure and improve operational performance by eliminating the forging defects.

Although the SS / DFSS tools are not new, its application and the form of deployment are unique and very effective, which explains the success of the program which is the challenge of forging the methodology.

The integration of the LM / LD with the SS / DFSS has a central focus, which has been the basis for its structure and tools. The truth is that both are methodologies that are complementary, not competing with each other.

5. CONCLUSION

The challenge of Lean Production (Lean Design and Design For Six Sigma), applied to the Near Net Shape, still remains. LM / LD focuses on waste elimination, defined as unnecessary for production of a product or service; this applies to every area of the business, including customer relations, product development and plant management.

Another highlight for forging, is how to incorporate the methodologies in an integrated manner, since the LM / LD does not have a structured improvement program, deep troubleshooting and statistical tools to deal with the variability aspect that can be complemented by SS / DFSS, which, in turn, does not emphasize the improvement of the speed of the process and reduces lead time, prominent aspects of LM.

The best way to take advantage of an opportunity is often to follow a structured sequence of steps from defining the problem to the solution deployment, and one of the most widely used models for improvement / design is the DMAIC / DMADV, accompanied by the development mapping the values stream flow (VSM).

Thus, product trends for the Near Net Shape cold extrusion technology goes towards a world class stage of knowledge, in the forged industry, are applications of science and knowledge, evolving into the technological improvement and adding increasingly more value to the forged product.

This ability to include the contributions of the LEAN MANUFACTURING as well as the SIX SIGMA approaches allows the forging industry to give an innovative response to its customers, offering to them a better level of technology and sustainability at the begin of this new millennium.

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