USE OF VALUE STREAM MAPPING TO EVALUATE THE IMPLEMENTATION OF CONWIP AND *KANBAN* IN A MANUFACTURING COMPANY

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Abstract. *Lean Manufacturing is characterized by a production philosophy where resources are optimized in order to generate better results, and it has been used by manufacturing companies that seek to reduce or eliminate waste, and to improve the production processes continually, reaching a significant reduction of costs. The present work presents an analysis and proposes improvements to a company that manufactures undercarriages components for tractors. The Value Stream Mapping (VSM) technique, which is an important tool of lean manufacturing, is applied to a product that compose the tractor track chain. In this work, a current state map was created for this product, which is called link. Based on this map, the future state map was created, and in this future map CONWIP (Constant Work-In-Process) and Kanban were proposed to be used in the programming environment. Finally, both future state maps were compared with one another, seeking to evaluate which is the best production programming and control practice to be applied to the problem considered, and the implementation plan is also presented.*

Keywords*: Lean Manufacturing, Value Stream Mapping, Waste, Kanban, CONWIP, Manufacturing Company.*

1. INTRODUCTION

The current Brazilian competition scenario, occurring due to the economical globalization, lead the companies to have an even greater commitment to the continuous improvement of their products, processes, and the elimination of waste. The inefficiency can not be passed on to the customer any more, because of the large increase of product options provided by the reduction of the customs barriers and the consequent opening of markets.

The absence of competition in some business branches, which many years ago financed the wastes of the mass production system, is currently almost an extinct factor of the world economy. The competition imposed by the new economical environment has been pressing the organizations to become absolutely efficient and effective.

The production system developed by Toyota, referred to as Lean Manufacturing, has been meeting the expectations of the companies with respect to the need to become competitive. The lean philosophy seeks to unceasingly eliminate the wastes inherent to the mass production processes.

The lean production system, when properly applied, leads to excellent results, because the sources of opportunities to reduce and eliminate wastes are many, among which it can be mentioned the large inventory and the operations that do not add value, the bureaucratic wastes, such as an inefficient information system, slow purchasing procedures, among others.

The problem considered in this paper concerns the implementation of the value stream mapping tool in a company of the metal-mechanic sector, seeking to evaluate the manufacturing process for future improvements. It is aimed at eliminating wastes, which not only reduce the production efficiency, but also increase the involved costs that contribute to the final price of the product. It is also intended in this work to suggest a pull system model to plan and control the production of the company.

2. LEAN MANUFACTURING

2.1. Evolution of the Manufacturing Systems

According to Rotandaro (2002), the improvement in the performance of processes in the manufacturing environment is a classic problem faced by the industrial leaders. Since the origins of the industrial revolution, with the gradual transition of the production systems from the craft way to the modern industrial organization conceived by the industrial capitalism, famous talents of the time, like Frederick Taylor and Henry Ford, became known for their contributions to the obstinate search by the companies for productivity increase. Taylor sowed the basis of the so-called scientific management, and Ford revolutionized industry introducing the mass production lines. The studies developed by Ralph Barnes (time studies), Frank and Lillian Gilbreth (study of fundamental movements) and Harold Maynard (system of measures of synthetic times), among other exponents of production engineering, also took place during that time of development of methodologies and procedures for the modernization of the industrial management. It can also be considered that the phenomenon of the expansion, leadership and pioneering of the North American industries with the contemporaneous growth of the consumption society between postwar periods and the 1970’s, was partly due to the competition resulting from the systematic application of those "new" techniques.

However, the globalization of the economy continued increasing the competition among the companies, and the patterns of competition have become more and more complex. For a long time the companies simply competed based on price; however, with the increase in competition, origination mainly from countries that were known as the "Asian Tigers", besides price, quality started to be a critical success factor in the market. And as more and more companies became dominant of the competence of producing with greater quality, new differentiating attributes, such as reliability, delivery time, and innovation, increased to be demanded by the market. It should be pointed out that such expansion of the scope of expectations by the customer occurs mainly due to the tendency observed in the recent past of the companies to provide more and more to the consumer a mix of diverse products, which have been manufactured in decreasingly minor series. Therefore, the domain and application of a group of techniques, such as division of work, rationalization of methods, timing, standardization, mechanization, automation, and line balancing, originated with Frederick Taylor, Ford and their disciples, became obsolete and insufficient for the companies to remain competitive in manufacturing.

A new group of principles and techniques that characterize the system so-called lean manufacturing, has as objective to produce more and more with less resources. The lean production system was conceived and developed by Toyota Motor Corporation so that its factories became capable of operating "just-in-time" (JIT), in other words, able to manufacture and deliver only the necessary products, in the exact amount and in the exact moment. The JIT concept had already been idealized by the direction of Toyota in the 1940's, but the bases of the lean production system took the three following decades to be developed. However, the results of that initiative were already significant and evident in the 1970's. In the 1980's, the lean production system won wide reputation by being recognized as one of the pillars of sustentation of the vigorous growth recorded by the Japanese automobile industry at that time, and by being pointed by researchers of Massachusetts Institute of Technology (MIT) as the most competitive production model among those adopted by automobile companies all over the world.

The production lean system is now in a process of wide dissemination in several industrial segments, not limiting to the automotive sector or the largest companies. However, a methodology does not exist for its implementation that can be pointed out as the most advisable and effective.

2.1. Lean Manufacturing and the Toyota Production System

The Toyota Production System is an management philosophy that attempts to optimize the organization in order to respond to the customer's needs in the shortest possible time, with the highest quality, and with the lowest cost, and at the same time it increases the safety and moral of their collaborators, involving and integrating not only manufacturing, but all the parts of the organization. Being a much more efficient, flexible, agile and innovative production system compared with mass production, it is a system that is qualified to face a market in constant change. Actually, its essence is to seek, identify and eliminate each and every waste. It is what is known as "principle of no-cost", which is based on the belief by Toyota that the traditional equation *Price = Cost + Profit* should be replaced by *Profit = Price - Cost*.

In order to implement the processes according to lean manufacturing techniques, it is aimed at minimizing the production wastes, their effects, and to proceed with the continuous search of "zero defects, zero setup time, zero inventory, zero movement, zero failures, zero lead time, and one-of-a-king batch". Lean Manufacturing has some techniques and tools such as cellular layout, kanban (pull production), value stream mapping (VSM), among others.

Lean manufacturing has a series of principles to eliminate waste during production, seeking to reach, or even overcome the customers' expectations (MACDONALD et al., 2000). According to Hines and Taylor (2000), the five principles of Lean Manufacturing are:

- To specify what adds and what does not add value under the customer's perspective. Unlike what is done traditionally, this evaluation should not be made under the point of view of the company or its departments.
- To identify all the necessary steps to produce the product along the production line, so as to avoid the generation of waste.
- To promote actions in order to create a continuous value stream, without interruptions or wait.
- To produce only in the amounts requested by the consumer.
- To make an effort to perform continuous improvement, seeking to remove losses and wastes.

Womack and Jones (1992) emphasize that seven types of waste were identified by Shigeo Shingo, which are the following:

- Overproduction: loss for producing more than the customer demands, resulting in an inefficient flow of parts and information, or inventory excess. The lean production system requires that only what is necessary should be produced, according to customer's demand.
- Wait: long periods of idleness of people, parts, and information, resulting in an inefficient flow, as well as in long lead times. Usually the loss due to wait is associated with high amounts of machine use, because a line of products is formed before a stage of production. Among the concepts of lean manufacturing, the continuous flow of materials should be guaranteed. Lean manufacturing also places emphasis on man and not on the machine. Man cannot be idle, but the machine can wait to be used.

- Transport: excessive movement of people, information or parts, resulting in unnecessary expenses of capital, time and energy. The time and the resources expended in material transport, e.g by rolling bridge, forklift or any other means of transportation, add cost to the finished product.
- Process: it corresponds to unnecessary operations, introduced in the process to solve problems caused by the equipment or operation, affecting the quality of the material.
- Movement: the disorganization of the work environment, resulting in low performance of the ergonomic aspects and frequent loss of items, leading to the time lost due to activities that are not necessary or that could be carried out in a shorter time. Lean manufacturing seeks the reduction and consistence in the movements through the study of methods and times of work, resulting in simple and low cost solutions.
- Rework: it is the loss with activities that are done for correcting defects in the products, processes and delivery periods. Lean manufacturing seeks to consistently reduce defects and the continuous improvement of the processes.
- Inventory: excessive inventory of materials, which include raw material, work-in-process (WIP), and finished products, resulting in excessive costs and low performance of customer service. Many times inventory hides the inefficiency of the process, quality, reliability and production problems. The loss because of inventory originates other types of loss such as transport and rework.

3. MODELS OF PRODUCTION PLANNING AND CONTROL SYSTEMS

There are two ways of controlling production: the push and the pull production methods. In the first method, the planned production amount is determined by the demand forecasts and by the available inventory. Successive production periods are determined based on standardized information sent to each manufacturing process. The product is then manufactured sequentially since the first process. In the pull system, the final process withdraws the necessary amounts of the precedent process at a certain moment, and this procedure is repeated in the reverse sequence, going through all the previous processes.

According to Tubino (2000), in the conventional systems where production is pushed, in order to follow the master production schedule (MPS), a complete production program is elaborated periodically, from the purchase of raw material to the assembly of the finished product, and it is conveyed to the responsible areas through the emission of purchase, production and assembly orders, but before it is passed through a sequencing stage, to adapt it to the constraints of physical capacity of the manufacturing process. In the following programming period, based on the remaining inventory, new orders are programmed to follow through a new MPS.

In the kanban system of pull production, nothing is produced until the customer (internal or external) requests the production of a certain item. In this case, the production programming uses the information in the MPS to emit orders to the last stage of the manufacturing process, usually the final assembly, as well as to determine the amount of kanbans for the work-in-process (WIP) in other sections. As the customer of a process needs items, he/she turns to the kanbans, acting directly on the process so that the consumed items are manufactured and restored to the stock.

Bonvik and Gershwin (1996) affirm that a tool similar to kanban was also developed and called CONWIP (constant work-in-process). CONWIP is a hybrid system (pull and push) to control production. As in the kanban system, CONWIP limits the amount of WIP in the system, with the benefit of reducing costs and lead time. Unlike kanban, where the control is carried out among adjacent stations, in CONWIP the production is pulled from the last station of the line, where the entrance of new orders takes place, keeping WIP constant, and the flow within the system follows the logic of the pushed production. Figure 1 illustrates the differences among the models: push (MRP), kanban and CONWIP.

According to Souza (2002), a common point among the kanban and CONWIP systems is that the level of WIP cannot exceed a certain limit, which is determined by the total amount of kanbans circulating through the whole line. In this work the application of the kanban and CONWIP systems to a company of the metal-mechanic sector is proposed, and a comparison between these approaches is presented.

4. VALUE STREAM MAPPING (VSM)

The objective of VSM is to reduce significantly and in a simple way the complexity of the production system and still provide a group of guidelines for the analysis of possible improvements. In that sense, the VSM technique helps in the conceptual development of the "future situation" of the manufacturing system, applying lean production techniques.

VSM is quite important for the implementation of lean manufacturing, allowing the visualization of the value stream, composed by the flows of processes, materials and information, helping to identify wastes, as well as their sources. VSM helps making decisions about the represented stream, turning it more logical and simple. Once VSM for the current state is accomplished, which seeks to represent the map of the current situation (today's picture), the following step corresponds to the elaboration of the future state map, pointing out the potential improvements, based on the observations accomplished along the mapping of the current state. This technique, presented by Rother and Shook (2003), seeks to accomplish the mapping "door to door ", i.e., from the reception of the raw material to expediting to the final customer.

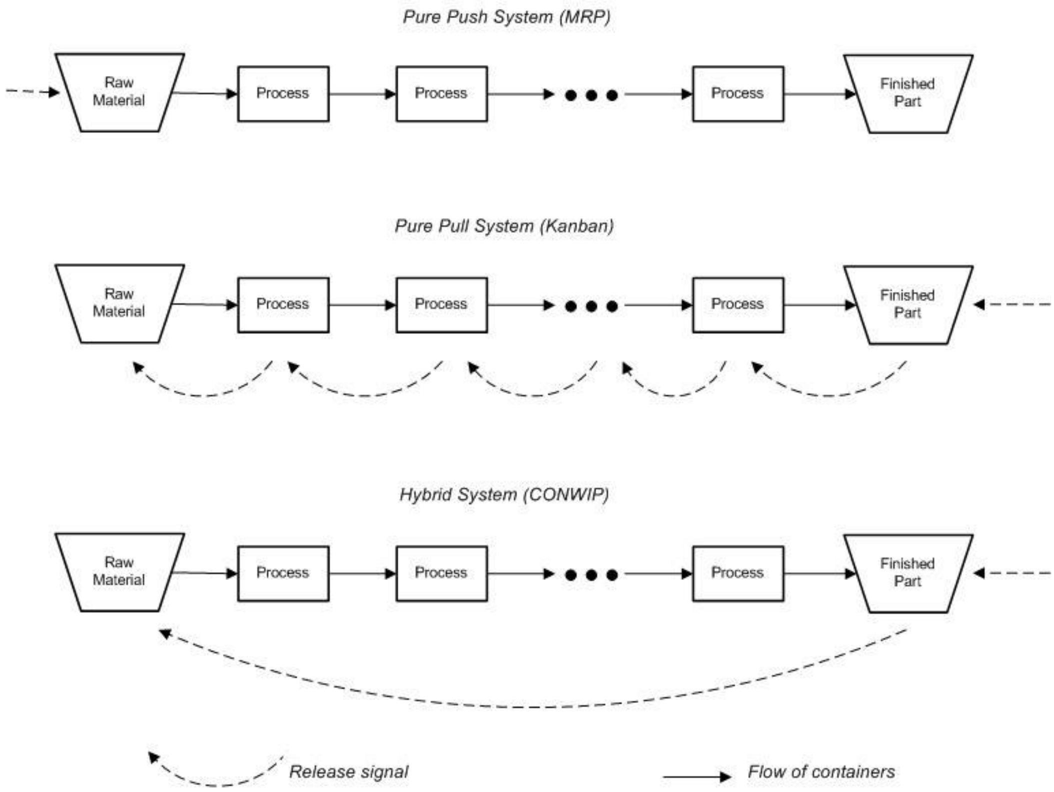

Figure 1. Mechanisms of push, pull and hybrid production

The stages of VSM, shown in figure 2, indicate that VSM can be used as a communication tool, a business tool, and a tool to manage the process of change. In this work the mapping will be approached as tool to plan the changes seeking the implementation of lean manufacturing. VSM is presented according to the following stages:

- Product family: identify which product or family should be focused;
- Draw the Current State: current situation of the process, and these pieces of information are obtained directly from the shop floor;
- Draw the Future State: situation that should be reached;
- Implementation plan: how the transition between the current state and the future state will be performed.

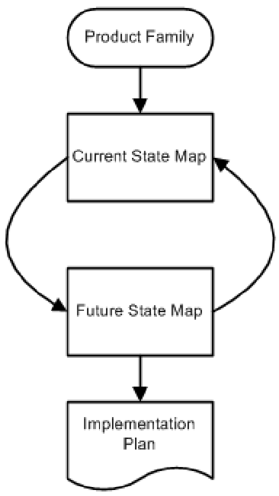

Figure 2. Phases of Value Stream Mapping (VSM). Source: (Rother and Shook, 2003)

It can be noticed in figure 2 that the arrows between the current and future state maps have double sense, indicating that the development of the current and future state maps are superposing efforts, in other words, ideas on the future state will occur while the current state is being mapped and, in the same way, the future state map will show important information about the current state that had not been noticed.

5. VALUE STREAMMAPPING APPLIED AT COMPANY OF THE METAL-MECHANIC SECTOR

5.1. Description of the Company

The company studied in this work encompasses operations such as casting, forging, machining, thermal treatment, and the necessary logistics to their activities. Its vertical integration structure is one of its main business characteristics.

It manufactures parts for belt tractors, which includes the rolling set for tractors and diggers, as well as their components (links, bushings, pins, rollers, shafts, bearings, guide wheels, and motor wheels).

The company produces parts to the replacement market, supplying to the following manufacturers: Caterpillar, Fiat-Allis, Komatsu, Volvo, Case, Poclain and others. This work describes the mapping of the part called "link" for tractors and diggers.

The production system of the company can be considered as a repetitive batch production system, which is characterized by the production of a medium volume of standardized parts in batches, which move through a series of operations, and are programmed whenever previous operations are accomplished. This system seeks the manufacture of economical batches in order to absorb the setup costs of the processes. However, since there are large waiting times of the batches between the operations, the manufacturing lead time is high. The company is structured in a departmental manner, which usually presents the seven wastes of Shingo: overproduction, waits, transport, inventory, process, movement, and defective products.

According to this scenario, it is evident the need to implement a lean manufacturing system, as well as the need to clarify and to spread, among all people involved in the production process, the best path to reach the objectives proposed by lean manufacturing.

5.2. Current State Map of the product called Link

This process begins with the loading of raw material onto the guillotine that accomplishes the cut according to the specified dimensions, preparing the blank for the batch of parts that will be forged. This material is then fed to the forging cell, composed by an induction oven, forging hammer, a deburring and calibration press, and a tank for thermal treatment.

The blank is heated up in the induction oven, reaching in a few seconds the temperature of 1300°C through an electromagnetic field, being later thrown automatically through a gutter to the hammer for forming. After the forging process, each part moves on a rolling belt to the next press, which removes the burrs and gages the parts, and then they proceed on belts to the cooling tank for the first total tempering process. Later, the parts proceed to the area of thermal treatment, where they undergo a normalization treatment to reduce hardness and relieve tensions.

After this process, the parts return to the forge where they undergo two types of finishing processes, one with emery wheel, and the other with grinders or manual flying wheel machines. The finishing with emery wheel is applied to adjust the articulation, i.e., the external parts of the link that contribute to the rotation of the belts in the wheels are polished with the emery wheel, while the second process is to remove the resulting burrs of the forging process.

After moving by those finishing processes, the parts proceed to the conventional milling machines with two heads, where the races are machined, and then they undergo shot blasting that removes the machining burrs, besides cleaning the scales left by the forging process.

After the shot blasting process, the parts proceed to the induction section, where a thermal treatment of the material to a certain temperature is carried out, so that through a thermal shock the desired mechanical resistance of the link is reached. In this process a superficial treatment is accomplished, increasing the hardness of the link´s race, which is the portion of the part that suffers more wear and tear in its application. It should be pointed out is that in this equipment the tempering of the right and left link is carried out simultaneously, and there are two stations that accomplish this operation.

After having accomplished all these processes, the parts proceed to the final machining station, which is carried out in a machine that was especially designed for manufacturing links. This machine manufactures the grooves where the bushings and pins are assembled, besides the drilling for the assembly of shoes. Similarly to the previous equipment, this machine also executes the process on left and right parts simultaneously.

During all the processes presented above, the parts undergo a meticulous quality control analysis, and they are directed to the subsequent processes only if they are approved.

Lastly, the parts proceed to the area where the final inventory is located, where they await the requests by the expediting area to be assembled and sent to the sale locations. All the data regarding cycle times (T/C) and setup times (TR) were obtained directly through timing during the production processes.

The EMS system (supplied by the company Datasul) was used to determine the sales of belts for the period of one year, and with that information the monthly consumption averages of these materials were determined. The EMS system was also used to determine the inventory between processes. With these data the takt time and the lead time of the processes can be calculated. The current state map of the link can be seen in figure 3.

5.3. Future State Map for the Link

For the elaboration of the future state map, some modifications should be accomplished in the processes in the current state map, which are described in this section.

It is necessary to incorporate a continuous flow along the cutting stations (guillotine) and the forging cell, since the guillotine is only to manufacture this family of products. It is also necessary to create continuous flow is the last two stations, the one for tempering the race, and the final machining, because they have a similar cycle time and both work simultaneously with right and left links.

It is also necessary to eliminate the following operations: deburring finishing, articulation finishing, and machining of the race. In order to eliminate these operations it is necessary to modify the design of the tools. In the case deburring finishing, it can be eliminated by changing the angles of the die, leading the punch to cut the part only at the center of the part (called parting line), and not on the whole area of the part. This change also influences the finishing of the articulation, because with the punch cutting only at the parting line of the part, the force necessary to cut the part decreases, and consequently it is not necessary to apply a large force to the gage, and thus not much material is distributed on the sides of the part, and as a consequence this operation is eliminated.

Finally, in order to eliminate the machining of the race, it is necessary to create a new tool, which works as a guillotine, so that it cuts the part soon after being forged. This tool has been tested in production, but a problem is occurring during calibration, because when the cut is accomplished the part bends. On the other hand, it is known that this operation is feasible, since the forging process performed y other companies result in the required quality.

Since the philosophy of the company is to have parts for immediate delivery whenever the customer requests, it was chosen to keep an inventory of finished products of all the items, and production begins with the consumption of the final products, leading to their replacement, and the items are manufactured according to the rhythm of the demand, with the request sent to the initial pull process. The WIP will vary according to the planning and control system of the adopted approach, kanban or CONWIP.

For the future state map that uses kanbans, supermarkets of WIP will be created between the manufacturing processes, where the subsequent processes pull the production from the supermarkets of the previous processes, and these processes produce according to the final customer's demand. In the case of the application based on CONWIP, a supermarket will be created only for the finished products, because between the other processes only the constant WIP will be kept. The future state maps for the kanban and CONWIP approaches are shown in figures 4 and 5.

When comparing the kanban and CONWIP approaches, it can be noticed that in both cases the lead time decreased in relation to the current state, as well as the WIP. In the current map of the link, the lead time was equal to 171 days, while in the future map for the kanban the lead time is equal to 105 days, whereas for the CONWIP approach the lead time is equal to 88 days. Regarding the WIP, they are equal to approximately 36 days in the current map, while they are equal to 22 days in the case of the kanban, and 5 days for the CONWIP.

With these data it can be observed that the best system is the one that applies the CONWIP approach, because it enables the significant reduction of both the lead time and the WIP when compared to the use of kanbans. However, for this system to work correctly, it is necessary a strong commitment to the continuity of the process, since a failure in any of the operations affects the system as a whole. On the other hand, in the case of the kanban system, since intermediate inventory exists, they can supply eventual failures for a certain period. As the cycle times are well below the takt time in the future map of the link, it can be chosen to implement the CONWIP approach directly. The implementation plan for the value stream of the link is shown in table 1.

6. CONCLUSIONS

In this work it was verified that, with the implementation of the elements of Lean Manufacturing in the considered company, it can attain the following positive goals: lower inventory (raw material, WIP, final products), shorter manufacturing lead limes, elimination of unnecessary operations, decrease of work shifts. Besides, such gain can be reached with reduced investments.

It is recommended the use of the CONWIP approach, due to the great diversity of models of parts manufactured by the company, and in this case it would be extremely difficult to keep a supermarket of products between each station for all the models of parts. Besides, as the CONWIP system allows a greater flexibility in the way the parts move between the resources, enabling that bottlenecks, temporary or not, are conveniently protected. Finally, by allowing that the WIP is placed in front of the bottleneck resource, CONWIP can work with lower levels of WIP than the kanban for this case study.

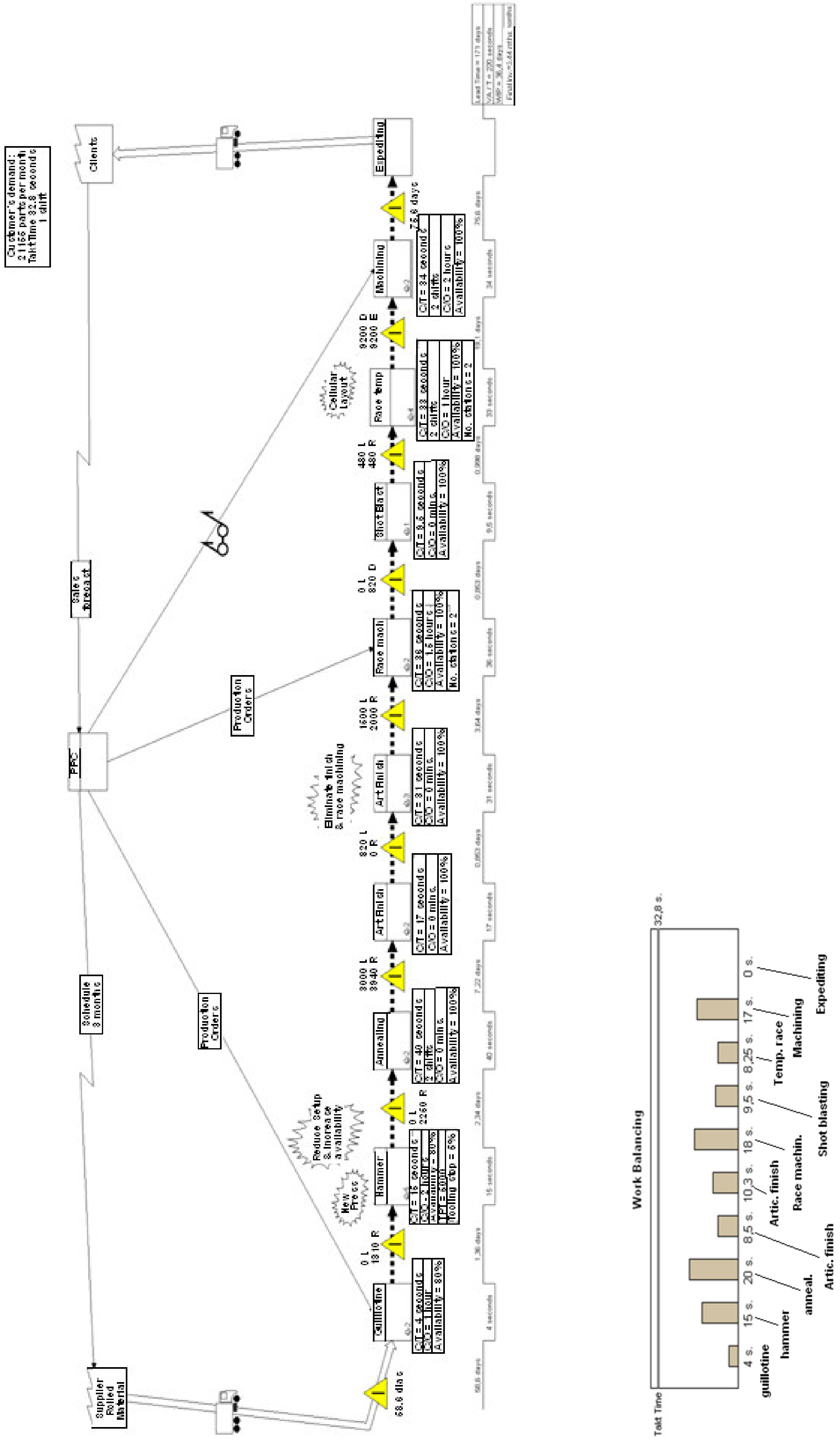

Figure 3. Current state map for the product called Link

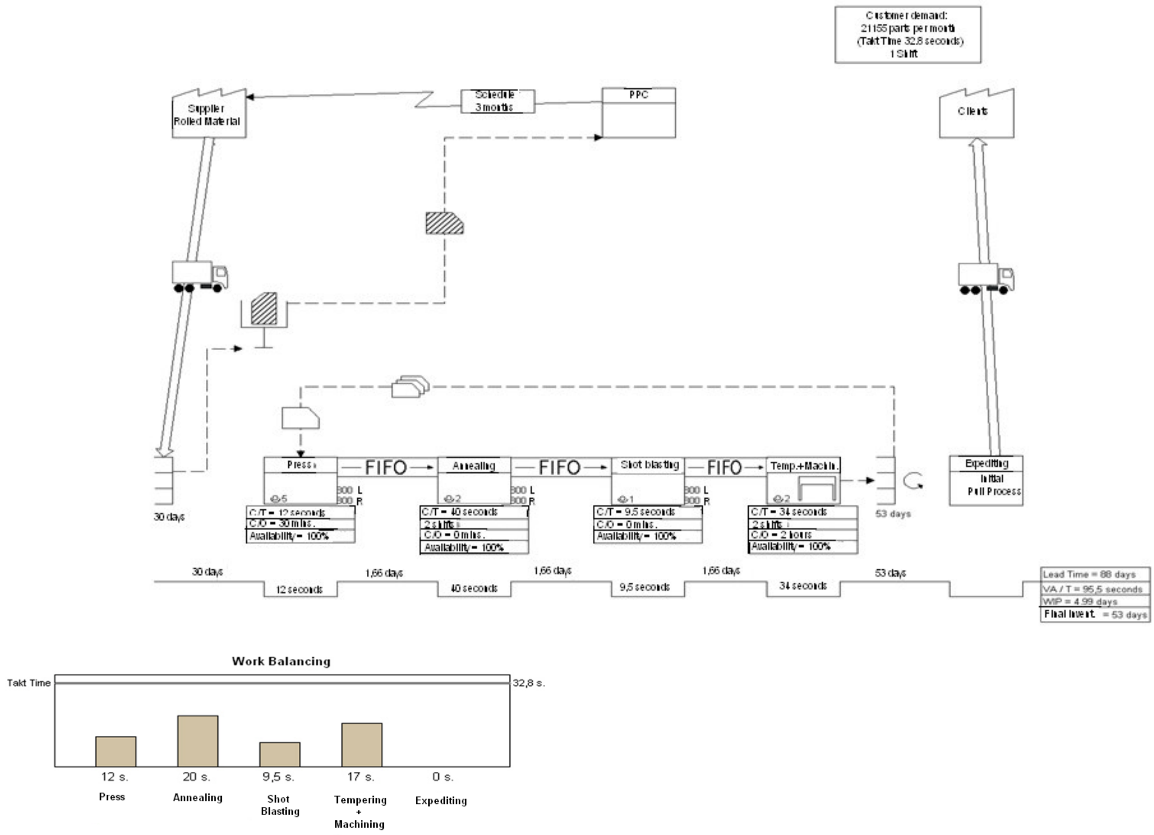

Figure 4. Future state map for the link (CONWIP)

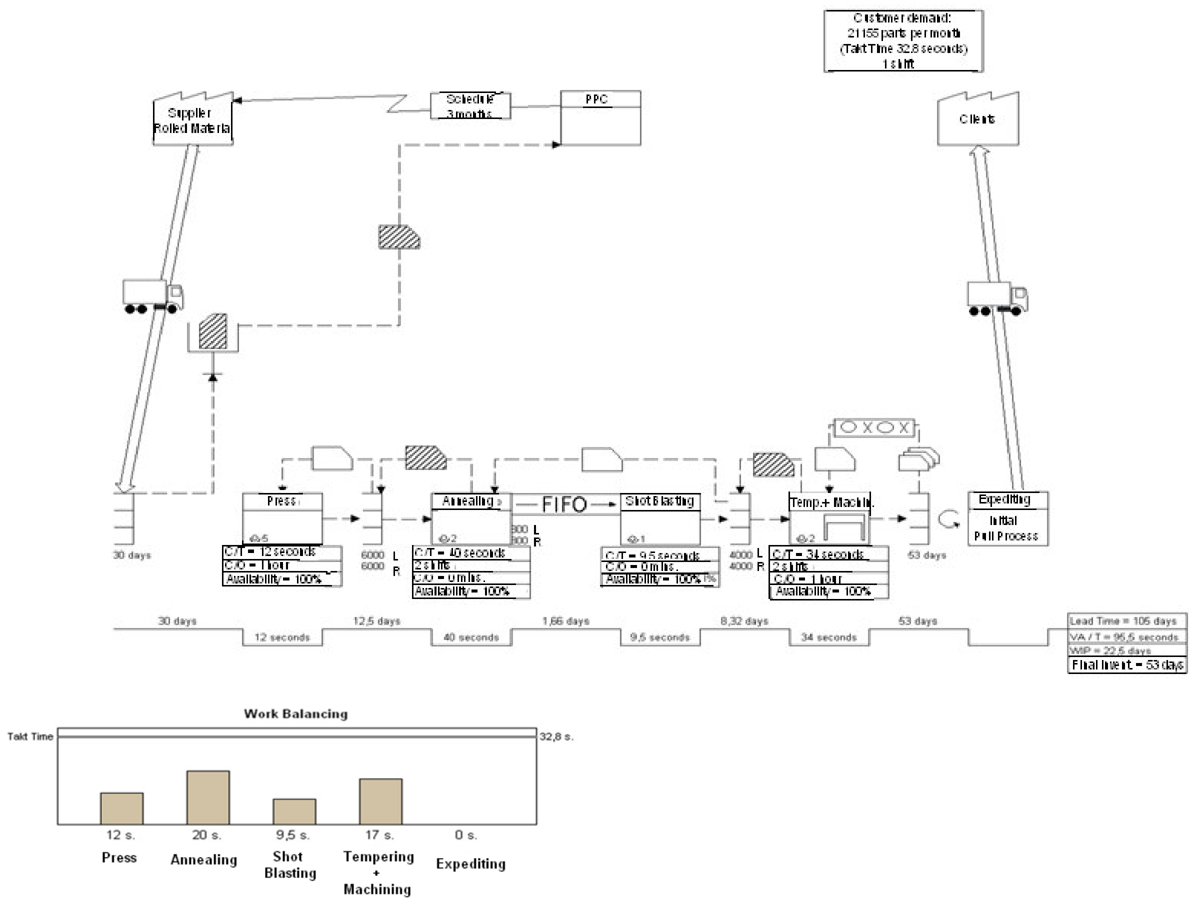

Figure 5. Future state map for the Link (*kanban*)

However, that does not mean that the CONWIP system is better than the kanban approach for all cases, because both systems can be considered similar with regard to the way they treat the demand, in other words, whatever the customer demands is manufactured. Nevertheless, the manner in which the parts move in the production system is sequenced in a different way, that is, it depends on the specifics of the considered production system.

Table 1. Implementation plan of the future state map for the Link

Implementation plan of the future state map (link)													
Objective	*Goal*	*Execution Schedule (months)*											
		1	2	3	4	5	6	7	8	9	10	11	12
Redesign the forging tools	Eliminate machining and finishing of the races												
Layout change	Create cell for tempering/machining												
Manufacture tools	Change the forging process												
Implement the CONWIP system	Manufacture according to the market demand												
Evaluate the efficacy of the implementation	Check if the system is working according to the Takt time												
Continuous improvement (*Kaizen*)	Reduce costs and the continuous improvement of the manufacturing processes												

A difficulty for the complete implementation of the proposal presented in this work is the fact that the company now has a departmental structure, where each area is responsible only for reaching its specific targets, and not the customers' needs. Each area is controlled through productivity graphs, where the greater is the monthly productivity, the lower will be the area´s costs, even if parts that the customer does not need at the moment are being manufactured.

Thus, in order to apply the proposal presented in this work, the first stage to be executed is the change of the directors' and employees' mentalities, who believe that the manufacturing system works in a more efficient way when large batches are produced, since the control elements adopted by the company use the metric of the mass production systems models. Also, through the point of view of lean manufacturing, producing large batches is not a positive factor, because they hide the wastes and inefficiencies of the system. Then, the control elements and the productivity goals should be altered, so that they become more adherent to the requirements of lean manufacturing.

As a result of this work, it was possible to observe that there are several benefits resulting by lean manufacturing, considering that, with the current globalized economy, it is necessary to seriously take into consideration the changes imposed by the market, and consequently the manufacturing systems cannot any more pass on their inefficiencies to the customers.

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