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ORIGINAL ARTICLE

Redesigning an assembly line through lean manufacturing tools

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Abstract The implementation of a lean manufacturing strategy represents a robust contribution to the phase sequence that leads to operational excellence and the continuous improvement through the elimination of non-value-added activities. Therefore, lean practices contribute substantially to plant operational performance. This paper studies the use of value stream mapping (VSM) as a tool in lean manufacturing implementation and a framework of improvement activities, in particular for an efficient introduction of kanban and milkrun techniques. A case study illustrates VSM use, as well as kanban and milkrun systems application on an assembly line. Finally, the results obtained show the path of improvement, measured through the lean rate (LR) and dock-to-dock time (DtD).

Keywords Lean manufacturing · Value stream mapping · Parts flow · Kanban · Assembly line

1 Introduction

The implementation of a lean manufacturing strategy allows strengthening the phase sequence that leads to operational excellence, a continuous improvement, and the elimination of nonvalue-added activities [1]. Thus, the influence of lean practices contributes substantially with the operating performance of plants [2, 3] and the use of lean tools allows the improvement of results [4]. The tool value stream mapping (VSM) is applied as a way to progress toward lean manufacturing and as a formula to lead the activities of improvement [5–9]. In this sense, the contribution of internal transportation and its scheduling is specially important. Kanban card has been used to identify problems of production flow, maintaining the synchronization of inventory and material flow among production cells [10]. We can find that practical approaches to determine the optimal kanban size via simulation have been established [11] and some real applications have been published [12–14]. However, the literature does not include authentic industrial applications showing the integration of kanban and internal transportation and its effects in the strategic productive factors. Moreover, it is necessary to study the empirical lean situations [3, 15, 16] to contextualize the lean concepts.

This paper is focused on the analysis and use of the VSM to get improvements by means of kanban and milkrun, implemented in an efficient way. Their strategic influence is measured by means two lean metrics: lean rate (LR) and dock-to-dock time (DtD) [6]. These metrics are important to establish gains and identify areas for further improvement. Some authors have demonstrated their relevance to system performance in pull environment [17, 18]. LR is a key, fundamental, and paradigmatic metric and it should be reduced. It is useful to find and tally inventory accumulations where the flow of value has to be interrupted due to process problems. DtD depicts the material flow through the value stream. Therefore, it is a measure of the ability to deliver on time and it is generally a good indicator of the effectiveness of lean initiatives to improve the flow.

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It is a reliable indicator of the extent to which inventories are being reduced and the cash flow improves [5].

A case study illustrates the use of the VSM and the implementation of kanban and internal transportation (milkrun), lean tools applied in an assembly line. The study is focused on a specific products family, an injection valve.

2 Brief literature review

Lean manufacturing has received ample attention in academic literature and practical performance, from how the lean production concept was formulated and disseminated [19] until recent comprehensive literature review [3, 15, 16]. In them, a common topic appears, that is, the need to explore the implementation and performance relationship with a practical focus and with a definition of the context because the results depend on the manufacturing environment.

However, it has been defined from a macroscopic or organizational viewpoint [3]. We affirm that it is not possible to define the context without including the product and the manufacturing process, at least from an operational and technological perspective. In this sense, a real and detailed case study provides the sufficient items to valuate the implementation and under what conditions, allowing the benchmarking between practical of companies. It is possible to find analysis of case studies about steel production [7], forging processes [9], aircraft manufacturing [15], or assembly lines of vehicles [1]; although the last one has been studied deeply, some criticisms can be found in the literature due to lack of resulting data [19]. Their methodology is similar, using lean tools, and they are adapted to the study variables, but the improvement point and the results achieved are different. Furthermore, in line with Milterburg [20], how an implementation can be done is a subject that benefits from research. In addition, "a line of interesting researches is one that follows real one-piece flow production systems over time to learn what problems are most difficult at different points in time, how these problems are solved" [20].

Currently, assembly lines are still fundamental to get the smoothing of production system [20], and they are studied under several operative perspectives seeking its flexibility [21, 22]. Both concepts are subjects of pull systems. In assembly lines, pull and lean systems are concepts frequently connected, although they pursue different objectives; pull system toward the reduction of work-in-process (WIP) and lean system toward minimizing the buffer variability [23]. Moreover, with respect to the election of production control system in a pull system, the alternatives considered are focused on kanban [24] and constant work-in-process (CONWIP) [25], both of them focused toward the reduction of WIP. Although some authors have observed the advantages of the CONWIP with respect to the kanban [25, 26], others argue that when the total number of cards in both systems is equivalent, the average WIP will can be less in the kanban system, being the appropriate distribution of kanbans a relevant element to get the minimum WIP [27]. Besides, kanban allows maintaining the flexibility of the system [28] and also, in favor of kanban, Yang [26] found that kanban is a system more flexible and that "CONWIP may require a larger storage space between alternate stations because all full containers may gather between any pair of alternate stations." On the other hand, kanban and pull are still considered synonymous by practitioners [16]. So, in a small space, we suggest that the better option is a kanban system. Once more, we can appreciate that similar systems can give different solutions, hence the importance to detail how the line assembly runs and what processes and operations are carried out.

Although many tools exist, from its origin, VSM has demonstrated its efficacy [5–9]. Following the benchmarking perspective, as well the use of a contrasted tool, facilitates the interchange of improvements. It is a tool that provides communication solutions for practitioners to obtain maximum efficiency and definitions of theoretical development points to become a reference among redesign techniques [8]. The recent criticism [29] only shows that this tool continues being adequate and its flexibility has allowed to adapt it to complex situations [5]. A detailed description of VSM can be seen in Rother and Shook [30]. Thus, as improvement tool simplifies the measurement of times without added value, so the calculation of indexes of lean metrics is easier and it is possible to enhance the operative actions with strategic results.

This paper unifies several gaps and it shows how redesign operative actions can achieve high levels of performance in a short time and in a real industry, inside a context of an assembly line with a small space, and that it requires flexibility, that it is studies in-depth. The academic literature requires of similar case studies [15].

3 Methodology

Methodology is based on the continuous improvement. Consequently, it will be a continuous process of status study, calculation of metrics, implementation of progress, observation of the results, and new decision-making of improvement.

A first design of VSM is realized according to the original data from production processes and the layout, identifying the key times of each workstation. This design represents the starting point of improvement. Next, the map of the parts flow is shown to verify the materials movement between the workstations, calculating the productive and unproductive times, stocks and metrics that will help to characterize the process, and marking some targets of progress. This design of the VSM allows the beginning of the progress in the manufacturing line [30]. Metrics used are DtD and LR. DtD depicts the material flow through the value stream, the time it takes for material to flow from the receiving dock (or order entry point) to the shipping dock (Eq. 1). LR is the ratio of working time of added value to DtD or throughput time (Eq. 2):

$$\mathrm{DtD} = \text{Time for material flow through value stream}, \qquad (1)$$

$$\mathrm{LR} = \frac{\text{Added value work time}}{\mathrm{DtD}}. \qquad (2)$$

Another important issue is to regulate and reduce the accumulated stocks. Consequently, it will be necessary to establish a control of the accumulated stock. The control will be accomplished easily in accessible stores and shelves. This activity facilitates the management of parts waiting to be processed because the visual control is more effective. It will use the takt time [6, 20, 24], a fully known lean metric (Eq. 3), as Eq. (4) defines:

$$\text{Takt time} = \frac{\text{Total time available for production per shift}}{\text{Required numbers of parts per shift}}, \qquad (3)$$

$$\text{Stocks} = \frac{\text{Time of entire step} - \text{Time added value}}{\text{Takt time}}. \qquad (4)$$

Once the takt time is defined, it is possible to establish the cycle time, a basic parameter in pull system [6, 24]. So, traditionally, objectives such as high machine utilization and high production volume are less important when the takt time is defined because the aim is work within the time [20]. However, a better materials flow can conciliate both objectives: work within the takt time and higher LR.

Next, the necessary progress will be implemented to achieve the desired state of the manufacturing process. There are two main improvements: firstly, it is a system to control intermediate stores (kanban system), and in addition, it allows improving the material flow between workstations to obtain a more flexible process, optimising the job of each workstation (milkrun). Every 2 months, a new VSM is checked and metrics are recalculated and analyzed to control improvements.

4 Manufacture and product description

The product is a combustible injection valve called EV6. This paper deals with the assembly process of three main components of the valve: the stem, the cup, and the needle with a major pursuit of the cup due to its machining processes.

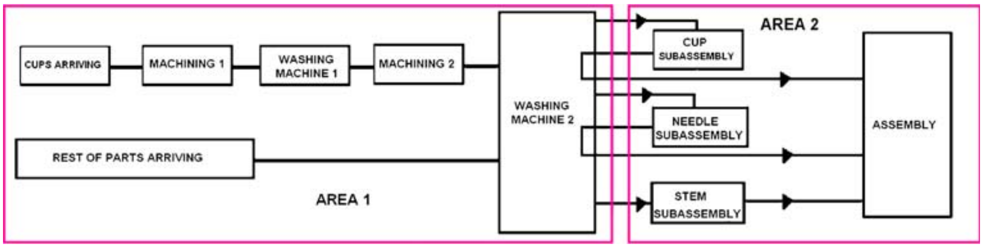
The major process steps in manufacturing are sketched in Fig. 1. To emphasize that washing machine #2 is the same as washing machine #1, they are named with different numbers to avoid difficulty in understanding the order of activities. All the parts of EV6 are received in production area #1 where they are stored. It is necessary that it undergo full decontamination, demagnetization, and washing before the assembly. Area #2 includes three main subassemblies at different workstations. Subassembly processes have several stages which are carried out in automatic and independent workstations that do not permit a continuous materials flow. Finally, after subassembly tasks, 20 stations with a continuous materials flow compose the assembly line.

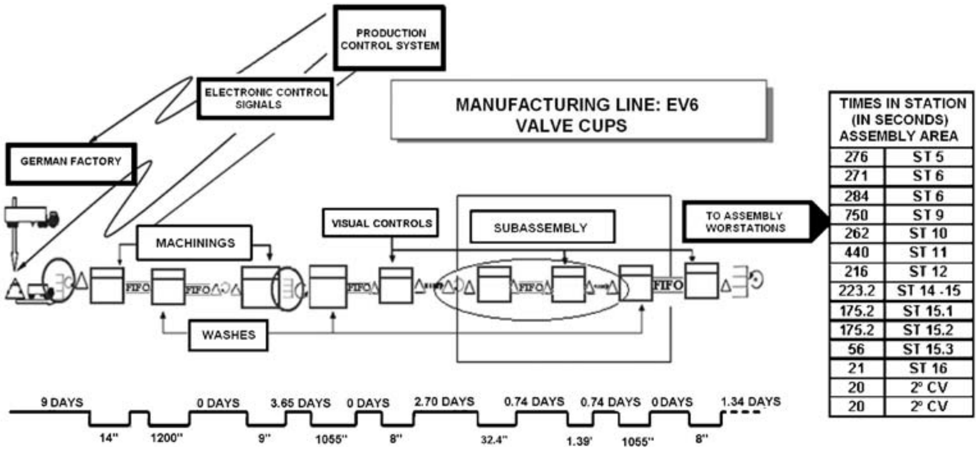
5 Initial value stream mapping

Initial conditions for the analysis of the VSM of March appear in Fig. 2. This state is based on the cup because it is the component that requires the longest trip inside the factory: before the subassembly, there are two machining processes and two washes. The production of the cups is a push system due to the two machining process that they are always producing and storing parts. The flow of information and WIP are described as follows (see Figs. 1 and 2).

The central factory in Germany is at the same time the main supplier and final customer of the valves plant. Every 4 weeks, the factory introduces, in a computerized system, the material requirements for the manufacture. In parallel,

Fig. 1 Manufacturing line flowchart





TIMES IN STATION (IN SECONDS) ASSEMBLY AREA	
276	ST 5
271	ST 6
284	ST 6
750	ST 9
262	ST 10
440	ST 11
216	ST 12
223.2	ST 14 -15
175.2	ST 15.1
175.2	ST 15.2
56	ST 15.3
21	ST 16
20	2° CV
20	2° CV

Fig. 2 VSM for the month of March

an external store is sent an electronic order about the mailing that is going to realize the factory in German. The German factory is about 2,500 km from external store, located near Madrid, and mailing is realized once a week. The external store is 6 km from Madrid and there is mailing by truck every 2 h. Cups are stored as raw material at machining #1 workstation in shelves very close to it. This machining has a feeder in which the cups settle to be machined. Cups in the feeder are considered stock and two parts is the lot size. Machined cups settle in containers to lead the washer. After that, the cups are washed in the preassembly washer following first in first out (FIFO), and still following FIFO, go to machining #2. This installation is close to the first machining (approximately 50 m) and near the preassembly washer. The lot size is two parts again. Machined cups settle in containers to lead the washing machine #2 (see Fig. 1) and they remain in the supermarket of the washing machine #2 until they are processed. The machining processes require 14 and 9 s per piece, respectively. There is a continuous work of 24 h/day, which implies that everyday about 2,500–3,000 cups are ready, when the daily demand is about 1,800 valves. So, there is an overstock of machined cups caused by the push production system.

In the washing process, the lot size is 2,464 and the time of step is always the same because the process time is unique regardless of the lot size. Under a FIFO order, parts pass a visual control by lots, stocking the rest of production on the shelf. Later, cups are pushed up to shelves along with the preassembly. From washing machine #1 up to the above-mentioned shelves, there are 20 m. From these shelves, the components are taken to obtain finished preassembly final cup. These cups will be stored in other shelves waiting for a new visual control to eliminate defective cups, and finally, finished cups have to be washed again in washing machine #2. From this point, the cups arrive to the assembly area to meet the other components of the valve. In the achievement of the VSM, it is taken into account whether it is added value or not. The results can be perceived in Fig. 2. There are some points that accumulate a major time without added value. These points, marked with circles in Fig. 2, are those where more stock is accumulated and there are already long waiting times. These are the points where we focused our actions of improvement.

The first one appears in the external store until machining #1. This total time is the sum of three partial times: The one that spends the cup in the external store, the time which remains in the supermarket, and finally, the time at the feeder of this machining. The second one appears just before washing machine #2 and the third one is focused on the storage of the finished cups before passing to assembly.

The assembly area does not cause problems, except workstation #5 where there is an accumulation in time of 1.34 day and in the final store where the assembled EV6 wait until they are shipped to Germany. The mean lead-time at this store is 22 days (annual turnover of about 10 days). The final calculations of DtD and LR provide the following results: DtD=19.82 days and LR=0.383%. These metrics have been calculated without the external stores, so they only depend on what happens inside the factory. The amount of parts stored at the different critical points is also very important. One of the improvement objectives is to reduce these intermediate stocks.

6 Improvements

A first analysis of the line reveals that it is convenient to convert the push system into a pull production system by means of kanban and supermarkets. The intention is to reduce stocks and times of step, and thus to increase LR. In order to solve the problem that an external store uncontrolled represents, the following change is introduced: shelves in which the cups are stored before spending to the machining #1 raisin, working as a supermarket. They are regulated by kanban cards against the external store.

This action limits the stock in the mentioned supermarket and it allows a self-controlled system. Another kanban circuit is needed to control stocks between machining of cups and washing processes. This kanban circuit will be referred to later. Another objective was the reduction of stock of cups. A lower lot size is adequate in order to reduce stock of the finished cups, ready to be assembled in one of the critical workstations of stock accumulation. The lot came down to 682 opposite to the previous setup of 1,232. The shelves are not completely filled up, but they are left empty to the middle of its capacity. With this lot size, reduced flow of cups speed up across the process.

A critical point is workstation #5, the assembly starting point. Assembly problems appear in some workstations due to a reduced space available to accumulate parts-in-process and finished parts. Parts cover the different workstations in dissimilar amount because the trays have different capacities. Due to this, the idle material is accumulated. There is not a good control of the internal logistic and this problem cannot be tackled only though mathematical programming. To get the correct replacement of material, it is necessary to use a system that improves the times of supply. This could be made with an efficient and effective standardized routing and a conveyor (milkrun) to transport the trays between the workstations. Milkrun implementation will be realized in May. It is very important to control the state of the process that is why it is decided to establish two new VSM in May and August.

6.1 First improvement: kanban system

The implantation of a kanban system responds to the need for reducing stocks. The production line requires a quick detection of potential problems at the different workstations, not identified in the stocks, reducing to a minimum the number of parts affected. The line includes several stages of preassembly and treatment of some components before final assembly, a rapid flow of material would suppose major capacity of reaction to quality problems of production.

With a classic production system, parts are processed at the speed that allows process capacity, without considering that the following processes could be slower or to go so far as to stop. When this happens, there exist a few bottlenecks in which the material accumulates, incurring in different situations:

- Stored material consumption does not guarantee FIFO, so the traceability gets lost.
- Previous process could be producing defective pieces and storing them without detecting the problem, and until the following process does not use these component parts, the problem does not come evident. All the materials produced with these defective pieces will have to be reworked or eventually scraped.
- The risk of stopping all the former processes due to a stock breakage of conform pieces.

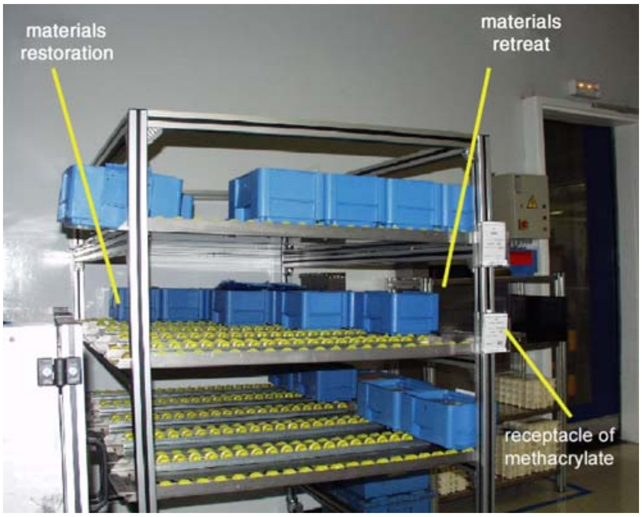


Fig. 3 Shelve with kanban cards

Observing previous situations, it is possible to affirm that the accumulated problems and errors can cause worse difficulties, and they even can go so far as to affect final client and it is possible to sum up in a chain of losses and inefficiencies. Kanban is an economic and effective solution to control material involved in different processes. In this case, a first important factor is the origin of suppliers, most of them German, so frequent deliveries become costly. Due to the high number of variants in the final product, the storage of large lot of pieces of many different references should be avoided. A huge warehouse space and a low rotation (cash flow) are not feasible. As a first solution, an intermediary service of logistics is hired next to the factory, to storage in big volumes with frequent

KANBAN ESTANTERÍA LAVADORA
EV6
Asiento rectificado
Referencia: 1 288 699 791
Cantidad : 2.000
Cantidad especial : 2198
Tarjeta N°: 4/5

Fig. 4 Kanban card

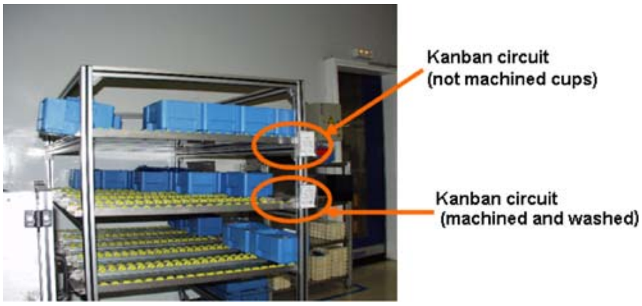


Fig. 5 Kanban shelve with two kanban circuits

mailing of material. The idea was to entrust storage to an external logistic operator.

With this service, the quantity of material in flow is reduced, but the problem still appears at the time of realizing orders of material from the factory. It was established for safety specifications that the material had to be served with the original packing of the provider, without external manipulations. Components do not come packed from equal form, not with equal quantities. Some of them are received in hermetic bags, others in not reusable shelves, etc. This was a difficulty added at the time of realizing orders, since the frequency of achievement of orders was not the same with all the components. To avoid excess of material in the limited space of the one that was getting ready, shelves were made to place the material (see Fig. 3). The shelves were organized to have small stocks of each reference. These shelves have a little inclination and a few rollers, so that process of storage is more ergonomic and the picking reliable. The material must be fed on the back, whereas the picking of material must be realized on the front. With this system, FIFO is guaranteed and the material is consumed in the order that it is received.

The information of kanban cards are: (1) name and reference of the component: there are components with equal name but different references, so the reference is fundamental to identify every component; (2) name of the piece: EV6; (3) trip of the card: although the normal thing is that kanban circuit have a place of beginning and other of end, in this case, it does not happen this way, kanban only circulates along the washing machine; (4) quantity and special quantity: these quantities reflect the quantity of original packing and another one for special orders which the received quantity does not coincide with that of original packing; (5) number of card and quantity of cards in circulation: cards are numbered correlatively. Figure 4 illustrates it.

Another problem was the definition of the number of cards because although there are known mathematical formulae that define the exact number, the initial situation was not very stable for the processes, so in certain components, the requirements for extra stock was established to cover the delays that these processes could provoke. This definition is based on the experience of the planners and for a moment of production at which the line was not employed to 100% of its capacity. As this is a flexible system, introducing or eliminating kanban cards is possible to simply regulate the number of stock between the processes [28].

Fig. 6 Kanban circuit diagram

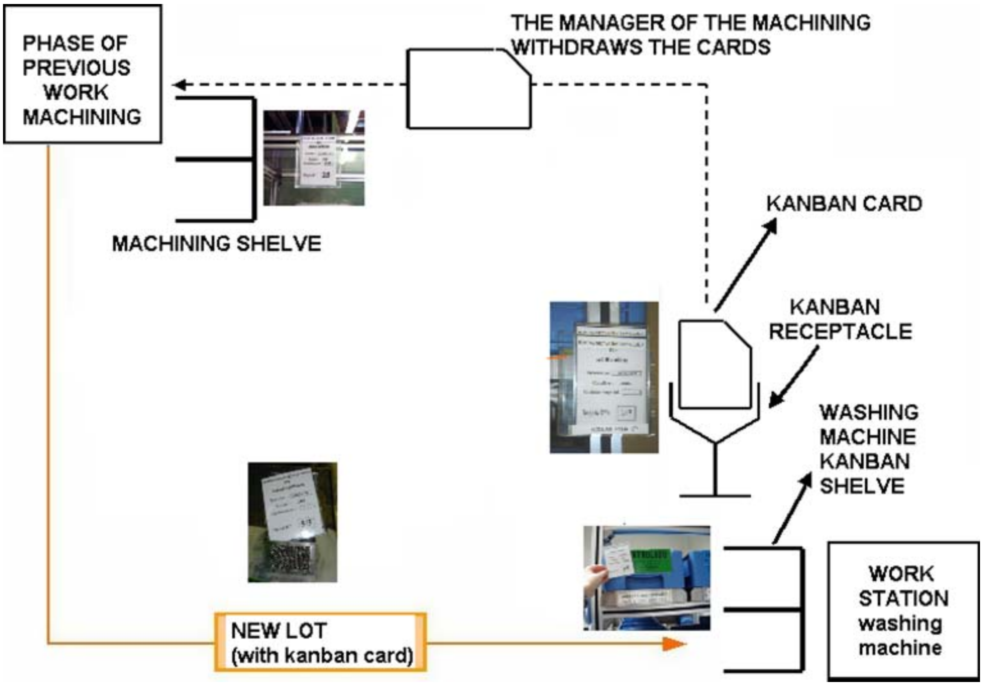


Fig. 7 Milkrun

6.2 Kanban circuit 1: shelves kanban in washing machine 1

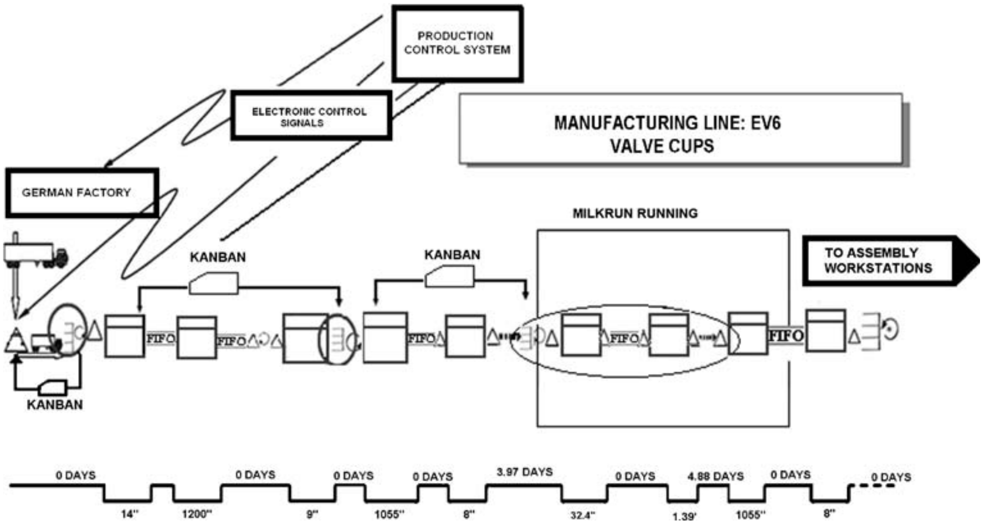
To support the control of stock once received and to facilitate the material requirements to the external store, a special kanban has been designed, named *Shelves Kanban*. The cards do not arrive to the provider because, in this first phase, providers have not been included in the system, only they have been informed about the need to receive lots as the quantity of original packing to minimize the risks that the manipulation supposes. The factory is connected with this external store by electronic way and the request of material is reported in the kanban.

The number of cards is limited, according to the quantity by lot and of the necessary stock. Every lot that is received is accompanied by a kanban card and is stored in the shelves of washing machine #1 depositing the receptacles on the back and later, when material is needed, taking the material from the front following FIFO. The associated kanban card is taken too and it is placed in a receptacle of methacrylate (see Fig. 3) attached to the side of the shelves.

At the beginning of every work shift, the person in charge of the washing machine will gather all the cards that exist in the kanban receptacle and will order to the external store the material that indicate the cards and in the quantity that the same ones should indicate. It is important to use the material in the quantities of the original packing to avoid problems at the time of realizing orders.

As seen in Fig. 1, cups have a first machining before they arrive at the washing machine. Although this process is not realized near the washing machine, only the personnel of this one are authorized to realize requests of material. Cups are received at the washing machine and then they are transported to the area where the machining

Fig. 8 VSM for the month of August



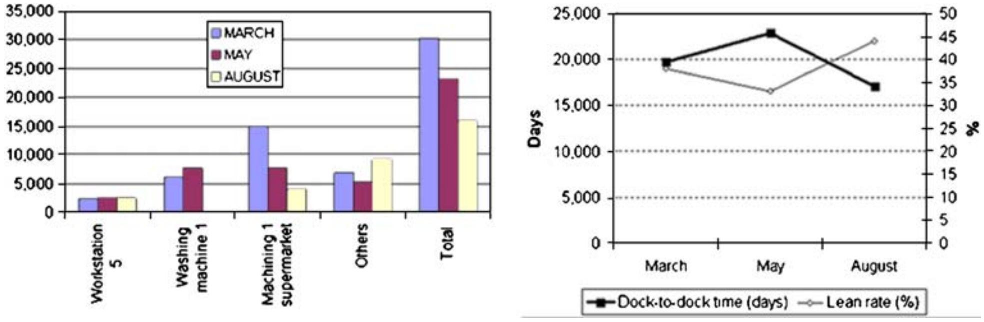


Fig. 9 Metrics and accumulated stocks evolution

one is realized. They are stored in supermarket shelves with kanban card and receptacle of methacrylate. The machine operator will have to take the kanban cards that indicate the quantity that must be restored. In the machining phase, there are two kanban circuits established (one of raw material for restoration of material and the other of material going to the next phase). Two colors have been established for cards; these colors also are different from those of the washer, so at first sight, the circuits to which every card belongs are identified. Figure 5 illustrates this phase.

6.3 Kanban circuit 2: machining 1

Kanban circuit of machining #1 (see Fig. 6) is the following one: as soon as the cups are machined, a kanban card is enclosed with them and they move to the washing area. They are placed in the shelves of the washing machine supermarket, depositing the cups at the back part and retrieving them from the front side. In these shelves (see Fig. 5), two places have been enabled to store the cups, to have a safety buffer, for the instability of the previous machining process. If the machining process stops for quality problems, it is a safety quantity to continue with the production.

Once the machined cups go on to the following phase, the card settles in the pigeonholes enabled for it. These pigeonholes are different from that of the supply of material for the provider, and although it is placed near, they are perfectly identified with a cartel with the origin and destination of the cards (see Fig. 5). Implantation of kanban system achieves that manufacture orders are always the same cards, avoiding neither papers nor notes to arrange the work; the administrative tasks are simplified. Also, since every worker can only make the pieces withdrawn by the later process, manufactured parts will coincide with real requirements for every moment. Conversely, on having reduced the inventories, location of problems that could arise in the productive process is easier. It is also a perfect tool to be able to realize and to update material flows and to be able to prepare VSM.

6.4 Second improvement: milkrun

To create a fluid flow of materials that prevents some idle stations and others from having excess of stock, two decisions must be taken. The first one is related to the conveyor. A kind of conveyor must run through the line without interrupting the workers. This conveyor must have the capacity to transport the trays between the workstations. After several studies of capacity, distances, speed, and easy handling, the best solution would be a conveyor with wheels handled by a worker instead of other possibilities, called *milkrun* (see Fig. 7). The second one is to establish the route for the milkrun, so it was necessary to consider: (1) the rate of material consumption and calculate the speed of the assembly line and (2) the amount of trays needed for each part. Thus, it is necessary to establish milkrun routings and visit frequency to workstations. After realizing the diverse stage of trips, needs, and times, the routes were established [11].

7 Results and discussion

A case study results have been evaluated across VSM diagram. The calculation of several critical magnitudes indicates if the manufacturing process improves or deteriorates according to the criteria previously established. The outcomes appear in the diagram of the VSM (see Fig. 8) and in the justificatory and comparative stages of the results.

Inventories have been reduced as we can see in Fig. 4. This provokes the reduction of idle times, from initial 32 to 10.9 h in August. Improvement objectives were twofold: reducing stocks while avoiding idle times or movements of worker due to accumulated material. Both have been reached. The metrics, LR and DtD, have been improved. DtD is reduced from 19.75 days in the VSM of the month of March to 17.1 days in August. LR is increased from 0.38% to 0.44% at the same time. Global results in Fig. 9 explain the milkrun effects to improve the metrics that had not got better between March and May in spite of kanban implementation. Lean manufacturing has significantly improved the parts flow.

It is possible to see in Fig. 9 that the LR and DtD results obtained with the second analysis are worse than the first one; nevertheless, it is possible to appreciate a good tendency with reduction of stocks. The changes do not produce an instantaneous progress. Workpeople need to become familiar with the new habits of work. The analysis of the third month with milkrun and kanban fully implemented shows a clear progress in both metrics and accumulated stocks.

8 Conclusions

This paper provides a case study of the redesign of an assembly line by means of lean tools, which connects manufacturing system design objectives to operational objectives. It focuses the redesign of operations by eliminating nonvalue-added time and decreasing the intermediate stocks through VSM to identify improvement points and kanban and milkrun to eliminate inefficiencies. Results from the VSM explain that the design of kanban circuits is insufficient without the adequate conveyor, while the integration of kanban and milkrun reduces the waste in terms of unnecessary inventories, excessive transportation, and idle times applicable to every production and layout designs. After 3 months of studies and evaluation of results, including secondary data, it is confirmed that the application of these skills of production help to enhance the materials flow in the assembly line in a short time and under particular conditions of small storage space and requirements of flexibility.

The empirical results drawn from the case implementation serve to demonstrate that an operative decision has helped to improve the metrics lean, in particular to reduce the DtD and increase the LR and shows the transformation of a former line manufacturing organization into a better lean organization that has set a lowest cycle time. The combination of lean tools will be a way for routing increased flexibility and process improvement for any industry. They appear useful and practical, even when every factory is different and some planned adaptation necessary.

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