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Lean manufacturing applied to a wiring production process

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Abstract

This project was carried out at a company in the electric mobility sector, which manufactures chargers for electric vehicles, specifically in the wiring section. The main objective of the developed work was to improve the production processes in order to enhance responsiveness to the growing demand. After analyzing the processes in the section, the objectives were outlined to enable the improvement of some practices in the production department, such as the ones related to the organization of the raw material supermarket, as well as the calculation of the wiring consumption by chargers, and the implementation of a production control system. After the improvement actions were implemented, it was possible to observe a 14,9% reduction in the changeover process of the cable cutting process; weekly wiring consumptions were estimated, and procedures were defined to generate orders of raw material and supply to the workstation, which led to the elimination of stock shortages. In addition, worker autonomy increased and production downtime was reduced.

Keywords: Lean Manufacturing, Process improvements; 5S; Production control; Changeover; Stock shortages; Production practices; Time wasted.

1. Introduction

With the exponential increase of competitiveness in the industrial sector, the focus on products and the innovation of projects have become essential to ensure quality and low costs [1]. Consequently, one of the major dilemmas that companies are confronted with daily is that of increased productivity. In an attempt to achieve improvements in production, manufacturers aim to reduce lead *time* and production waste [2]. Since the universe of electric mobility has grown exponentially, it is essential to enhance all the administrative and production processes so that companies will remain relevant in the market and able to hold their own due to the quality, innovation and customer satisfaction provided. The work described in this article was developed at an electrical mobility company, which is responsible for assembling electric vehicle chargers, more specifically in the wiring section. With the constant increase in customer orders, solutions are required to improve production processes, as well as to increase productivity and efficiency, in order to address market needs. For this purpose, it has become important to ensure that production downtimes are minimized. Furthermore, communication procedures should be improved and the permanent supply of raw material in the workplace must be assured. It is also essential that the criteria for the organization of material are clearly determined, and that production is defined and controlled, with greater responsibility and autonomy being handed over to the operators. This article is organized as follows: section 1 contains the introduction; section 2 consists of a review of literature pertaining to good practices in *Lean Manufacturing*; section 3 describes the methodology adopted in the development of the project;

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section 4 presents the production process of wiring, and identifies ensuing problems and their solutions; section 5 presents the results obtained during the project; finally, section 6 discusses the conclusions reached.

2. Literature Review

Lean culture implies following a set of techniques and principles with the purpose of increasing product value, through methods which enhance relevant and valuable processes, while simultaneously eliminating those that add no value to the final product [3]. There are several Lean tools and methods which can be used to achieve the improvement of production processes. These have been demonstrated by the numerous cases of Lean applications in the industrial context, which have proved to be essential when improving the production conditions of an organization. The implementation of the Value Stream Mapping (VSM) tool at a company which manufactures plastic bags, enabled the detection of waste and increased value-added activities from 15% to 90%, culminating in a reduction in takt time from 46.6 to 26 minutes [4]. It was also reported that the application of VSM, as well as experiment design, simulation, and alteration from cell production to a pull system at a company in the electronic sector, allowed for a reduction of 72% in the organization's energy consumption [5]. At a company in the automotive sector, it was reported that the implementation of VSM and Value Stream Design (VSD) in a Just-In-Time (JIT) production system led to the identification of waste in production. By using the pull system and *kanbans*, lead time was reduced by 39% and Overall Equipment Effectiveness (OEE) was increased by 6% [6]. It was ascertained that the implementation of Lean tools such as one-piece flow, standard work, *kanban*, *jidoka* and *heijunka* at an automotive company culminated in a reduction in lot size from 30 days to 16 and, on average, setup times dropped by 50% [7]. VSM and Single Minute Exchange of Die (SMED) methodology have also been reported to improve the quality of a printed circuit board production line, as well as reduce production costs and lead time. The implementation of VSM allowed for the detection of waste on the line, which was caused by the excessive amount of time required for changeover and Work In Progress (WIP). The application of SMED in the bottleneck of the production process, alongside Kaizen techniques, led to the achievement of the results required. There was a reduction of approximately 2 seconds in cycle time, as well as a decrease from 144 to 0 in the WIP inventory, and a reduction of 145 to 54 seconds in changeover time [2]. Also Correia et al. [8] used several Lean tools to improve the performance of an assembly line of video cameras for security systems through the application of VSM, SMED, LLD (Lean Line Design) and LLB (Lean Line Balancing) methodologies. This work made it possible to verify that with a combination of tools that allow a deep analysis of the productive systems, it is possible to save about 10% of the time normally spent in the production of these products. It is also curious to observe that 3% were gained by replacing the practice of applying thread lock glue to the screws for a solution of nylon patch screws. At another company in the automotive sector, lean tools such as VSM, Kaizen, Visual Management, 5S, Standard Work, Plan-Do-Check-Act (PDCA) and the SMED cycle were used to enhance the efficiency of the production processes on several production lines devoted to the manufacture of Bowden cables for the automotive industry, with a productivity increase of more than 40% achieved on each line [9,10]. At a company which manufactures bottle stoppers, a VSM was developed and SMED methodology applied to equipment with high changeover time, culminating in a 43% reduction in total changeover time, which was translated into a monthly savings of €2,340 per machine [11]. Martins et al. [12] also applied SMED methodology to reduce setup times in a production system which uses Electron Beam Irradiation in coated electrical cables for automobiles. In this work, it was found that the transformation of internal to external setup tasks did not have the desired effect, so it was necessary to adjust the equipment in order to significantly reduce the setup time. This was successfully achieved, with a time reduction of more than 50% in the setup. It was reported that the implementation of standard work to increase productivity at a company in the automotive sector, led to the optimization of the objectives for production and cycle time, as well as an increase in the OEE of machines from 70% to 86% [13]. In another project developed at an electronics device company, Standard Work and VSM were used to ensure that cycle time was shorter than takt time, culminating in a 10% productivity increase, which was complemented by an overall increase in efficiency and reduction of waste, as well as a reduction in the movement of workers within the production cell, while improving the ergonomics of the jobs [14]. At a factory in the textile industry, Lean tools such as the PDCA cycle, 5S and 5W2H were implemented to ensure a continuous improvement system. This led to savings of 4 hours in each working week per worker, which corresponds to a 10% gain of available time per worker [15]. In addition to the work described above, there are many other cases to be found in literature which report success in the application of lean tools, namely in the automotive sector [1,16-18] and in the metalwork industry [19], amongst others.

3. Methodology

Given the nature of the problems encountered in the industry and the need for direct intervention to solve them, this article follows a research methodology which is based on *Action-Research.* The methodology has become widely used amongst researchers due to its ability to involve all the intervening parties in the problem-solving process, which is of real importance to all [20]. What distinguishes it from other methodologies is its practical component, since it is characterized as research in action rather than research about action [21]. The *Action-Research* methodology can be implemented in a project through a cycle consisting of five main phases [22]: (1) Diagnosis, in which the analysis of the detected problems and data collection occurs; (2) Action Planning, where the actions to be implemented to achieve improvements are identified; (3) Implementation of actions, during which the planned actions are put into practice, with a view to addressing the problems at hand; (4) Evaluation, where the results obtained in the implementation phase are analyzed; and finally, (5) Conclusions, in which the changes ensuing from the implemented improvements are identified, and an analysis of the learning and difficulties found during research is undertaken.

4. Analysis and Improvement of Production Processes in the Wiring Sector

4.1. Description of Wiring Production Processes

The wiring section is divided into two main areas: cutting and crimping. The first area is reserved for the operation of two Komax Kappa 330 automatic machines (see Fig. 1). These machines execute the reference marking for each cable, as well as the connection coordinates which enable line workers to know where a particular cable is connected to the equipment. The workers also strip the cable to the required length by removing the insulation, and subsequently cut the cable to the desired length (see Fig. 2). Once the cable set has been cut , it is placed on a cart and transported to the crimping area (see Fig. 3).

Fig. 1. Komax Kappa 330.

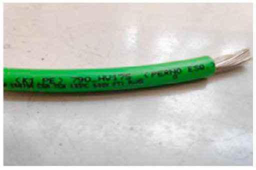

Fig. 2. Stripped cable with markings.

Fig. 3. Cable Cart

In the crimping section, workers receive the carts containing the previously cut sets of cables and proceed with the crimping operation. The process requires the worker to check the list of charger connections being produced, which contains information pertaining to the cable in question and, subsequently, to insert the tip or terminal indicated on the list. The next step is the execution of crimping operation on the Phoenix Contact CF500 semi-automatic machines (see Fig. 4). Once this assembly has been finished, the cable is placed on a cart, which transports the material to the assembly line. Fig. 5 shows a cable with a crimped terminal onto one of its tips.

Fig. 4. Semi-automatic crimping machine: Phoenix Contact CF500.

Fig. 5. Cable with crimped terminal onto one of its tips.

In the wiring section, the production process begins with the consultation of planning for the following week. Based on this, the cable cutting process is initiated for equipment to be produced in week n+1. In the crimping sector, planning is only consulted to enable the team leader to distribute the chargers which require crimping to the 12 crimping benches. The appropriate serial number is also added to the cover sheet pertaining to each part of equipment. Due to the difficulty involved in accompanying the pace of the assembly lines, the crimping process usually operates only one day ahead of the activities planned for the lines.

4.2. Identification of Problems

Table 1 shows the problems in the wiring area.

Table 1. Problems detected in the wiring area.

Area	Description	Problems
Wiring	Cable production process	Supermarket disorganization
		Downtime due to lack of material
		No production control

4.2.1. Supermarket disorganization

There is no identification of supplies in the raw material supermarket found in the cutting area. This failure causes delays in *the changeover* time of the cable cutting process on the Komax Kappa 330, since the operator takes too long to search for the required cable, rather than identifying it promptly.

4.2.2. Downtime due to lack of material

In the wiring section, more specifically in the cable cutting area, there are recurrent production constraints due to the lack of material. The lack of knowledge relating to cable consumption has made it difficult to provide supplies for each reference and, consequently, ensure that there are no failures in the raw material stocks. This constraint occurs regularly and has severely impacted the assembly lines and the wiring production process itself. Thus, normal production cannot follow the planning initially done, and is forcibly interrupted to replenish the missing cables for the WIP sets, often awaiting the supply of the missing references.

4.2.3. No Production Control

There is no system in the crimping sector to assist the management of production by the person responsible for the section. The current method requires several interruptions in production so that the sector supervisors can inform the workers about the equipment to be produced, both at the beginning of the shift, or at the end of the equipment production. This excessive dependence of workers on the team leader must be eliminated and, to this end, a system must be developed to allow engineering staff to perceive the outputs, as well as to justify deviations in production, when they occur. Since the crimping sector cannot accompany assembly line takt-time, the issue of downtime due to the lack of information provided to the workers must be addressed.

4.3. Proposals for Improvement

Table 2 presents proposals to improve the problems listed.

Table 2. Proposals for improvement.

Area	Problems	Proposals for improvement
	Supermarket disorganization	Organization and identification of raw materials.
Wiring	Downtime due to shortage of material	Calculation of consumption and establishment of procedures to supply the wiring sector.
	No production control	Implementation of a control board containing the production orders.

4.3.1. Organization and identification of raw material

On analyzing the cabling production processes, a major failure was detected in the storage of wiring on the rack dedicated to raw material. No criteria were being adopted in the storage of cables on the shelves and there were no labels to identify the material. This failure generates some confusion on consulting the shelf, thus leading to delays in changeover time, when the cable is changed to be cut on the Komax machine. Fig. 6 shows the rack before it was organized. The boxes were supplied randomly and the operator distinguished them only by observing the codes registered on the box, even though this was not an intuitive method of selection.

Fig. 6. Raw material supermarket, before improvements.

Fig. 7. Raw material supermarket after improvements.

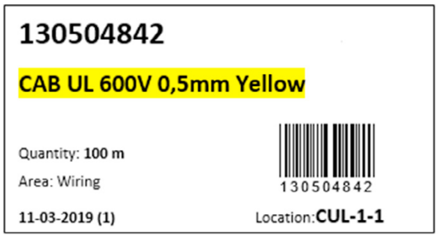

Fig. 8. Example of *Kanban* in the supermarket.

The first improvement action was to define a criterion to organize the wiring boxes on the racks. Since the characteristics that distinguish the various cables are the wiring section and its color, it was implemented an organization method which follows an ascending order for each section and an alphabetical order for the colors. There are ten shelves on the rack; however, due to ergonomic reasons, only the top nine are used. The four top shelves contain eight wiring boxes because they are of a shorter length (0.5; 0.75; 1; 1.5 and 2.5 mm^2). The fifth shelf stores seven boxes; the following two shelves accommodate six boxes and coils; and the bottom shelves only store five boxes and coils due to the long cable cross section (10 mm^2). Fig. 7 shows the arrangement of wiring in the raw material supermarket. At each location, a label holder was provided with its respective *kanban*, containing all the information required by workers, both for those operating the Komax machine as well as the Logistics operator who supplies the raw materials from the warehouse. Fig. 8 presents an example of the *kanban* used on the rack. Each *kanban* contains the same information. Prominently displayed are: the name of the cable assigned by the warehouse; date when the reference was created on the database; and its respective internal reference. The name is highlighted in the cable color to facilitate visual identification on the rack. Information is also provided concerning the amount of cable per container, as well as the location of the reference on the rack, in order to guide the warehouse worker when replenishing references to the supermarket. The location code begins with the letters "EUL", which stand for "UL cable rack" (the American certification to which the cables are subjected). This is followed by two numbers: the first shows the position of the shelf (number 1 pertains to the highest shelf), and the second number indicates the position on the shelf (beginning from left to right). Although this is currently a manual process, a barcode was included on all the *kanbans* with the warehouse reference number; this will enable the future automation of the raw material supply process by means of barcode readers, which will transmit all the information to the database. Finally, since the supply process is carried out from back to front, label holders were placed on the back of the rack to facilitate the work of the warehouse worker. In order to quantify the gains achieved after the implementation of improvements in the supermarket, it was proceeded with the collection of ten samples of the cable *changeover* process at the Komax machine, before and after the changes have been implemented. After the average changeover times have been analyzed, it was possible to conclude that a reduction occurred during the process, from 67 to 57 seconds, which is translated into a decrease of 14.9% in average cable *changeover* time.

4.3.2. Calculation of Consumption and the Establishment of Processes to Supply Wiring

One of the major problems detected in the wiring sector is the waste of time generated by the shortage of wiring in the raw material supermarket, or even the absence of stock of a particular reference, caused by delays in order placements. This is due to the lack of procedures to supply wiring from the warehouse to the supermarket, as well as the absence of criteria when generating a new order for the supplier. In order to solve this problem, a tool was created on MS Excel®. (Fig. 9).

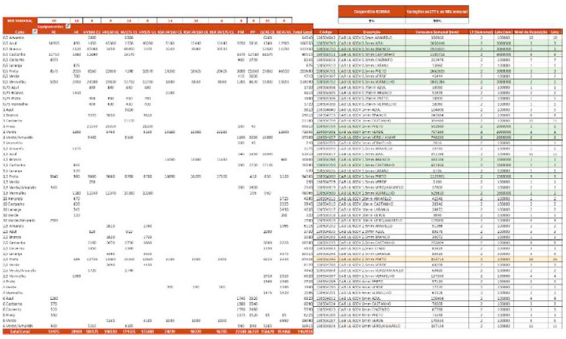

Fig. 9. Wiring consumption calculation tool.

Since the supplier's lead time is two weeks, and given the variations in the weekly production and waste of the Komax machine, it was defined that the ideal level of replenishment should be one that would ensure no stock shortages for a time period of 3 weeks. Once the wiring replacement level was established, one proceeded with the definition of the supply procedures to the sector, as well as order placements to the supplier, in order to eliminate interruptions or delays caused by shortages in raw material. The most practical method of regulating the stock of raw material in the wiring section is that of using both the label holders on the shelf and the *kanbans* to request supplies from the logistics operator. There is space in the supermarket to accommodate, per reference: four boxes of cables up to 2.5 mm^2 of cross section; three boxes for 4 to 6 mm^2 cables; and two coils for cables which are 10 mm^2 of cross section. Thus, each label holder indicates this amount of *kanbans*. When a box runs out, the Komax worker removes one of the *kanbans* which contains the respective reference, and places it in a container, which has been added to the supermarket (see Fig. 10). This acts as a supply order for the warehouse worker to follow through. The warehouse worker previously selected to execute the task of collection, proceeds with the daily removal of all the *kanbans* from the container at the end of his shift, and places these in the warehouse container, as is shown in Fig. 11.

Fig. 10. Container for kanbans.

Fig. 11. Container for *kanbans* at the warehouse.

Fig. 12. On the left, a non-removable card to indicate the reference; on the right, a removable card to generate the order.

When starting the shift on the next day, the employee who is responsible for supplying raw materials to workstations has access to all the information required to supply the boxes with the missing references. When this has been accomplished, the *kanbans* are inserted into their label holders once again, thus completing the cycle. With regard to the process of generating orders for raw material, they were established procedures which are similar to those of internal supply. In order to assist the task of managing the wiring boxes, two *kanbans* were introduced in the warehouse for each reference and in their storage locations (see Fig. 12). The first *kanban* is non-removable and its purpose is of consultation and assistance to the worker. It contains information about the wire reference and description, as well as the packaging format (box or *conipack),* the quantity in each package, the supply zone and the supply status. The second *kanban* is removable, and is fixed to the metal structure with magnetic adhesive tape. This is the card which generates the order for the respective wiring required. When the number of boxes in the warehouse reaches the replenishment level, the employee removes the order *kanban,* and places it in the container assigned to this purpose, which is presented in Fig. 13. The warehouse team leader carries out a daily check to determine whether there are order *kanbans* in the container; these are then collected and delivered to the supply manager, who subsequently creates a new order for the references on the *kanban*. Once the orders are generated, the supply manager returns the *kanbans* to the same person, who deposits them into another container (see Fig. 14).

Fig. 13. Container dedicated to order kanbans.

Fig. 14. Container dedicated to the reception of wiring.

The order *kanban* is stored in the container dedicated to the reception of raw materials until its reference is delivered. When the supplier delivers the material ordered, the warehouse worker receiving it stores the package in the corresponding location and removes the order *kanban* from the container. He then repositions it on the shelf, thus finishing the wiring order cycle.

4.3.3. Implementation of a Control Board for Production Orders

In order to reduce periods of interruption by workers in the crimping sector, both at the beginning of shifts or between sets of chargers, a board was devised to act as a production guide for all the workers in the area. The structure of the board was developed to facilitate the reading and comprehension of the content by all those consulting it, even if they are not familiar with the production processes. Thus, the board was divided into three main sections (see Fig. 15):

- The first section acts as an introduction and presents the layout of the crimping sector and of the workers involved in the production processes, with the arrangement of their positions on the benches, including the section supervisor. A space was designated to mark cases of absenteeism for that day.
- The second section is reserved for production orders, and this constitutes the most important part for workers. It is in this area that information is provided regarding the chargers to be produced by each bench. Since the assembly line *takt-time* is 120 minutes, and each charger takes longer to be crimped, there is a need to create teams on more than one bench to work on the same charger reference/order. The composition of teams depends on the number of chargers whose must be produced. Cards are placed before team composition, which contain information regarding the chargers to be crimped during the shift. The cards are stored in a container which is attached to the frame, and are distinguished by their color. A space was designated for the section head to fill in the charger serial number, and another for descriptions and customizations. Finally, an additional space was created so that necessary observations could be noted down in relation to each team's daily production. This space is completed with information pertaining to the estimated and actual quantities of production. An additional space was provided to justify non-compliance with the planned objective when this occurs. The engineer responsible for the wiring section, together with the team leader, should assess the observations resulting from non-compliance with the expected output, and take subsequent action to ensure that planning is met.
- The third section deals with output analysis and raw material control. It is in this section of the board that daily output of chargers in the crimping section is presented. This indicator assists section supervisors in the detection of deviations in production so that an attempt can be made to eliminate these. Planned output is displayed in blue and the actual output carried out is shown in green. A table follows, on which shortages in raw material are recorded; additional space is provided to write the name of the missing component and its respective warehouse code, thus facilitating replenishment. Finally, a table is presented, which contains information concerning the component quality errors that may arise. In the event of an error, the section supervisor must fill in the table with the number of errors detected on the component and what the associated error is, so that these can be analyzed by the Quality department.

Fig. 15. Production control board.

4.4. Analysis of the results achieved

Table 3 shows the results achieved through the improvements implemented.

Table 3. Analysis of the results obtained.

Improvement proposal	Qualitative gains	Quantitative gains
Organization and identification of raw material	Reduction in time wasted to look for material;Increased comfort at work.	14.9% reduction in *changeover* time in the cable cutting process
Calculation of consumption and establishment of procedures for supply to wiring	Accounting of weekly consumption of wiring; Elimination of interruptions caused by material shortages; Reduction of WIP sets in the cable cutting sector; Definition of procedures and accountability of work; Improved communication between departments.	Not applicable
Implementation of a control board containing production orders and KPIs	Reduction of downtime in production; Improvement in communication between the team leader and workers/supervisors; Increased control of production and accountability for production deviations	Not applicable

5. Conclusions

The objective of the work developed throughout this project was to improve the production processes in the wiring section of a company which manufactures chargers for electrical vehicles. In view of the organization's growth and increasing demand, it has become essential to act upon the rudimentary processes that have hampered the company's development. The main contributions of this project to the company included: organizing and identifying the raw material in the supermarket, culminating in a reduction in *changeover* time of 14.9%; developing a tool to calculate cable consumption, establishing procedures for supply and the generation of orders, resulting in the elimination of stock shortages in the area; implementing a production control board for the wire crimping sector, thus minimizing production downtime; reducing the variability of wiring references in order to allow for the installation of an automatic cutting and crimping machine. Despite the improvements recorded, the organization should continue to implement Lean philosophy across all departments and must seek to improve communication and cooperation amongst all of the stakeholders so as to enhance the company's growth and achievement of all its expected potential.

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