Production management model to reduce late deliveries in a metal-mechanical SME using lean tools

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***Abstract*—The metal-mechanic industry is indispensable for the economic growth of a country since it generates capital goods for industrial sectors at a national and international level. Currently, metal-mechanic SMEs face different challenges to meet their customers' demand at the right time and with quality products. The article studies a medium-sized metal-mechanic company with an on-time delivery percentage of 66.94%, generating dissatisfaction in its customers and economic losses close to 50 thousand dollars. To solve the problem, a production management model is proposed exclusively for SMEs with MTO production systems that includes 4 Lean tools. To validate the model, a pilot program was chosen, and an adequate production rate was achieved to meet the required production demand, thus validating the efficiency of lean techniques to solve problems in a scenario of medium-sized manufacturing companies.**

Keywords— Metal-mechanics, SME, On-time delivery, MTO, Lean Manufacturing

I. Introduction

The metal-mechanic sector is one of the subsectors of the manufacturing industry, whose importance lies in its relevance for other industrial sectors since it is considered a fundamental link due to its functions [1]. It is responsible for supplying capital goods such as machinery and equipment in various sectors such as mining, construction, automotive, among others [2]. In macroeconomic terms, in 2019 in Peru, the manufacturing sector reached a contribution of 16.5% of GDP, of which the metal-mechanic sector accounted for 1.6% of the country's gross domestic product and 12.1% of the gross value added. In the same year, exports reached 636 million US dollars [2]. Despite being an engine of development, currently, metal-mechanical SMEs, which make up 99.6% of the metal-mechanical sector in Peru, face a series of challenges such as low production efficiency and limited financial resources to implement improvement projects [3]. This situation generates a problem for the companies in the delivery of their products on time, since failure to meet orders on time generates delays, economic penalties, and customer dissatisfaction.

The importance of delivering orders on time is that it directly influences the satisfaction of its customers and the reliability of the company in terms of its level of service [4], [5]. This takes greater relevance in metalworking SMEs since they develop in a highly competitive environment, so it is necessary to maintain a concept of continuous improvement [6], increase their operational efficiency and achieve a flexible production system [7]. Previously, several studies have been conducted to reduce lead times in conventional manufacturing companies [8], in companies with production-to-order or MTO systems [9] and of various sizes [10] [11].

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Previous studies agree on the application of the Lean Manufacturing methodology together with its tools to improve lead times, achieving improvements of 30 to 50% [12] [13]. In addition, the success cases presented improvements in productivity levels, overall machine efficiency (OEE), work environment, among others. Although there are several studies on the application of lean in large companies, the number of investigations carried out in MSEs that produce a variety of products but with low volume is still scarce [14]. In fact, the effectiveness of lean manufacturing is criticized only in companies with large production volumes [13]. Moreover, it is currently being discussed which are the most effective lean tools to improve on-time orders, since the results vary depending on the technique applied and the way they work together.

Faced with this scenario, a production management model is proposed that has as its main objective to minimize late deliveries through the implementation of 4 Lean tools. In addition, due to its characteristics and form of implementation, the model is exclusive for SMEs with MTO production systems. For validation purposes, the model will be implemented in a medium-sized Peruvian metal-mechanic company that works under order. The company presents a 66.94% compliance of its deliveries on time and, therefore, annual losses of $52 375 are generated. The motivation of the research is to contribute a new management model in a context of small and medium Latin American companies and to verify the effectiveness of the application of Lean Manufacturing in SMEs. The article is organized in 6 parts: (I) introduction, (II) state of the art, (III) contribution, (IV) validation, (V) conclusions and (VI) references.

II. State of the Art

A. *Lean manufacturing*

The Lean Manufacturing methodology is widely used in manufacturing companies to reduce product delivery times through the elimination of waste in the production process [15]. As proof of this, there are several studies where through the application of lean tools improvements in the production system were achieved and as a consequence a reduction in delivery times, for example a parts manufacturing company that reduced its delivery times by 33% [16] or the case of a manufacturing company with problems of out of time deliveries achieved the reduction of it through the improvement of 60% of the cycle time and the reduction of unnecessary movements by almost 50% after the application of lean tools [9].

In general terms, the articles reviewed show that the reduction of late deliveries was achieved through the operational performance of the production process after the application of various lean tools. It is necessary to highlight that there is still a debate about which techniques are the most effective for the mentioned problem and that several authors indicate that there is still a field to be explored about the application of lean in SMEs. This last mentioned is relevant since small and medium enterprises present greater challenges and difficulties in the implementation of Lean Manufacturing [17].

B. 5S method

The 5S method is one of the most widely used Lean tools to improve the performance, competitiveness, and productivity of a company [18]. This is achieved through the organization of the workplace and the promotion of the commitment of the operator with his workspace, as a result, an improvement in the efficiency and effectiveness of the production process is achieved [3]. There are several cases that demonstrate the effectiveness of 5S in increasing productivity by up to 25%, reducing cycle times by 20% to 35%, eliminating activities that do not add value and improving the compliance indicator by 25% to 38% [19]-[21].

In summary, there is a consensus among the authors to implement 5S as the first step in an improvement process. Moreover, it is a tool that does not require large investments and results are obtained in the short and medium term.

C. Poka Yoke

This Lean tool is the most effective and influential tool to solve rework problems and reduce waste [22] [23]; in general terms, its effectiveness in minimizing rework due to human error is recognized. This, through the reduction of nonconforming products and thus, saving money, resources, time and labor [24]. Among the most relevant results, the number of reprocesses was reduced by up to 34.7% and up to 35% of defective products were recovered, leading to an increase in productivity [25], [26]. In other cases, the number of customer complaints decreased by 75% and production time by up to 91.6% [27].

In summary, it can be stated that the Poka Yoke tool helps to reduce or eliminate rework. Moreover, it is effective when applied in any industrial context, unlike other Lean tools. Therefore, it is useful for small and medium-sized companies because it does not require large investments and is effective in reducing reprocesses caused by human errors, a frequent problem in them.

D. Preventive maintenance

It is known that corrective maintenance on equipment are activities that do not add value and extend costs and production times [28]; for this reason, it has been identified that the TPM pillar: preventive maintenance generates an impact in minimizing the number of failures, and thus in this type of corrective maintenance. In several cases, with the implementation of this pillar, an OEE growth ranging from 60% to 70% was obtained [29]-[31]. In addition, a 50% reduction in breakdown times was achieved [10], between 20% and 30% in the number of breakdowns and between 20% and 40% in corrective maintenance actions [30], [32]. In turn, the creation of preventive maintenance plans reduced breakdowns by 30% and increased OEE by 5% [30].

Regarding the authors' proposals, each one applies the TPM pillars differently, because they consider the economic, resource management and technological barriers present at the time of implementation in SMEs. In addition, they agree that there is a field of research to be developed in the application of TPM in SMEs. Finally, it should be noted that the case studies used different pillars and there is little research where only one pillar is evaluated, such as preventive maintenance, in order to know its impact.

E. Single-Minute Exchange of Die (SMED)

The SMED technique focuses on the reduction of machine setup times [33]. The relevance of SMED application lies in the fact that a minimum setup time allows greater flexibility in the production process [34]. There are several successful cases of the application of the technique to reduce machine setup times with results between 45% to 75% and achieve an increase in overall equipment efficiency (OEE) [33]-[36].

In conclusion, the SMED technique is highly effective in reducing machine setup times. Although in the cases presented there is a high variation in the results [33]-[36], it is due to the use of other tools in conjunction with SMED, so there is a field of research on the tools that in conjunction with SMED can achieve the best results, particularly for small and medium-sized companies.

III. CONTRIBUTION

The research proposes a production management model, shown in Fig. 1, to reduce late orders through the application of 4 Lean Manufacturing tools. The proposal was designed from the motivation of developing a model that integrates Lean tools that can be applied in manufacturing SMEs to improve their production process and as a result, minimize the orders delivered out of time.

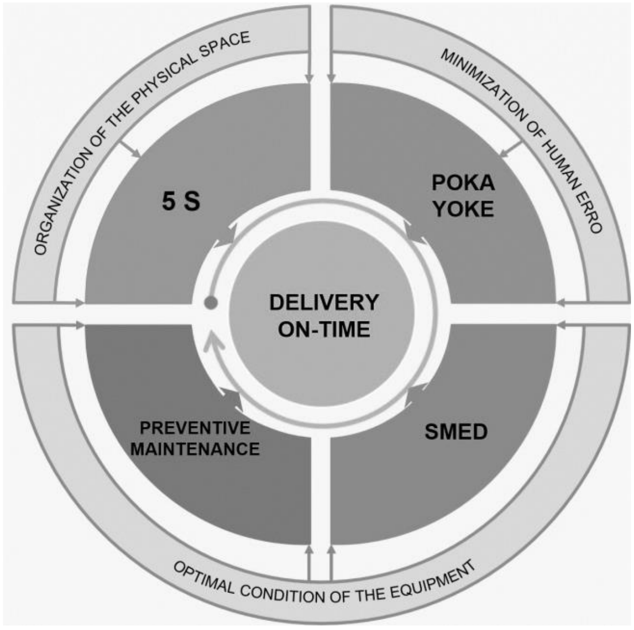

Figure 1. Proposed production management model

It can be seen in Fig. 1, that the model is composed of 3 essential components to achieve the research objective. The components emerged from the research conducted in terms of the minimum necessary conditions that should be considered in an improvement process that seeks to increase its on-time delivery rate. The model is exclusively applicable to small and medium-sized manufacturing companies, since it was designed considering the conditions in which manufacturing SMEs operate, and the proposed components and their corresponding techniques are focused on providing solutions to the main problems that will be detailed in the following paragraphs. As shown in the Figure, the process starts with the application of the 5S, then the poka yoke and finally the joint implementation of SMED and preventive maintenance.

The first component: organization of the physical space, is necessary to be able to develop production activities normally and without any obstacle. In addition, it seeks to eliminate unnecessary activities and movements that prolong the cycle time of each process. Finally, a clean and orderly environment offers greater flexibility and speed of daily activities and increases the productivity and efficiency of production processes. To achieve the organization of the physical space, the 5S technique is used because of its ability to eliminate waste and activities that do not add value. In addition, 5S is a low-cost alternative, making it suitable for small and medium-sized companies that do not have the necessary resources to invest in large improvement projects.

The second component: minimization of human error is relevant since operator errors in the production process generate reprocesses, delays in activities and non-compliance with delivery deadlines, including rejection of orders due to non-compliance with the established specifications and requirements. To minimize human error, the application of the Poka Yoke quality technique is proposed, since it is highly effective in reducing reprocesses and waste. In addition, it does not require large investments and is focused on minimizing errors caused by operators. The technique will be applied by identifying the main human errors in the production process, determining the causes and implementing action plans to prevent the same error from occurring in subsequent jobs.

The third component: optimal condition of the equipment is necessary to achieve on-time orders since the optimal operation of the machinery is required for the execution of the production process. Otherwise, the occurrence of machine stoppages usually generated by breakdowns or long set-up times affects the availability of the equipment and delays the production process. As a result, more time is required to complete the order processes and there is a risk of not fulfilling the order on time. To ensure the optimal condition of the equipment and its continuity in the production process, two techniques are proposed: Single Minute Exchange of Die (SMED) and preventive maintenance. On the one hand, SMED is considered because it is effective in reducing equipment setup times and is performed through the evaluation of machine setup times, the identification of internal and external activities and the implementation of improvement plans to convert internal activities into external ones to reduce setup times. On the other hand, preventive maintenance is applicable because it reduces the possibility of machine breakdowns by performing periodic equipment overhauls. This maintenance is performed through the inspection of each of the equipment and the subsequent execution of a maintenance plan for each of the equipment with activities such as cleaning, inspection, lubrication. In summary, both SMED and preventive maintenance together can keep the equipment in optimal condition and ready for use.

Finally, the evaluation of the effectiveness of the proposed model and the achievement of the main objective will be carried out through the fulfilment of the indicators shown in Table 1 below:

Table 1. Indicators

Indicatores	***Ideal***	***Target***
On – time deliveries	96.5%	85%
Efficiency	85%	85%
OEE	85%	80%
Defective products	5%	5%

IV. Validation

The efficiency of the model is validated through a pilot program, which was implemented in the plasma cutting process in the machining area and lasted 2 months. It is necessary to highlight that due to the nature of a pilot program: a small-scale implementation, in order to verify that the model works on a large scale, it was chosen to calculate the takt time after the implementation since it calculates the production rate of a process to be able to fulfill the orders.

The tooling area was chosen since all manufacturing orders go through this area, the largest number of quality problems due to human error are generated in the cutting area and the most critical machines for the whole process are in the tooling area.

A. 5S implementation

First, an evaluation of the initial situation was carried out, where a level of compliance with the 5S of 16% was obtained and the training and induction talk to the operators was started. The classification began with an inspection and subsequent classification of the tools, machines and instruments according to their frequency of use, quantity and current condition. In terms of organization, the cutting area was labeled and the shelves were reorganized according to the frequency of use and relevance of the process. Finally, the cleaning is done 30 minutes before the end of the work shift and the supervisor oversees verifying that the organization, order and cleanliness of the work area are in compliance with the established standards.

After the application of the 5S, the cycle time of the plasma cutting process was reduced from 4.3 hours to 3.5 hours, which means a reduction of 18.61%.

B. Poka Yoke implementation

For the application of the Poka Yoke tool, it was identified the area with the highest number of errors, being the area of the cutting process, specifically in the cutting process. This error is caused by the operator's mistake at the moment of choosing the type of material to work, in this case steel.

A Poka Yoke control system was designed to prevent the operator from making a mistake. This consists of the use of color coding to differentiate the types of steel, in other words a visual method. Also, this coding is done in the corner of each steel plate, as it will allow a quick visualization when the operator selects the plate to be cut.

Finally, the operation of the poka yoke technique is verified by means of a control check list and to observe if the tool is fulfilling its objective or if there is any opportunity for improvement. At the end of the pilot program, there were only 5 errors in the cutting process, in other words a defective product indicator of 0.1%.

C. *SMED implementation*

For the application, a series of activities were followed as shown in Figure 2.

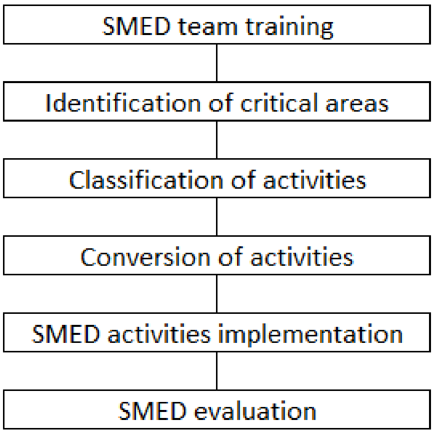

Fig. 2. SMED step by step

The SMED application starts with the formation of the SMED team, who are responsible for identifying the critical areas, in the case of the pilot program: the plasma cutting machine.

Time was taken for the preparation activities and the result was that an average of 17.40 minutes was required to start the operation of the machine. After this, we proceeded to determine the nature of each activity: internal or external, and together with the maintenance team, we identified opportunities for improvement to minimize the number of internal activities or the total setup time.

As a result, the following actions are presented:

- Acquire an assembled base to only place the cutting table.
- Develop an instruction manual to prepare the plasma cutting equipment.
- Reduce the size of the rails to be able to relocate them while the machine is in operation.

After implementation, the times were taken again and compared with the initial situation. The comparison between the setup times before and after SMED are shown in Figure 3.

Type of activity	Before implementation		After implementation	
	Percentage	Time	Percentage	Time
Internal	100%	17.40	88.89%	10
External	0%	0	11.11%	1.4
Total		17.40		11.40

Fig. 3. Situation before and after SMED implementation.

In summary, a reduction in setup times from 17.40 minutes to 11.40 minutes was achieved.

D. *Implementation of preventive maintenance*

For preventive maintenance, all metalworking machinery was inventoried. To prioritize maintenance, an asset criticality matrix is created, based on factors such as failure frequency, operational impact, repair cost, safety impact and environmental impact. As a result of the criticality matrix, it is shown that the most critical machines in the company are plasma cutters, cutting carts and CNC cutters. Due to the priority, these machines will be part of the pilot.

Manuals and data sheets were used to better control the machine characteristics. Also, the FEA tool was used to identify possible failures and their causes in order to prevent or minimize them. So that, with all this information, maintenance interventions are planned monthly, which includes specific activities to be carried out for each asset chosen.

After the preventive maintenance actions, the changes of the time factor in the machines are monitored. Through this monitoring, the variability or improvement of indicators such as OEE, availability, performance and quality are observed. It is worth mentioning that, during the development of the pilot program, no corrective maintenance has been performed, which means an increase in availability, performance and OEE. Likewise, after monitoring the operating time of the machines, the company currently has an OEE of 73.81%.

E. *Calculation of takt time*

At the end of the pilot program, the takt time was calculated since it calculates the production rate to meet the demand. If the proposed model achieves that the production rate of the plasma cutting process is optimal to meet the demand on time, it can be inferred that the model is effective to optimize production and meet the orders on time if it will be applied on a large scale in the company.

For the calculation of the takt time, the available monthly production time, the availability of the machines and the monthly product demand were considered, as shown below.

$$Takt\ time = \frac{Avail.prod.time \times Mach.\ availability}{Product\ demand}$$

The takt time result was 3.57 hours, in other words, a production rate of 3.57 hours is required for each plasma cutting process to meet the monthly demand. After the implementation of the 4 lean techniques, a final cycle time of 3.4 hours was achieved, in other words, each plasma cutting process takes 3.4 hours. Comparing the new cycle time and the takt time, the new cycle time is less than the takt time so that the demand can be met on time and extrapolating to a large scale, the model would be able to meet the orders on time.

V. CONCLUSIONS

It is inferred that the proposed model would reduce the orders delivered out of time since the new cycle time of the process, 3.4 hours, is less than the takt time, 3.57 hours, after the application of the model, that is, the minimum time required to meet the demand of its customers. Moreover, since the cycle time is below the takt time, the production volume could be increased, and a higher demand could be met. Therefore, it is demonstrated that the production model would achieve a reduction in production cycle times and ensure the fulfillment of orders within the agreed time.

With respect to the application of 5S in the project, a reduction in cycle time of almost 20% was achieved, due to the elimination of time spent searching for tools and objects necessary to carry out the cutting process. Among other 5S results, an improvement in the work environment was achieved because the workers had a defined space for their personal equipment, tools and objects. In terms of the process, the definition of places for each object improved the management of materials and a workflow with fewer interruptions.

In relation to the application of the poka yoke tool in the metal-mechanic company, it achieved a significant benefit in medium-sized companies. The results obtained with the poka yoke tool allowed a significant reduction in the errors of the plasma cutting process, approximately 96%. It is necessary to emphasize that the poka yoke philosophy adapts according to the type of process to be improved and it is this flexibility that allows it to be one of the most used and effective lean techniques.

The application of the SMED technique in the plasma cutting process reduced the setup time of the cutting carts from 17.40 minutes to 11.40 minutes. The main reduction was achieved through the standardization of the activities by means of instructions. Finally, the efficiency of the technique to reduce machine times and increase process flexibility was validated.

It is concluded that lean tools are effective for improvement projects in medium-sized companies, such as the company where the pilot program was implemented, and the expected results were achieved. As inferred in the literature review, there are several studies where models composed of lean tools are used and developed for problems in large companies; however, there are still few studies that validate the effectiveness of lean techniques in small and medium-sized companies.

The lean tools applied in the model not only achieved an improvement in the manufacturing system, but also in environmental management since water consumption was reduced in the cutting process, the use of resources due to the elimination of reprocesses and contributed to the circular economy through the recycling of inputs.

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