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Cloverleaf Model for Efficiency Improvement Through the Application of Lean Tools in a Metalworking SMEs

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***Abstract*– There are several factors affecting the metalworking sector: elongated waiting times, late deliveries and low quality of end products. All these variables tend to cause low efficiency in production, which generates delays in the delivery of orders and penalties for failure to meet delivery dates. To understand this problem, order records are reviewed, a time study is carried out to know the duration of each process, a cause-effect diagram is drawn up and the Pareto principle is applied by performing an 80/20 analysis of the root causes. Therefore, the model generates a contribution in the expansion of the knowledge of the application of Lean Tools as Total Productive Maintenance (TPM), Kanban, Poka-Yoke, Line Balancing (LB) and Systematic Layout Planning (SLP) within medium-sized companies.**

***Keywords*-- Production Efficiency, Total Productive Maintenance, Kanban, Lean Manufacturing, Poka-Yoke.**

I. INTRODUCTION

The metalworking sub-sector is currently in constant growth all around the globe. In Europe, this is one of the most important sub-sectors from the manufacturing sector, containing around 3.9 million employees in Germany alone [1]. Similarly, Argentina has more than 24,000 metalworking companies, 88% of which are medium-sized companies located in the country's most important cities, providing jobs for nearly 300,000 people [2]. In relation to world trade, the sector represents more than 30% of the world's total revenue with 13 billion dollars per year with China and the European Union being the regions with the greatest importance in the export economy [2]. In Peru, the metalworking field was the manufacturing sub-sector with the largest growth during the last 6 months of 2021 and the first 6 months of 2022 [3]. However, the study conducted by the National Industrial Society indicated that companies in the sector showed an average production inefficiency of 62.1% in 2021[4].

While the metalworking sub-sector keeps on growing, problems start being more noticeable. Because of its importance in the Peruvian context, studies are being conducted towards improving the production efficiency to maintain companies competing in the market. To solve this problem, research on different Lean tools is taking place. The application of Single Minute Exchange of Die (SMED) with an integration of 5s as starting point for a TPM implementation is very effective against reducing cycle times by 21% and increasing the Overall Equipment Effectiveness (OEE) by 8% [5]. Also, 5s, Value Stream Mapping (VSM), Work Standardization and LB were applied to increase the efficiency by 6.4% while reducing defective products that caused reprocesses by 12.63% and increasing on time deliveries by 27.5% [6]. In a similar context, Poka-Yoke was applied with other LM tools reducing the defects rate by 53% and the IDLE workstations by 30%, this study was done with only 4 weeks of previous data [7]. In addition, an SAP- LAP analysis after 5s, Single Minute Exchange of Die (SMED), TPM and Poka-Yoke reduce delays in the production line achieving a growth of 5% in production in a metalworking company [8]. However, the above research does not mention that such tools have been applied within companies with fewer resources and sales. In addition, the data collected in the previous research tends to be very limited and from short amounts of time.

The present research seeks to expand the knowledge by applying the tools mentioned before in MSE with different approaches, solving related causes from previous studies did not cover. Also, the study should consider at least one year of historical data, to deepen our understanding of the underlying problems and refine our proposed model for a more accurate solution. This empirical approach not only enhances the robustness of our findings but also certifies its relevance and suitability for real world scenarios. This model is based on the use of LM philosophy tools such as TPM, Kanban, Poka- Yoke, LB and SLP in order to provide an adequate solution to common issues such as unnecessary paths, material shortages, defective products due to human error and machinery failures. In summary, our study represents significant advancements in research by integrating different methodologies with empirical insights, we believe it will help pave the way for improvements in manufacturing processes. The benefits of our study would not only affect the production process, but it would also have an impact on the company as a whole by reducing their delivery times and costs.

The content of this article contains six sections: the second section presents a review of the literature presenting the problem in previous studies. Next, section three defines the methodology to be used to analyze the problem is developed. Sections four and five address the analysis of the problem in the company and the innovative proposal. Finally, section six will present the conclusions of the study and the proposed future work. The reference articles used in the research are also presented.

II. Literature Review

Low production efficiency is caused by factors such as fatigue due to poor posture and work overload in employees or machinery breakdowns and failures that generate order delays and high cycle time. For this reason, a model applying VSM and Kaizen with the objective of reducing order lead time by balancing workload and efficiency in the furniture production line will be proposed [9]. Similarly, the research by Greinacher et al [10] presents improvements in order delivery reliability as a result of their model that is oriented to resource optimization using the lean philosophy but with more positive results such as improved production times of metal parts, reduced energy consumption and even a reduction in part material costs.

On the other hand, the reduction of bottlenecks or cycle times is one of the objectives of the study whose model is based on human-robot interaction to reduce the work overload of operators in manual processes and improve their posture to increase efficiency [11]. While another study focused on reducing set up times in machines within 6 areas because its contribution is focused on the implementation of SMED and VSM to increase efficiency in production and avoid machine set up times delaying production [12].

Likewise, Castañeda and Mauricio [13] argue that low efficiency leads to difficulties in the production processes of companies to adapt to certain projects, so they implement a model based on the data envelopment analysis of variable returns. On the other hand, unproductive times and failures in the integration of the areas produce low efficiency, so Poka-Yoke is implemented to solve it [14]. Within a Mexican remanufacturing company, the performance of the operators impacts the efficiency of the processes so they should be studied to improve the core quality of the products [15]. Likewise, process variability in a manufacturing company affects production efficiency, so this study proposes to develop a useful guide for processes using six sigma and robust optimization [16].

III. Methodology

Kumar et al. [17] mentions that there are basic approaches, which belong to the quality circle and are used to identify and analyze a problem. Based on this, the methodology of analysing the problem within the company starts with the identification of the company's production processes. Then, the record of orders placed in a certain period of time is analysed to evaluate how many products have been ordered and the reasons for the delays. Based on this, a data collection study was completed with the help of the time study technique in order to measure the duration of each process of an operator and compare it with that of a standard operator.

Once this has been completed, a cause-effect analysis is performed where an Ishikawa diagram will be used to identify the possible factors that influence the efficiency of the plant. After that, a Pareto diagram will be used in order to perform an 80/20 analysis and evaluate the causes that represent and impact 80% of the effects on the problem. Finally, with the analysis performed, the improvement proposal will focus on reducing those causes selected from the analysis by implementing tools that have a significant impact on the problem.

IV. Problem Analysis

A. The Productive Process

The research is carried out within M2T, which is a small and medium-sized company with two businesses: metal mechanics and graphic printing. The company has key processes which are considered within the study because they are related and aligned to the objective of analyzing the production process as shown in Fig. 1.

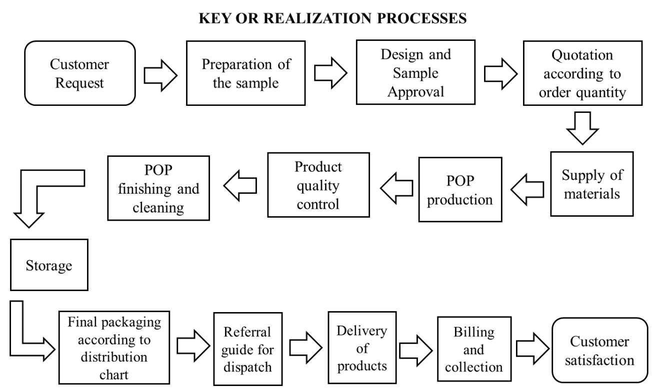

Fig. 1 Process map of the M2T company.

The company produces, in larger quantities, the banner with shelves, display furniture, advertising corporeal, booths and carts. To manufacture them, these products have processes in common that are called core processes, which are cutting, painting, and welding, as shown in Fig. 2.

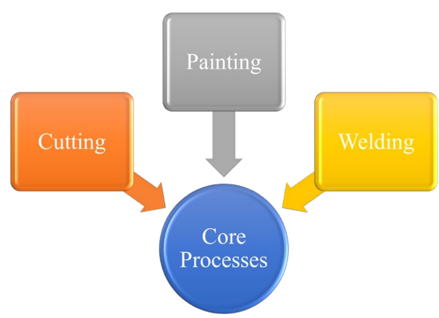

Fig. 2 Company's Core Process.

B. The Problem

To identify the problem, the company's order register for the period under study was reviewed and analysed. Upon review, it was identified that the area where the most frequent problem is registered is the low production efficiency in the metal-mechanic sector, as can be seen in Fig. 3.

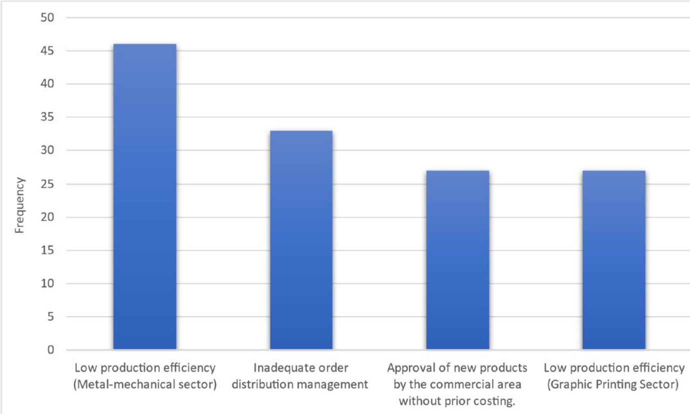

Fig. 3 Frequency of problems identified within the company.

Similarly, a time study was carried out for each of the products. For this purpose, 10 observations were made considering a confidence level of 95%, an error of 5%, and outliers were eliminated for each element involved in production. Table 1 shows the standard time for each of the products, which are below the standard time.

TABLE I
STANDARD TIME FOR THE FIVE PRODUCTS

Products	Standard Time (min)
Banner with bracket	39.91
Display Cabinet	49.48
Sign	41.04
Trolley	75.74
Booth	64.50

Finally, Fig. 4 presents the average efficiency during the study period calculated from the current and standard production records. Based on this, it was observed that the average efficiency of the production area is 52.77% which is lower than that of the sector, which was mentioned above.

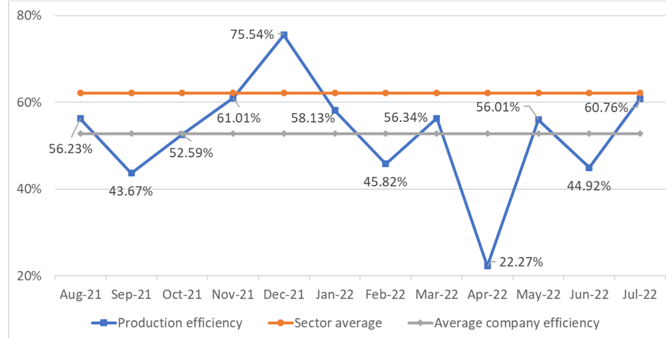

Fig. 4 Comparison of the average efficiency of the sector vs. the company.

C. Root-Cause Analysis

To identify the root causes, an Ishikawa diagram was constructed, as shown in Fig. 5, which made it possible to classify them appropriately based on the categories methods, machine, manpower, environment, materials and management. With this, a Pareto diagram was completed, applying the 80/20 principle, which showed that the causes of unnecessary trips, crossing of requests for material requirements, defective packaging and machinery breakdowns produce 80% of the effects (see Fig. 6).

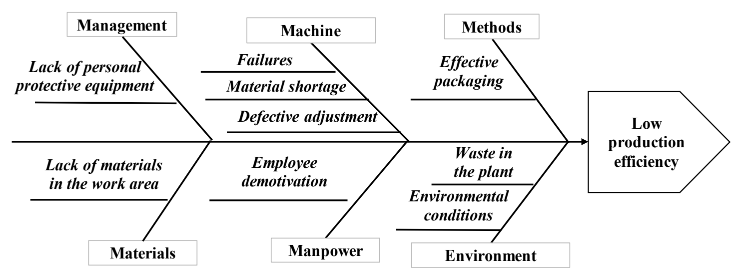

Fig. 5 Ishikawa diagram of root causes.

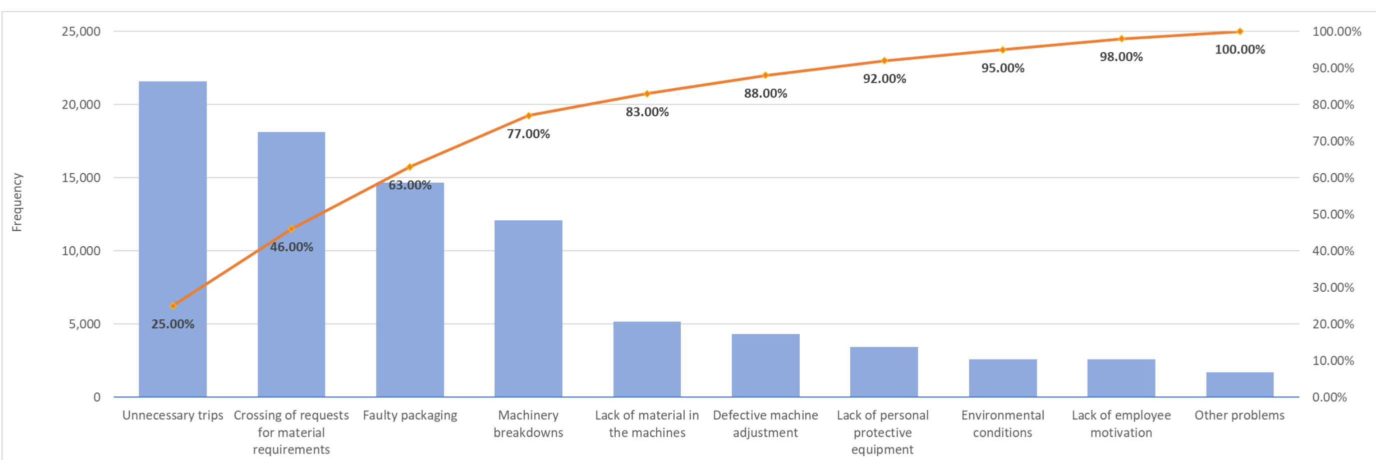

Fig. 6 Root Cause Pareto Diagram.

With the information presented, it was identified that the most important problem to be solved is the low efficiency in the production of the metal-mechanic sector, where the main causes

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are unnecessary trips, crossing of requests for material requirements, faulty packaging and machinery breakdowns, which generates an economic impact of $83,741.55 per year. Therefore, the proposed model seeks to optimize the processes by reducing the identified causes.

V. Innovative Proposal

A. Baseline

The proposed model is based on the studies of [18]–[20]. The first study proposes an Order Fulfillment model that starts with the identification of wastes, then the tools are presented with their specific objectives as shown below. Finally, the expected results are introduced before the main objective [18].

- Objective 1: Optimizing the work method.
- Objective 2: Organizing workstations.
- Objective 3: Improve purchasing and production management.

The second study displays inputs, that contain the description of the information needed to implement the model; components, with the different tools presented in a determined order of application and their specific objective; and outputs, where the main objectives are exposed [19]. The third study suggests a similar system of inputs, outputs, and components with a predetermined order of implementation [20]. Unlike the first model, the last two models have an order of application of the components settled, leaving no room for prioritization of objectives [19] [20]. However, both models display detailed information in the inputs and outputs, contrary to the one described in [18].

The proposed model is superior to the ones mentioned before because, in the inputs, it displays the information used for a better understanding of the causes of the problem and the different variables, instead of just a one cause identification tool. In addition, components have an individual implementation, so they do not depend on previous phases.

B. Proposed Model

A Process Optimization model is proposed with a system composed of inputs, outputs and three main components. The inputs present the initial documentation needed for the implementation, the components are composed of different Lean Tools, and the outputs present the expected results and objectives, these can be observed in Figure 7.

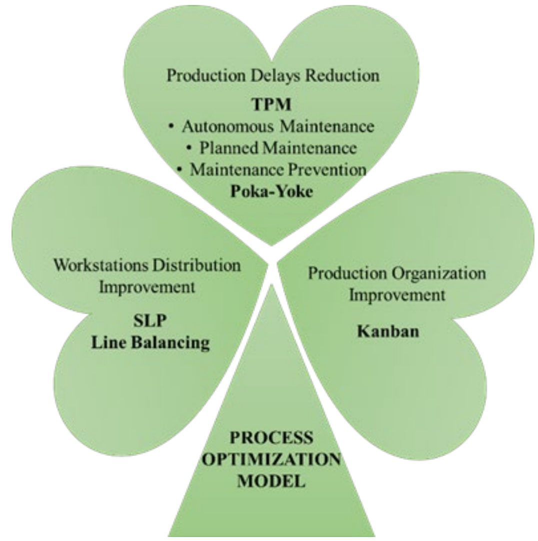

Fig. 7 Cloverleaf model for process optimization.

As can be seen, the main structure of the proposed model would be the components which will be described below:

Workstations Distribution Improvement: Is presented as the first component and represents the need to re- organize the current plant layout, to reduce the number of unnecessary routes provoked by residues in the paths. To achieve this goal, SLP and LB will be integrated. The planned use of LB consists of balancing the cycle time and SLP would establish a new and more efficient layout distribution with shorter paths and transfer time.

Production Organization Improvement: The second component consists of the objective of reducing the shortage of materials in the workstations caused by cross requests of materials. An internal Kanban for transport/movements based on Kanban cards and a board with the current state of the cards are responsible for avoiding the shortages.

Production Delays Reduction: The third and final component has the purpose of reducing the breakdowns in the machinery that causes defective parts and the defect rate caused by human errors during the packaging process. Three pillars of the TPM methodology will be implemented: Autonomous Maintenance, Planned Maintenance, and Maintenance Prevention to increase the OEE and reduce the number of defective parts. In addition, a Poka-Yoke type grouping will be applied in the packaging process to try to reduce the defective products caused by a defective package.

C. Model Details

SLP: This methodology will be applied in the production area of the plant; the main purpose of the implementation is to reduce the transfer time and shorten the paths between the workstations.

LB: This tool comes after the SLP implementation and seeks a reduction in the cycle times and a re- distribution of the workers in the different workstations with equitable work shifts. It is applied in the same area as the SLP.

Kanban: This method will be used in the production areas that require the use of materials from the inventory and the equivalent storage area that sends those materials to the corresponding production workstations.

TPM: Autonomous Maintenance, Planned Maintenance and Preventive Maintenance are the three pillars from this methodology that were considered while designing the model. These will help with the design of a maintenance and revisions chronogram to avoid breakdowns during the production process.

Poka-Yoke: This technique will be implemented in the packing area of the plant, and it is a grouping type of Poka-Yoke where a kit is assembled with all the materials that are required for the packing process, this will prevent the opportunities of defects in the final product.

D. Indicators

Efficiency: Measures the efficiency of the production in the plant. The study from [6] achieved an increase of efficiency and it will be expected to achieve an increase of about 10.42% with the model implementation. Formula:

$$Efficiency\ (\%) = \frac{Real\ Production\ Rate}{Standard\ Production\ Rate} \tag{1}$$

Cycle time: It is used to measure the time between a multitude of materials and its completion, the time of the different tasks, and the time of transfer. According to the studies of [21], [22], a reduction in cycle times of about 15% is expected for activities, in transfers and in material requests. Formula:

$$Cycle\ Time = \frac{Production\ Time\ per\ Shift}{Production\ Volume\ per\ Shift} \tag{2}$$

OEE: Measures the Overall Equipment Effectiveness of the machinery in the prgoduction process, specifically the ones that are presenting the breakdowns. According to [23]–[25], it is possible to achieve a 15% increase in the OEE of the machines. Formula:

$$OEE = Quality \times Availability \times Efficiency \tag{3}$$

Defects percentage: Measures the percentage of defects that occur from the total volume of production. The study of [26] reduce the defects percentage by a 13.07%, and [7], [27] seek to achieve the Zero Defect (ZD) philosophy. Formula:

$$Defects\ percentage = \frac{Defects\ number}{Sample\ Size} \times 100\% \tag{4}$$

IV. FUTURE WORK

With the analysis of the current situation of the company, it is expected to validate the proposal through a prototype, a pilot implementation, and a simulation, in order to corroborate the importance of the proposed clover model and to obtain its improvements by executing it. The validation will increase efficiency by almost 15%. This will be done with the implementation of Lean Manufacturing tools such as Poka-Yoke that will focus on the reduction of more than 5% in defective packaging due to human errors.

On the other hand, it is expected to consider how the proposal can affect the company in the economic, social, environmental, and cultural sense to provide a complete improvement that is not only focused on the operational part and that can be adapted to different industries.

V. CONCLUSIONS

In conclusion, this article shows the problem of low efficiency in production in the company M2T where a production efficiency of 52.77% is caused by unnecessary routes (25%), crossing of requests (21%), machine breakdowns (15%), and defective packaging (17%), resulting in orders being delivered late. For this, a model is proposed that focuses on optimizing the processes through the implementation of Lean Manufacturing tools, which will be put into practice and their effectiveness will be validated through a prototype, pilot and simulation to increase production efficiency.

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REFERENCES

[1] T. Müller, J. E. Dølvik, C. Ibsen, and T. Schulten, "The manufacturing sector: Still an anchor for pattern bargaining within and across countries?," *European Journal of Industrial Relations*, vol. 24, no. 4, pp. 357–372, Dec. 2018, doi: 10.1177/0959680118790817.

[2] Asociación de Industriales Metalúrgicos de la República Argentina (ADIMRA), "Sector metalmecánico," 2016. Accessed: Apr. 18, 2023. [Online]. Available: https://www.oneplanetnetwork.org/sites/default/files/from-crm/guia_metalmecanica.pdf

[3] Banco Central de Reserva del Perú (BCRP), "CUADRO 80 PRODUCCIÓN MANUFACTURERA (Variaciones porcentuales anualizadas) 1/ MANUFACTURING PRODUCTION (Annual growth rates) 1," 2022. Accessed: Sep. 30, 2022. [Online]. Available: https://www.bcrp.gob.pe/docs/Estadisticas/Cuadros-Estadisticos/cuadro-080.xlsx

[4] Sociedad Nacional de Industrias (SNI), "Coyuntura Industrial," 2022. Accessed: Sep. 30, 2022. [Online]. Available: https://sni.org.pe/coyuntura-industrial-febrero-2022/

[5] J. C. Quiroz-Florez and M. F. Collao-Díaz, "Production model using Lean Manufacturing tools applied in a continuous production line of a Peruvian metalworking company," in *2022 Congreso Internacional de Innovacion y Tendencias en Ingenieria, CONIITI 2022 - Conference Proceedings*, Institute of Electrical and Electronics Engineers Inc., 2022. doi: 10.1109/CONIITI57704.2022.9953698.

[6] L. R. Del Rosario and E. L. Dulce, "Modelo para mejorar la eficiencia en el proceso de producción de una MYPE peruana del sector metalmecánico mediante el uso de herramientas Lean Manufacturing," Lima, 2021. Accessed: Nov. 23, 2022. [Online]. Available: https://repositorioacademico.upc.edu.pe/handle/10757/655175

[7] A. Sharma, N. Bhanot, A. Gupta, and R. Trehan, "Application of Lean Six Sigma framework for improving manufacturing efficiency: a case study in Indian context," *International Journal of Productivity and Performance Management*, vol. 71, no. 5, pp. 1561–1589, May 2022, doi: 10.1108/IJPPM-05-2020-0223.

[8] A. Leon-Huerta, L. Zamora-Huamancha, E. Altamirano-Flores, and C. Raymundo, "Lean Manufacturing Model for Production Management

Based on SAP-LAP to Reduce Delays in the Production Line in Mypes of the Metalworking Sector," in *Lecture Notes in Networks and Systems*, Springer Science and Business Media Deutschland GmbH, 2021, pp. 473–481. doi: 10.1007/978-3-030-80462-6_57.

[9] B. Suhardi, N. Anisa, and P. W. Laksono, "Minimizing waste using lean manufacturing and ECRS principle in Indonesian furniture industry," *http://www.editorialmanager.com/cogenteng*, vol. 6, no. 1, pp. 1–13, Jan. 2019, doi: 10.1080/23311916.2019.1567019.

[10] S. Greinacher, L. Overbeck, A. Kuhnle, C. Krahe, and G. Lanza, "Multi-objective optimization of lean and resource efficient manufacturing systems," *Production Engineering*, vol. 14, no. 2, pp. 165–176, Apr. 2020, doi: 10.1007/s11740-019-00945-9.

[11] L. Gualtieri, I. Palomba, F. A. Merati, E. Rauch, and R. Vidoni, "Design of Human-Centered Collaborative Assembly Workstations for the Improvement of Operators' Physical Ergonomics and Production Efficiency: A Case Study," *Sustainability 2020, Vol. 12, Page 3606*, vol. 12, no. 9, p. 3606, Apr. 2020, doi: 10.3390/SU12093606.

[12] A. Ebrahimi, R. Khakpour, and S. Saghiri, "Sustainable setup stream mapping (3SM): a systematic approach to lean sustainable manufacturing," *Production Planning & Control*, 2021, doi: 10.1080/09537287.2021.1916637.

[13] P. Castañeda and D. Mauricio, "A model based on data envelopment analysis for the measurement of productivity in the software factory," *International Journal of Information Technologies and Systems Approach*, vol. 13, no. 2, pp. 1–26, Jul. 2020, doi: 10.4018/IJITSA.2020070101.

[14] C. V. Ferreira, F. L. Biesek, and R. K. Scalice, "Product innovation management model based on manufacturing readiness level (MRL), design for manufacturing and assembly (DFMA) and technology readiness level (TRL)," *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 43, no. 7, p. 360, Jul. 2021, doi: 10.1007/s40430-021-03080-8.

[15] K. C. Arredondo-Soto, A. Realyvasquez-Vargas, A. A. Maldonado-Macías, and J. García-Alcaraz, "Impact of human resources on remanufacturing process, internal complexity, perceived quality of core, numerosity, and key process indicators," *Robot Comput Integr Manuf*, vol. 59, pp. 168–176, Oct. 2019, doi: 10.1016/j.rcim.2019.04.004.

[16] F. Bertocci, A. Grandoni, M. Fidanza, and R. Berni, "A Guideline for Implementing a Robust Optimization of a Complex Multi-Stage Manufacturing Process," *Applied Sciences*, vol. 11, no. 4, p. 1418, Feb. 2021, doi: 10.3390/app11041418.

[17] J. Kumar, K. K. Kataria, and S. Luthra, "Quality Circle: A Methodology to Enhance the Plant Capacity through Why-Why Analysis," *International Journal of Mathematical, Engineering and Management Sciences*, vol. 5, no. 3, pp. 463–472, 2020, doi: 10.33889/IJMEMS.2020.5.3.038.

[18] G. Apaza-Casabona, S. Bacilio-Peve, C. Leon-Chavarri, and E. Ramos-Palomino, "Designing a Lean-based Production Management Model to Reduce Non-fulfilled Orders at a Metalworking Company," in *Proceedings - 2022 8th International Conference on Information Management, ICIM 2022*, Institute of Electrical and Electronics Engineers Inc., 2022, pp. 135–140. doi: 10.1109/ICIM56520.2022.00031.

[19] J. C. Quiroz-Flores and M. L. Vega-Alvitres, "REVIEW LEAN MANUFACTURING MODEL OF PRODUCTION MANAGEMENT UNDER THE PREVENTIVE MAINTENANCE APPROACH TO IMPROVE EFFICIENCY IN PLASTICS INDUSTRY SMES: A CASE STUDY," *South African Journal of Industrial Engineering*, vol. 33, no. 2, pp. 143–156, 2022, doi: 10.7166/33-2-2711.

[20] E. Ramos-Valle, A. Paulino, P. Chavez, J. C. Alvarez, and S. Nallusamy, "Pilot Implementation of Innovative Proposal for Service Level Improvement in a Spare Parts Trading Company," *International Journal of Engineering Research in Africa*, vol. 62, pp. 173–187, 2022, doi: 10.4028/p-70sd0q.

[21] G. Kovács, "Combination of Lean value-oriented conception and facility layout design for even more significant efficiency improvement and cost reduction," *Int J Prod Res*, vol. 58, no. 10, pp. 2916–2936, May 2020, doi: 10.1080/00207543.2020.1712490.

[22] M. Pekarcikova, P. Trebuna, M. Kliment, M. Mizerak, and S. Kral, "Simulation testing of the e-kanban to increase the efficiency of logistics processes," *International Journal of Simulation Modelling*, vol. 20, no. 1, pp. 134–145, 2021, doi: 10.2507/IJSIMM20-1-551.

[23] O. Bataineh, T. Al-Hawari, H. Alshraideh, and D. Dalalah, "A sequential TPM-based scheme for improving production effectiveness presented with a case study," *J Qual Maint Eng*, vol. 25, no. 1, pp. 144–161, Mar. 2019, doi: 10.1108/JQME-07-2017-0045/FULL/PDF.

[24] E. Ramos, R. Mesia, C. Alva, and R. Miyashiro, "Applying lean maintenance to optimize manufacturing processes in the supply Chain: A Peruvian print company case," *International Journal of Supply Chain Management*, vol. 9, no. 1, pp. 264–281, 2020, Accessed: Jun. 22, 2023. [Online]. Available: https://repositorioacademico.upc.edu.pe/handle/10757/653828?show=full

[25] R. S. Mor, A. Bhardwaj, S. Singh, and A. Sachdeva, "Productivity gains through standardization-of-work in a manufacturing company," *Journal of Manufacturing Technology Management*, vol. 30, no. 6, pp. 899–919, Oct. 2019, doi: 10.1108/JMTM-07-2017-0151.

[26] S. Kumar, A. K. Dhingra, and B. Singh, "Process improvement through Lean-Kaizen using value stream map: a case study in India," *International Journal of Advanced Manufacturing Technology*, vol. 96, no. 5–8, pp. 2687–2698, May 2018, doi: 10.1007/s00170-018-1684-8.

[27] S. Krishnan, K. Mathiyazhagan, and V. R. Sreedharan, "Developing a hybrid approach for lean six sigma project management: A case application in the reamer manufacturing industry," *IEEE Trans Eng Manag*, vol. 1, no. 1, 2021, doi: 10.1109/TEM.2020.3013695.