Application of Lean-Total Productive Maintenance Tools to Reduce Setup Times and Machine Stoppages on the Molding Line of an SME in the Food Industry

Renzo Peralta-Pereda*, Frank Zamora, Juan Quiroz-Flores, Martín Collao-Diaz, and Alberto Flores-Perez

***Abstract*—The demand for the food industry has maintained sustained growth in recent years. In Peru, as a consequence of the high competitiveness in the food sector, it has reflected a considerable contribution to the manufacturing GDP with 20% and 2.6% to the national Gross Domestic Product (GDP). However, the high demands of the market are not satisfied due to problems such as the availability of machinery, mainly due to high programming times, high frequency of machine stoppages, among others. These problems generate large monetary losses and a bad image in front of large potential customers. Thus, this research work, taking as a case study an SME (Small and Medium-Sized companies) of the food sector, seeks to provide the application of the tools of the Lean Manufacturing (LM) and Total Productive Maintenance (TPM) philosophies, to reduce the high setup times and the high frequency of machine stoppages that currently harm the company and generate an impact of 3.95% in operational costs. The model was validated using the Arena simulator, where a 30.83% reduction in machine programming time and a reduction in machine stop frequencies were obtained, which led to an improvement in Mean Time to Repair (MTTR) indicators with a 21.60% reduction and a 4.66% increase in Mean Time Between Failures (MTBF). This new integration of engineering tools makes it possible to solve the main problems faced by large companies in the sector to meet market demands and adapt to new needs.**

***Index Terms*—Lean, machine stoppages, Total Productive Maintenance (TPM), food Sector, arena simulation**

I. Introduction

The demand for the food industry has maintained sustained growth in recent years [1]. In Peru, as a consequence of the high competitiveness in the food sector, a considerable contribution to the manufacturing Gross Domestic Product (GDP) was reflected with 20% and 2.6% to the national Gross Domestic Product (GDP) [2]. However, the high demands of the market are not met due to problems such as the availability of machinery.

According to the literature, the main problem is presented by different inefficiencies such as high setup times, high times between failures, the unscheduled machine stops, among others [3]. Which, requires careful attention and response from the companies in the sector, as it can seriously affect the production capacity and as a consequence, low effectiveness [4]. Likewise, this problem has also been identified in other scientific researches in different countries of the world. For example, a food company in India saw that the implementation of Total Productive Maintenance (TPM) can lead to commendable reforms and significant improvement in productivity and quality, in addition to a good reduction in labor costs, as well as optimization of preventive maintenance costs, which can also be considered to improve efficiency [1]. Another research conducted in several manufacturing plants in the food industry in Vietnam, mentions that information sharing, participation, trust in management and training, cluster unfavorably to transformation opposition to change, with change training having the greatest effect. Employees who are well trained and equipped with tools and knowledge about change are less likely to resist and, consequently, the correct adoption of the work methodology will provide great productivity improvements [5].

In this context, it is of vital importance that food companies can count on the greater availability of their production lines to meet the demand they occupy. Therefore, a case study was chosen to reflect the sector's problem of limited production capacity due to different operational waste. The waste identified were high machine downtimes due to: high setup times, high times between failures, unscheduled machine downtimes, which generate monetary losses of 3.95% of the net profit of the case study. The generation of value of our proposal was *approach*ed through the tools highlighted in the state of the art, integrating each of these tools to the Lean-Total Productive Maintenance (TPM) model that we propose as the main solution. The tools are varied, with applications that focus on enhancing our model, among them, the ones that stand out for implementation are the application of Single Minute Exchange of Die (SMED) and 5S, as tools of the Lean Manufacturing philosophy and the management of preventive and autonomous maintenance through the Total Productive Maintenance (TPM) philosophy. The model was developed from successful cases with similar problems found in the literature to meet the problem-solving needs of the sector and its contribution to the scientific community.

Manuscript received April 18, 2023; revised May 19, 2023; accepted June 30, 2023.

The authors are with Facultad de Ingeniería y Arquitectura Universidad de Lima, Lima, Peru.

*Correspondence: 20161099@aloe.ulima.edu.pe (R.P.-P.)

II. Estate of Art

A. SMED

The Single Minute Exchange of Die (SMED) tool is one of the pillars of lean manufacturing, whose purpose is to distinguish the times and reduce to the limit the preparation planning times, so that the conditioning of the time settings is reduced from hours to minutes. Likewise, the Single Minute Exchange of Die (SMED) is generally used to reduce changeover times and configurations (they are considered waste), causing a significant increase in costs. The objective of the Single Minute Exchange of Die (SMED) methodology is to reduce batch sizes and improve efficiency and productivity [6]. This methodology should be implemented

DOI: 10.7763/IJET.2023.V15.1236

by companies that have excessive batch sizes, very long mold change times, and high machine stop times [7]. On the other hand, the Single Minute Exchange of Die (SMED) tool was used by Brito *et al.* [8] to reduce by 34% the waste related to mold change time and increase by 11% the production capacity of the line. This allowed the company to achieve the proposed objectives, thus extending the working time of a shift from 8 to 10 hours during the peak period and avoiding the use of temporary workers during the peak months.

B. TPM

As a lean strategy, TPM (Total Productive Maintenance) aims to reduce the main losses that are considered significant in production processes. These include equipment failure losses, setup and adjustment losses, high downtime losses, start-up losses, and defect/rework losses. Total productive maintenance requires that all members of the organization, from top management to shop floor studio personnel, be committed to the TPM (Total Productive Maintenance) program, which is interpreted that the name begins with "T" for Total [3]. Autonomous maintenance contributes greatly to reducing damage due to machine downtime since the person in charge of the work station is responsible for the respective process and this person has experience in this case. It can be deduced that 80% of the questionable machine stoppages are repetitive and can be resolved by a trained operator, while only 20% require external assistance [9]. Braglia *et al.* [10] who implemented the total productive maintenance tool achieved a 15% reduction in machine failures, indicates that autonomous maintenance activities reduce most of the losses. Planned maintenance establishes an optimal performance level of the equipment by executing a list of activities oriented to recover the optimal state of the equipment and to preserve the state with tasks planned by the preventive and predictive maintenance personnel, as well as to take into account the proper handling of the equipment by the personnel assigned. Sahoo [11], Soltanali *et al.* [12] managed to obtain a reduction in failures to 20%, 14%, and 18%, respectively. The first one suggests that TPM (Total Productive Maintenance) does not necessarily guarantee high profitability and better performance, however, it has been fundamental in sectors such as the food and beverage industry [11]. The second indicates that maintenance is important in power plants since it optimizes the long-term supply of electricity, and maintenance costs are significantly reduced by 5% [13]. Finally, Soltanali *et al.* [12], highlights that maintenance is important in the automotive industry, as it reduces costs and optimizes production.

C. 5S

The 5S Philosophy focuses on effective work, an organized workplace, and standardized processes. Likewise, 5S corresponds to a set of steps, which are the following: Eliminate, Sort, Clean, Standardize, and Discipline. Also, the principles of this methodology are the easiest to understand and it is a less expensive tool. The objective of implementing this tool is to reduce waste and keep the workplace clean, as well as the machines that are used [14]. Haddad [15] indicates that 5S is used to improve machine efficiency to reduce bottlenecks. He also indicates that the order and cleanliness of the work area are important. On the other hand, Syreyshchikova [16] indicates that the implementation of the 5S should go hand in hand with the SMED (Single Minute Exchange of Die) tool since they improve the production times of watches. The 5S tool considerably reduces labor accidents by 75% and reduces maintenance costs by 22%. Ribeiro [17] makes known that the 5S tools are important, as it favors reducing failure times with the implementation of internal audits, cleanliness in the work area. This was reduced by 15%, which indicates an optimization improvement. The 5S tool increases material turnover, minimize waste, and minimize costs to increase productivity [18, 19].

III. CONTRIBUTION

A. Model Basis

Today, many companies in the food industry are forced to modernize their processes and machines to become more competitive. However, the sector still does not meet all the needs of its customers, as there are major problems with machinery availability. Therefore, a deep search for tools and methodologies to improve the mentioned shortcomings was carried out. Thus, Lean and Total Productive Maintenance were found in the literature as the main solution philosophies.

B. Proposed Model

For the proposed model it will be important to have historical data on machine downtime, the frequencies that occur in a given operating time, and machine scheduling times. In this way, better visibility of the current situation of the company will be obtained and will allow enriching the research. With the above mentioned, the next step would be to apply the tools of the Lean-Total Productive Maintenance philosophy that will be part of the study proposal.

C. Model Components

The following Table I shows the main causes affecting the organization and the engineering tools found in the literature review as the main solutions to these problems:

TABLE I: COMPARISON MATRIX CAUSES VS STATE OF THE ART

Causes / Scientific papers	**Machine Setup**	**Machine Stoppages**	**Maintenance Management**	**Workstation Organization**
Pinto *et al.* (2019)	SMED			
Lozano *et al.* (2019)	SMED			
Randhawa, and Ahuja (2018)				5S
Singh and Ahuja (2017)			TPM, Planned maintenance	
Méndez and Rodriguez (2017)		TPM, Autonomous maintenance		
Proposal	SMED	TPM	TPM	5S

D. Model Components

In the following subsections, we describe the different phases of the application of the Lean-Total Productive Maintenance tools, which can be visualized in Fig. 1:

1) Phase 1: Problem analysis

The first step to follow is to identify the operational waste of the process, with the help of the VSM better visibility of such waste will be obtained. Subsequently, the data collected will be analyzed quantitatively, using tools such as Pareto diagrams, and then a problem tree will be drawn up to identify the root causes of the most significant problems.

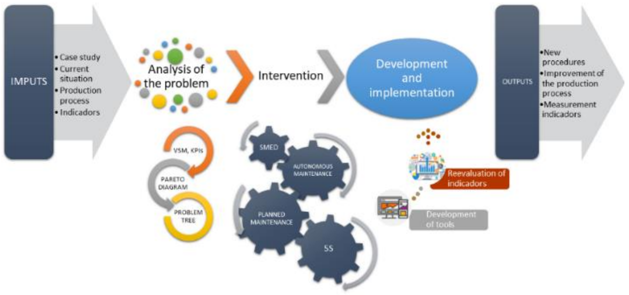

Fig. 1. General view of the application of Lean-Total Productive Maintenance tools.

2) Phase 2: Intervention

Having the above analysis, we will start with the internal diagnosis and the coordination of the 5S training to the plant personnel, to integrate continuous improvement in the company. Likewise, priority will be given to the organization of the machine programming tools with the use of red cards that will be used to identify the main points of disorder in the warehouses. In this way, the tools will be organized by color and will have a designated place so that personnel can acquire them without major inconveniences. In addition, weekly talks on the importance of applying the 5S tool will be given to the personnel to strengthen their commitment to adapting to this new way of working.

On the other hand, with the application of the ingle Minute Exchange of Die (SMED) tool, we proceed to identify the times of the mold change activity and then classify the times in Internal and External. With the data obtained, we proceed to analyze the internal times and evaluate which will be feasible to convert into external times. Subsequently, we will try to reduce the time and other wastes related to internal mold change activities. Also, the reduction of the duration of external activities to avoid delays in the search for tools. Finally, the personnel in charge of programming the machines will be trained so that most of the programming tasks can be carried out without interrupting production.

Concerning the application of autonomous and planned maintenance, deep cleaning of the workstations on the line understudy will be carried out. Likewise, operators will use red and green cards as tools to identify abnormalities. The red cards will be used to identify abnormalities that the operator considers he/she cannot resolve, and the green cards will be used to identify abnormalities that the operator considers he/she can resolve. Also, cleaning, lubrication, adjustment, and inspection standards will be established to carry out maintenance plans. It is important to note that the inspection standards will be presented in a checkpoint sheet; in addition, the operators will receive a training program focused on achieving a high level of knowledge on inspection methods. In this way, good visibility and better analysis capacity will be obtained in the inspection. On the other hand, the cleaning, lubrication, and adjustment standards will be presented in instructions, where the operators will learn which methods and tools will be necessary for the correct execution of the maintenance plan.

In addition to the above, the cleaning, lubrication, and adjustment standards established in the previous stages will be evaluated, and improvements in methods and times will be proposed based on the experience accumulated by the operator. Finally, as part of the standardization process, educational certifications, and recognitions will be provided to the members of the maintenance front for having fulfilled the training cycle proposed with the implementation of autonomous and planned maintenance.

E. Indicators

For this section, the following indicators will be used to analyze the improvement of the company's current situation.

- MTBF: It is the mean time between failures of a machine.

$$MTBF = \frac{Total\ time\ available - Time\ wasted}{Number\ of\ stops}$$

- MTTR: Total corrective maintenance time divided by the number of repair actions during a given period.

$$MTTR = \frac{Total\ corrective\ maintenance\ time}{Number\ of\ repair\ actions}$$

- The Total duration of mold change: This is the average mold change time in the machine setup.

$$Total\ duration\ of\ mold\ change = internal\ activity\ time + external\ activity\ time$$

- Duration of internal activities: This is the time of the operations performed when the machine is switched off

$$Duration\ of\ internal\ activities = sum\ of\ the\ times\ of\ internal\ activities$$

- Audit qualification: is the average of the 5S audits performed.

$$Audit\ qualification = Average\ of\ the\ 5S\ audits\ performed$$

IV. VALIDATION

To validate the application of the proposed tools, a simulation of the current process and the improvement will be carried out in the Arena program.

A. Initial Diagnosis

Currently, the SME has a high frequency of machine stoppages and high machine programming times. The economic impact generated is 3.95% of the company's total costs, where the costs of machine stoppages amount to S/. 82,901.66, and the costs of machine programming amount to S/. 62,566.37. The main causes of machine stoppages are: (a) obsolete machinery, (b) lack of monthly maintenance control, (c) correct cleaning, lubrication, and adjustment. On the other hand, the main causes of machine stoppages are: (a) High mold placement times, (b) Long cleaning times of the line machines, and (c) High assembly and disassembly times of the plates.

B. Validation Design and Comparison with the Initial Diagnosis

For the validation, a data collection of the operation times and the necessary times for the analysis of the indicators was carried out, all this in one month for the production batches of cream ice cream in the presentation of 63 grams, obtaining as data the daily production of 5443 boxes of ice cream (each box contains 40 popsicles of cream ice cream).

In component 1, the result of the VSM was the result of major operational problems. Subsequently, a quantitative and qualitative analysis was carried out and it became evident that the main problems with the greatest economic impact were caused by the high frequency of machine stoppages and high machine setup times.

On the other hand, the first tool implemented was the 5S. An initial evaluation was made to the company to know the average result. The score obtained by the company was 2.74 points out of 5, being below the optimum, representing a percentage of 54.79%, with the lowest phase being discipline continuing with cleaning.

The Single Minute Exchange of Die (SMED) tool was then developed. The sequence of activities for mold change consists of 9 activities: Washing of mold plates type 1, Transfer of mold plate type 2 from the warehouse to the work area, Disassembly of mold plate type 1, Transfer of mold plate type 1 to the machine side, Placement of mold plate type 2 on the rotary table, Assembly of mold plate type 2 on the rotary table, Transfer of mold plate type 1 to the warehouse, Washing of mold plate type 2, Cooling of the table and minor adjustments. From the data collection of the total duration of mold change times, a total of 280 minutes on average was obtained, and the times of internal activities, 254 min, and external activities, 26 min.

And finally, with the application of autonomous and planned maintenance, the data collection of the machine stoppages and respective calculations of Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR) of the seven machines of the line of study in one month was carried out. The machines involved in the process are Mix Plant, Freezer, Cold Compressor, Boiler, Air Compressor, Palletizer, Wrapper. A global average MTBF (Mean Time Between Failures) equivalent to 185.22 h was obtained and concerning the MTTR (Mean Time to Repair), a global average of 88.45 minutes/stop was obtained for the machines. During the analysis period, the following machine stops were observed: 2 stops in the Mix Plant, 8 stops in the Freezer, 3 stops in the Cold Compressor and Boiler, 1 stop in the Air Compressor, 86 stops in the Palletizer and 25 in the Wrapper. In the following Table II, we will be able to observe the above-mentioned.

TABLE II: GENERAL INDICATORS RESULTS

Indicators	Current	Expectation
Duration of internal activities	254 min	135 min
Total duration of mold change	280 min	190 min
Mean Time to Repair (MTTR)	88.45 min/stop	65.28 min/stop
Mean Time Between Failures (MTBF)	185.22 h	198.71 h
Audit qualification	54.79%	78%

C. Improvement-Proposal Simulation

The present model is the representation of the improvement proposal to the observed problems. An exhaustive analysis of the effect of the tools was carried out in a simulation model in Arena, which can be seen in Fig. 2, to establish the decrease of the machine preparation times and the reduction of the machine stop frequencies. The modeling was presented from the arrival of the ice cream bases to the last transformation process in the wrapper.

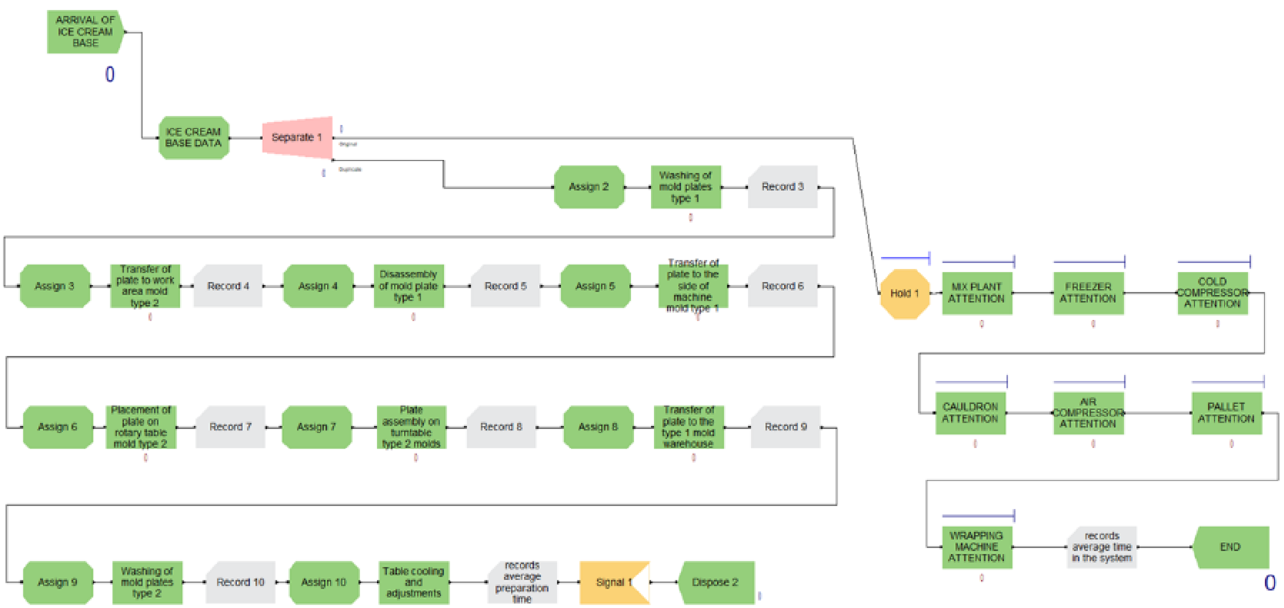

Fig. 2. Representation of the improved proposal in Arena.

The optimal number of replications in the simulation model was determined to be 173 to ensure statistical validity and data reliability. The results obtained from the proposed improvement are detailed in the following Table III.

TABLE III: SIMULATION CURRENT SITUATION VS IMPROVED SITUATION

Indicators	Current	Simulation
Duration of internal activities	254 min	145.314 min
Total duration of mold change	280 min	193.668 min
Mean Time to Repair (MTTR)	88.45 min/stop	69.336 min/stop
Mean Time Between Failures (MTBF)	185.22 h	193.858 h

The results obtained from the simulation were as follows:

A considerable reduction in machine programming times was observed from 280 min to 193.67 min on average, representing a 30.83% reduction in time. Likewise, internal activity times were reduced from 254 min to 145.31 min on average, giving a 42.79% reduction of the initial time. This proves the optimization of set-up times and the effective conversion of internal to external activity times. It should be noted that the implementation of the 5S tool was of vital help to establish organization and cleanliness of the work area.

This allowed improving the initial audit, giving a high level of good practices with 78%.

Finally, with the application of the autonomous and planned maintenance tools, a reduction of the MTTR (Mean Time to Repair) indicator was obtained, going from 88.45 min/stop to 69.35 min/stop, showing a great improvement in the time dedicated to the repair of the machines of the production line. On the other hand, the frequency of machine stops was reduced to the following numbers: 3 stops in the boiler, 5 stops in the freezer, 1 stop in the air compressor, 3 stops in the cold compressor, 15 stops in the wrapping machine, 2 stops in the mix plant and 52 stops in the palletizer. This resulted in an improvement in the MTBF (Mean Time Between Failures) indicator, from 185.22 h to 193.86 h on average.

V. CONCLUSION

It was possible to demonstrate that by implementing the tools of the Lean and Total Productive Maintenance philosophies it is feasible to reduce by 30.83% the machine programming time and also to reduce considerably the frequency of machine stoppages which led to an improvement in MTTR (Mean Time to Repair) indicators with a 21.60% reduction and a 4.66% increase in MTBF (Mean Time Between Failures).

The commitment to adopt these new ways of working must start from the highest levels of management down to the operators. It is important to establish a clear objective and integrate the whole team into it. In this way, the company will obtain great benefits and will become more competitive in the market.

In the future, it is advisable to have historical data of the machinery, reevaluate the indicators and propose the integration of engineering tools to adapt it as a model that can be replicated and contribute to maintenance management.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Renzo Peralta and Frank Zamora compiled the information on the status of the production plant with the cooperation of the supervisor during 2021. Juan Quiroz, Alberto Flores, and Martin Collao supervised this project and contributed ideas for the drafting of the document. All authors had approved the final version.

REFERENCES

[1] T. P. Singh and I. S. Ahuja, "Evaluating manufacturing performance through strategic total productive maintenance implementation in a food processing industry," *Int. J. Product. Qual. Manag.*, vol. 21, no. 4, pp. 429–442, 2017. doi: 10.1504/IJPQM.2017.085253

[2] D. Gestión, "Food industry would register the highest growth rate in the last six years | ECONOMY | MANAGEMENT," *Diario Gestión*, 2019. (in Spanish)

[3] D. P. Kshatra, R. P. Paladagu, P. Inturi, G. S. Vishnu, and V. S. V. S. Badrinath, "Calculation and improving the overall equipment effectiveness for textile industry machine," *Int. J. Emerg. Trends Eng. Res.*, vol. 8, no. 9, pp. 6085–6090, 2020. doi: 10.30534/ijeter/2020/193892020

[4] 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, 2019. doi: 10.1108/JQME-07-2017-0045

[5] D. T. Tran, H. T. Pham, and V. T. Bui, "The effect of contextual factors on resistance to change in lean transformation," *J. Asian Financ. Econ. Bus.*, vol. 7, no. 11, pp. 479–489, 2020. doi: 10.13106/jafeb.2020.vol7.no11.479

[6] J. Lozano, J. C. Saenz-Díez, E. Martínez, E. Jiménez, and J. Blanco, "Methodology to improve machine changeover performance on food industry based on SMED," *Int. J. Adv. Manuf. Technol.*, vol. 90, no. 9–12, pp. 3607–3618, 2017. doi: 10.1007/s00170-016-9686-x.

[7] G. F. L. Pinto, F. J. G. Silva, R. D. S. G. Campilho, R. B. Casais, A. J. Fernandes, and A. Baptista, "Continuous improvement in maintenance: A case study in the automotive industry involving Lean tools," *Procedia Manuf.*, vol. 38, no. 2019, pp. 1582–1591, 2019. doi: 10.1016/j.promfg.2020.01.127

[8] M. Brito, M. Vale, J. Leão, L. P. Ferreira, F. J. G. Silva, and M. A. Gonçalves, "Lean and Ergonomics decision support tool assessment in a plastic packaging company," *Procedia Manuf.*, vol. 51, no. 2020, pp. 613–619, 2020. doi: 10.1016/j.promfg.2020.10.086

[9] J. D. M. Méndez and R. S. Rodriguez, "Total Productive Maintenance (TPM) as a tool for improving productivity: A case study of application in the bottleneck of an auto-parts machining line," *Int. J. Adv. Manuf. Technol.*, vol. 92, no. 1–4, pp. 1013–1026, 2017. doi: 10.1007/s00170-017-0052-4

[10] M. Braglia, D. Castellano, and M. Gallo, "A novel operational approach to equipment maintenance: TPM and RCM jointly at work," *J. Qual. Maint. Eng.*, vol. 25, no. 4, pp. 612–634, 2019. doi: 10.1108/JQME-05-2016-0018

[11] S. Sahoo, "Assessment of TPM and TQM practices on business performance: a multi-sector analysis," *J. Qual. Maint. Eng.*, vol. 25, no. 3, pp. 412–434, 2019. doi: 10.1108/JQME-06-2018-0048

[12] H. Soltanali, A. Rohani, M. Tabasizadeh, M. H. Abbaspour-Fard, and A. Parida, "Operational reliability evaluation-based maintenance planning for automotive production line," *Qual. Technol. Quant. Manag.*, vol. 17, no. 2, pp. 186–202, 2020. doi: 10.1080/16843703.2019.1567664

[13] T. W. Kim, Y. Chang, D. W. Kim, and M. K. Kim, "Preventive maintenance and forced outages in power plants in Korea," *Energies*, vol. 13, no. 14, pp. 1–12, 2020. doi: 10.3390/en13143571

[14] K. Terdpaopong, A. Puapradit, and U. Malisuwan, "The effect of lean on the operational performance of medium-sized Thai manufacturing companies," *Uncertain Supply Chain Manag.*, vol. 9, no. 3, pp. 647–658, 2021. doi: 10.5267/j.uscm.2021.5.005

[15] T. Haddad, B. W. Shaheen, and I. Németh, "Improving Overall Equipment Effectiveness (OEE) of extrusion machine using lean manufacturing approach," *Manuf. Technol.*, vol. 21, no. 1, pp. 56–64, 2021. doi: 10.21062/mft.2021.006

[16] N. V Syreyshchikova, D. Y. Pimenov, A. P. Markopoulos, and L. Moldovan, "Value stream maps in clock production," *Russ. Eng. Res.*, vol. 41, no. 4, pp. 378–381, 2021. doi: 10.3103/S1068798X21040213

[17] I. M. Ribeiro, R. Godina, C. Pimentel, F. J. G. Silva, and J. C. O. Matias, "Implementing TPM supported by 5S to improve the availability of an automotive production line," in *Procedia Manufacturing*, 2019, vol. 38, pp. 1574–1581. doi: 10.1016/j.promfg.2020.01.128

[18] M. A. S. Mia, M. Nur-E-Alam, and M. K. Uddin, "Court shoe production line: Improvement of process cycle efficiency by using lean tools," *Leather Footwear J.*, vol. 17, no. 3, pp. 135–146, 2017. doi: 10.24264/lfj.17.3.3

[19] J. S. Randhawa and I. S. Ahuja, "An evaluation of effectiveness of 5S implementation initiatives in an Indian manufacturing enterprise," *Int. J. Product. Qual. Manag.*, vol. 24, no. 1, pp. 101–133, 2018. doi: 10.1504/IJPQM.2018.091170