Impact of the Application of Lean Manufacturing in Sausage Production Line Equipment in the Food Manufacturing Industry in Metropolitan Lima

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Abstract

The present investigation was carried out in a food manufacturing company in Metropolitan Lima, specifically in the Meats and sausages industry category. The investigation is focused on three stuffing machines within the sausage production line. The problem is the low overall efficiency expressed by the OEE indicator, which initially was an average of 60.479% for the three stuffing machines, compared to the world-class OEE, which according to Nakajima, is 85%. In order to improve the OEE indicator, the company implemented the use of Shoplogix software and applied lean manufacturing methodologies in its sausage production lines. Due to this, the main objective was to describe the impact generated by implementing lean manufacturing methodologies in the OEE. For this, information was collected from primary sources for four weeks, and historical data of four years was used on the OEE indicator, and the main problems detected in the stuffing machines. Finally, normality and Student's t-tests were performed, showing that implementing lean manufacturing methodologies positively impacted the OEE, increasing an average of 5.9583%. It was also shown that the software-generated implementation significantly changed the OEE's data collection and calculation. This improvement is translated into more than 2 million dollars in savings from its implementation until 2021.

Keywords
Lean manufacturing, OEE, food industry, statistical validation, sausages.

1. Introduction
Within the food industry, manufacturing directly influences aspects such as nutrition and the production of foods included in the diets of the world population. As a result of entering the global market, competition increases the

quality of products and the scope of available products and services and drives prices to a lower level (Radovic, 2015). Due to the low-profit margins in most sectors, the need to improve production efficiency, reduce energy consumption and save resources has motivated updating computerized production management systems (Osterroth et al., 2017).

Industrial food production requires unobstructed operation and unscheduled stops of mechanical equipment since a failure in one of the workstations can generate reductions in production and possible problems in the processed products. Defects must be detected early to plan their maintenance and avoid stoppages in the production process (Chaari et al., 2022).

The problem faced by many companies in this sector is the low overall efficiency in their production processes, which is measured by the Overall Equipment Effectiveness (OEE) indicator. OEE is a key performance indicator used in manufacturing systems to control and monitor the productivity of technical teams (Huang et al., 2002).

OEE measurement is commonly used for production performance monitoring as part of a company's performance measurement system; this indicator can also be used for internal benchmarking, quantifying improvements performed, internal performance comparison, and identifying the machine with the worst performance (Jonsson and Lesshammar, 1999).

The hypothesis for this research article stated that the application of lean manufacturing methodologies generates an average increase of more than 5% in the OEE indicator for the three stuffing machines under analysis.

1.1 Objectives

The research objective was to know the impact generated on the OEE indicator by implementing lean manufacturing methodologies in 3 stuffing machines in a sausage production line within the manufacturing food industry.

2. Literature review

The OEE indicator was initially conceived to provide a helpful indicator to identify and measure the inefficiencies of industrial equipment, grouped into three main categories of losses: time losses, speed losses, and quality losses (Schiraldi and Varisco, 2020). The OEE is the multiplication of its three components, availability, performance efficiency, and quality rate. World-class OEE is generally considered to be better than 85%, with 90% availability, 95% performance, and 99.9% quality rating (Chen and Voight, 2020).

The lean manufacturing approach, which has as its central basis reducing waste and improving efficiency, has become important recently (Womak et al., 1990). Implementing the lean manufacturing system is a practice that includes measuring the current situation and generating a design of the production system (De Souza and Carpinetti, 2014). The benefits of implementing Lean tools are waste reduction and efficiency improvement, which can be achieved by eliminating waste and producing high-quality products (Schonberger, 2007). The lean manufacturing tools applied in the machines under analysis were SMED, Kaizen, 5S, and Poka-Yoke.

First, SMED is a lean manufacturing methodology to reduce downtime in manufacturing processes (Almomani et al., 2013). It was made by Shigeo Shigo, who recommends a simple approach to improve change in operations significantly. This approach aims to reduce configuration times and increase credibility in the change process. The core of the SMED methodology is to reduce the time wasted on many changes by performing as many activities while the equipment is running as much as possible and streamlining the remaining steps by making the production flow smoother (Moxham and Greatbanks, 2001). The SMED methodology has not been limited to a single type of industry, being applied in manufacturing processes, administration services, and assembly operations. Whenever a new technology is proposed to configure a process, the expected benefit of its use must be compared with its costs (Trovinger and Bohn, 2005).

Secondly, Kaizen is a philosophy that analyzes the process in order to make constant improvements, increase quality and reduce costs; this methodology focuses on people and process standardization. Its practice requires an integrated team of production personnel in maintenance, quality assurance, engineering, purchasing, and other employees that the team deems necessary. Its objective is to increase productivity by controlling manufacturing processes.

reducing cycle times, standardizing quality criteria, and work methods by operation; it also focuses on eliminating waste (Gallegos, 2017).

Third, 5S is a technique used to establish and maintain a quality environment in an organization (Khamis et al., 2009). Initially, the 5S methodology was used to develop an integrated management system that evolved into Total Productive Maintenance (TPM) (Bamber et al., 2000). The name of 5S corresponds to the initial letter of 5 Japanese words: Seiri (Order), Seiton (Simplify), Seiso (Brightness), Seiketsu (Standardize), and Shitsuke (Hold). All five phases are essential and must be treated separately and in order. The first three phases are operational; the fourth maintains the state reached with the previous phases, and the fifth phase helps us work on continuous improvement (Jiménez et al., 2015).

Fourth, Poka-Yoke is a mechanism or device to avoid human errors that become defects and generate a decrease in the final quality of the product (Saurin et al., 2012). Poka-Yoke focuses on the prevention and detection of errors, preventing a product from continuing in the production line without being repaired, and it also supports quality control in mass production systems (Pötters et al., 2018).

In addition, some of the indicators used in the production line are productivity; in the context of manufacturing, it shows a production-input relationship of the target production (Andersson and Bellgran, 2015). Another indicator is reprocessing, defined as "the process when an element of the construction work does not meet the customer's needs and specifications, or when the finished work does not conform to the contract documentation" (Oyewobi et al. 2011). The mean time between failures (MTBF) is also considered, according to (Ameer and Haddi, 2021), a term commonly used in the reliability work maintenance system. It is known as an item's (average) or (expected) useful life or is a notational equivalent. The mean time to repair indicator is also defined as the value expected during the useful life before a malfunction occurs.

On the other hand, according to Grosfeld-Nir et al. (2007), the Pareto principle of 80/20 was extrapolated to describe other realities; later, it was upgraded to the "A", "B", "C" classification, where the "A" group, which consists of approximately 20% of the attributes, explains 80% of the phenomenon; group "B", that is, the next 30% of the elements, represents 10% of the phenomenon, and group "C", which contains 50% of the articles, represents only 10% of the phenomena.

3. Methods

The proposed model was based on measuring the impact on the OEE indicator after applying lean manufacturing methodologies. For this, a statistical comparison of the OEE was made in an initial and final period, using statistical tools such as the normality test and student's t-test. The statistical tests were carried out in the IBM SPSS STATISTICS 28 software. In addition, the methodology of this article is divided into three parts, detailed below. Figure 1 shows the proposed model for the diagnosis and validation of indicators.

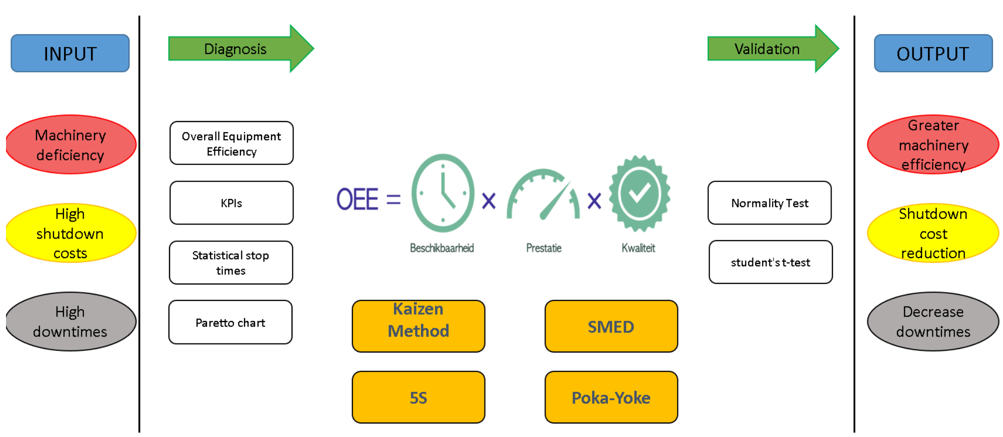

Figure 1. Proposed model

3.1 Production process

The production process of the sausage line was described; in addition, a block diagram was developed to graphically identify the sequence of activities using Visio 2019 software.

3.2 Detection of main problems

Two tables were prepared with the times of the causes of problems considering the information collected as a basis for 2019 and 2022, proceeding to order from highest to lowest to calculate the individual percentage per problem then and finally calculate the accumulated percentage. Subsequently, two Pareto diagrams were made to graphically classify the information from most to least relevant and focus the investigation on the main problems within the production process at the beginning of 2019 and April 2022.

3.3 Statistical tests

Statistical validation tests were carried out to determine if the proposed hypothesis is correct; SPSS statistical software was used to determine the normality of the data analyzed to later use the student t-test and determine the variation of the OEE indicator after the application of lean manufacturing methodologies.

4. Data collection

Over four weeks, information was collected on problems reported on three sausage machines stuffer. Due to the number of records in the database, it was impossible to retrieve more information about the problems in said stuffing machines.

The retrieval of information on the problems was carried out through the use of the Shoplogix Smart Factory software, which is an intelligent software that collects the information and various parameters of the plant floor that are key for the Production and Manufacturing Areas; for this, the engineer in charge accessed the stored historical data delimiting time intervals and downloading the information in excel workbook.

In addition, information was collected on the indicators described in the definition section. The collection of information related to these indicators follows a process identical to that used in collecting problems. Data recorded for 52 weeks were retrieved.

OEE data were also collected over four years; however, for the present investigation, the use of data obtained in the year 2020 was not used due to a large amount of atypical data present in the registry of that year caused by conjunctural measures. The collection of these data followed the same procedure mentioned above.

In 2019, the company under analysis implemented software with the unique quality of connecting to any machine and, in this way, managing to collect information. This is collected through sensors installed in the various machines, which detect the consumption of electricity, water, gas, and steam, among others, because the Shoplogix program is attached to the equipment. Likewise, the program detects the various stoppages and bottlenecks, among others, and the data is presented visually, which is why they are the basis for applying continuous improvement concepts such as Kaizen, TPM, or Lean Manufacturing.

Next, information is presented about the leading causes of problem stuffing machines. Table 1 corresponds to January 2019, before the use of the Shoplogix software and application of lean manufacturing methodologies, and Table 2 corresponds to the problems detected in April 2022, after the use of the software and the application of the methodologies of lean manufacturing. For the collection of information in Table 1, the company's historical data was stored in Excel books; for Table 2, information stored in the Shoplogix software was used.

Table 1. Causes of problems in the stuffing machine in January 2019

Problem subcategory	Downtime (min)	Percentage	Accumulated percentage
Product exchange	8.45	16.13%	16.13%
Lack of cars	8.38	16.00%	32.12%
Missing rods delay in thermal / cut treat	6.29	12.01%	44.13%
Lack of staff	6.08	11.61%	55.74%
Obstruction of production plant	4.08	7.79%	63.52%
Sort the area	3.39	6.47%	69.99%

Lack of mass	3.26	6.22%	76.22%
Pipe cleaning	3.1	5.92%	82.13%
Machine cleaning at the end of shift	2.15	4.10%	86.24%
Defective materials	1.42	2.71%	88.95%
Use of sanitary facilities	1.38	2.63%	91.58%
Cleaning machine during process	1.2	2.29%	93.87%
Machine regulation during process	1.11	2.12%	95.99%
Presentation change	1.05	2.00%	98.00%
Refreshment	0.55	1.05%	99.05%
Shift relay	0.4	0.76%	99.81%
Lack of materials	0.1	0.19%	100.00%
Total	52.39	100.00%	

Table 2. Causes of problems in a stuffing machine in April 2022

Problem subcategory	Downtime (min)	Percentage	Accumulated percentage
Small stops	30.09	26.53%	26.53%
Missing cars	17.22	15.18%	41.70%
Missing hopper mass	17.07	15.05%	56.75%
Product change	12.77	11.26%	68.01%
Maintenance	8.59	7.57%	75.58%
Machine failure	6.88	6.06%	81.65%
Mass color	5.54	4.88%	86.53%
Operational failure	3.77	3.32%	89.85%
Time-out	3.17	2.79%	92.65%
Defective materials	3.12	2.75%	95.40%
Logistical failures	3.04	2.68%	98.08%
Early output production	2.18	1.92%	100.00%
Total	113.44	100.00%	

5. Results and Discussion

The main findings of this investigation were, first of all, there was a significant change in the OEE indicator compared between the manual information collection and the collection using the Shoplogix software; it was stated that this significant change occurred because, in the manual collection, the probability of making errors distorting the information is higher, also being a manual collection, there is the possibility of manipulating information to avoid recording errors and avoid penalties.

Second, it was found that lean manufacturing methodologies positively impacted the OEE indicator. It was suggested that this impact was because these methodologies directly focus on problems such as small stops, planning problems, elimination of errors, and continuous improvement.

The average productivity during the year 2021 was 72.82 kg/h per week, exceeding the proposed goal of 70 kg/h per week. The weekly average production compliance during 2021 was 100.35% compared to the initial goal of 98%. The balances, masses, and reprocesses represented an average of 0.36%, exceeding the 0.35% established weekly goal in 2021. Total machine downtime hours in 2021 averaged 13.03 hours, below the 30 hours established as the weekly maximum. The average weekly preventive maintenance compliance was 88.91%, below the established goal of 90%. The mean time between failures per week was 59.9 hours, while the established goal was 50 hours per week. The average repair time was 0.32 hours per week, while the established goal was 0.39 hours per week.

It was compared with other related research, and it was found that Haddad et al. (2021) stated that applying the SMED technique is an effective approach to absorbing the downtime loss in the die change process. The reduction in downtime translated into a 3.26% improvement in extruder OEE. In the same sense, according to Jebaraj et al. (2013), the SMED technique has proven to be an effective approach to dealing with small stops, a loss considered one of the most difficult to reduce. The elimination of small stops resulted in a 2.08% improvement in OEE in the barrel production process in one of the largest barrel manufacturing industries in the Association of Southeast Asian Nations (AESAN) region. Similarly, for Sri Ngadono et al. (2020), applying lean manufacturing in a tire production line in one of the largest local manufacturers in Tangerang increased OEE from 61% to 64.8%. According to Ben Hassan (2016), the direct effect of the implementation of 5s in 4 CNC machines in a leading plant in the heavy equipment industry for quarries and mining applications had an increase in OEE from 55.89% to 63.84%, which indicates the implementation of 5S and the OEE would be contributing strongly with the support to the total productive maintenance. In this article, it was statistically demonstrated that lean manufacturing methodologies had a positive impact on the OEE indicator, the latter having an average increase of 5.9583%, from 60.479% to 66.438% on average in the three stuffing machines. The variation of the increase in the OEE indicator about the cited investigations occurred because each one is developed in different industries; in addition, in the present investigation 4 of the lean manufacturing methodologies were applied in comparison with the cited investigations where it was analyzed the application only one to two methodologies.

After carrying out the analysis, it was statistically demonstrated that one of the main events that contributed to the improvement of the OEE was the correct measurement of this indicator; it was possible to identify the leading causes of the low OEE, and the improvements were proposed using techniques of lean manufacturing such as SMED, 5s, Kaizen and Poka-yoke. It was possible to affirm that the application of lean manufacturing methodologies in production lines has a positive impact, reducing downtime, and failures in production processes, improving organization, and consequently increasing the OEE indicator.

It should be noted that this research was limited to a descriptive study carried out on a sausage production line in one of the leading food manufacturing companies in Peru. The research results fulfilled the proposed hypothesis, which proposed an increase in OEE greater than 5%. It is recommended to start with the collection of data, indicators, and related information as quickly as possible to define the meaning of the investigation better; it is also recommended to treat the data by eliminating or not considering periods with atypical data caused due to external events, in the case of this research data from the year 2020 was omitted for reasons related to COVID 19. In addition, it is essential to identify the type of test to be carried out, considering the randomness, distribution, and amount of data collected.

5.1 Numerical results

The application of lean manufacturing methodologies increased the OEE indicator in the three stuffing machines analyzed. In the machine 1, an average increase of 6.93% was generated, having an initial OEE of 56.63%, increasing to 63.56%. The stuffing machine 2 increased 5.50%, from 61.50% to 67.00%. The stuffing machine 3 increased 5.44%, from 63.31% to 68.75%. An average increase in OEE of 5.9583% for the three stuffing machines was generated.

5.2 Graphic results

The flowchart in Figure 2 shows the production process of the sausage line should indicate that stuffing represents the most critical process throughout the production of sausages.

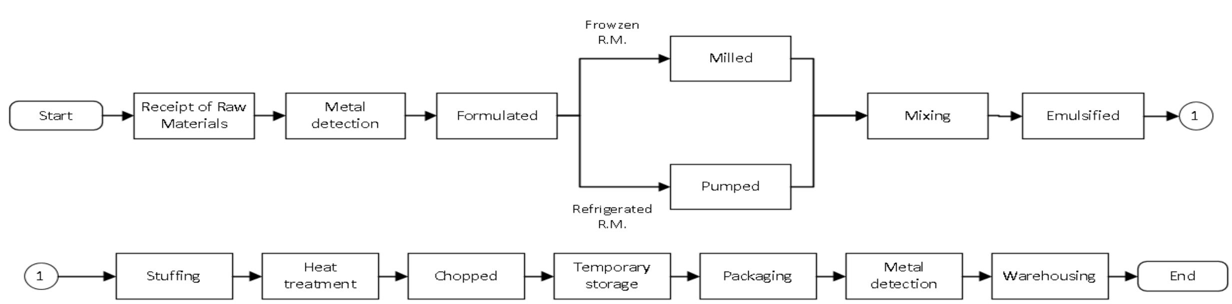

Figure 2. Block diagram of the sausage production process

The main problems detected were compared through a Pareto diagram in Figure 3, comparing the problems of 2019 before implementing the Shoplogix Smart Factory software and applying lean manufacturing methodologies. Six problems represent approximately 75% of the problems, with product change having the highest percentage with 16.13%.

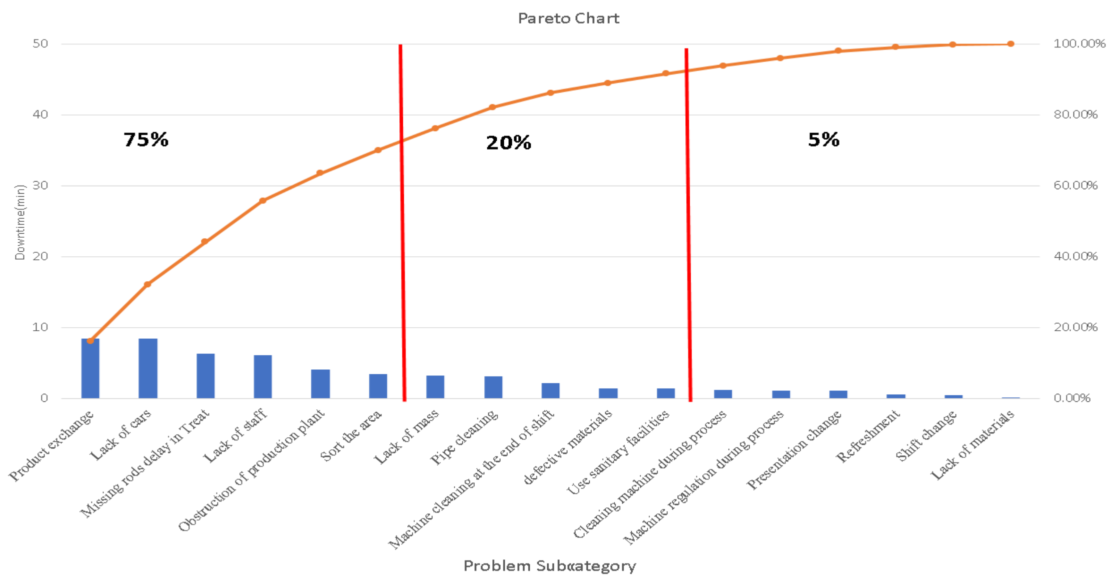

Figure 3. Pareto chart for January 2019

In the same way, a Pareto diagram in Figure 4 was made for April 2022 to discover the leading causes that negatively affect the OEE indicator. Shoplogix software was already being used by this date, and lean manufacturing methodologies had been applied. It was detected that five problems represent approximately 75% of the problems, with the small stops being the one with the longest time, representing 26.53%.

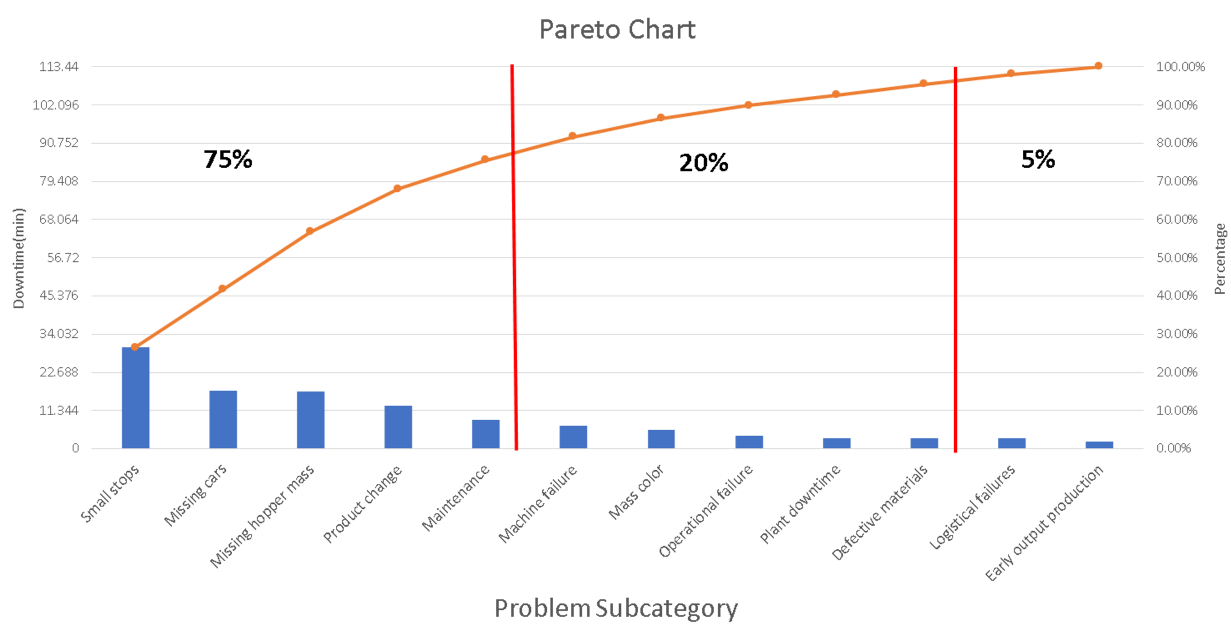

Figure 4. Pareto chart for April 2022

At first glance, it can be assumed that the application of these lean manufacturing methodologies had a negative impact, almost doubling downtime, but this increase has its causes in the change of the method of collection and treatment of information from a manual measurement to an automated measurement by the software. As a result of this change, problems that had not been identified by manual collection were the small stops that became the leading cause of the decrease in the OES. The statistical validation of this statement is found in point 5.4 of this research.

5.3 Validation

After applying solutions detailed in the previous point, the results obtained were analyzed, and it was found that the application of Lean Manufacturing had an impact on the reduction of downtime, which was also reflected in the reduction of times in problems and the OEE indicator, this was statistically validated in the following lines.

Likewise, it should be noted that problems, stoppages, and failures will always occur in the production line, and not all these events can be prevented because they occur due to various factors. However, continuous improvement can be made with the continuous use and analysis of the information obtained by Shoplogix; different solutions are focused on obtaining better results, and the system demonstrates it in its historical data.

When comparing the first five weeks of 2019 and 5 weeks of 2022, it was observed that implementing lean manufacturing methodologies generated an increase in downtime; stuffer 1 had an average time increase of 77.57%. Similarly, stuffer 2 had an average increase of 24.99%, and stuffer 3 increased its downtime by 15.53%.

The hypothesis was raised that this increase in downtime or inactivity was because the installed software collected the time information with greater reliability than a manual collection and treatment in Excel.
To accept or reject the hypothesis about the increase in downtime, the statistical software SPPS was used; it determined whether the compared data followed a normal distribution and then defined the type of test to be carried out to verify the hypothesis.

The normality test was carried out at two time periods using the OEE indicator; the periods under analysis include week 1 to week 19 of the year 2019 and week 34 to week 52 of the year 2019. These intervals are used because during the period not taken into account, the use of the Shoplogix software began in the company under analysis.

When performing the normality test, it was observed that for machine 1, significances of 0.685 and 0.284 were obtained for the first and second periods, respectively. For machine 2, significances of 0.920 were obtained in the first period and 0.379 in the second period. In machine 3 test, a significance of 0.756 was obtained for period 1 and 0.88 for period 2.

The Shapiro-Wilk test was chosen to measure significance because for all the samples, the amount of data was less than 50. The normality test results had a significance greater than 0.05, so it was determined that they followed a normal distribution.

Once it was shown that a normal distribution followed, the student's t-test for paired samples was used. The following hypotheses were raised:

Ho: There was no significant difference in the variation of the OEE.
Hi: There was a significant difference in the variation of the OEE.

After performing the student t-test for the three machines, the results for machine 1 were a P value of 0.04, for machine 2, a P value less than 0.001, and for machine 3, a P-value of 0.01.
The factor P test was less than 0.05 for each of the three tests; therefore, the alternative hypothesis was accepted, and it was stated that there is a significant difference in the variation of the OEE when comparing the periods before and after the implementation of the software.
Data collected with Shoplogix software showed a higher level of OEE than data collected manually.
Finally, it was statistically verified if the initial hypothesis on the application of lean manufacturing methodologies generated an increase greater than 5% in the stuffing machines analyzed. The null hypothesis and the alternative hypothesis were raised.

Ho: The OEE had an increase greater than 5%.

Hi: The OEE had an increase of less than 5%.

For this comparison of OEE, information was taken from 16 weeks of OEE between the periods comprised by week 34 and week 52 of 2019; these data were compared with data from the OEE of 16 weeks from periods comprised between week one and week 16 of 2021, the use of data from the year 2020 was avoided due to the large amount of atypical data generated, for the most part, by the measures imposed to mitigate the COVID 19 pandemic.

When performing the normality test, the Shapiro-Wilk test was chosen because there are 16 data points per period. For machine 1, a significance of 0.340 and 0.797 was obtained for the 2019 and 2021 periods. For machine 2, a significance of 0.305 was obtained for the 2019 period and 0.768 for the 2021 period. For machine 3, a significance of 0.255 for the 2019 period and 0.88 for the 2021 period. It was shown that a normal distribution is followed.

The student t-test was performed for a sample in the three stuffing machines; a significance of 0.06 was obtained for machine 1, 0.06 for machine 2, and 0.046 for machine 3. The three-student t-tests obtained a factor coefficient greater than 0.05; therefore, the null hypothesis was accepted. This means that it was statistically verified that the increase in OEE was greater than 5% in the three stuffing machines.
The initial hypothesis was accepted, statistically verifying that machine 1 had an average increase of 6.9375% in the OEE, machine 2 had an average increase of 5.5000%, and machine 3 had an average increase of 5.4375%.

6. Conclusion

The results obtained through validation using the SPPS statistical software reflected that the data collection underwent a significant change and then replaced the manual method with an automated method using the Shoplogix software. To verify this statement, a normality test was performed at periods before and after the change of method for measurement, and a student t-test was performed to demonstrate the significant change in measurement. Then, to demonstrate the significant change in the OEE, a normality test was performed again on the data under analysis, and it was determined that they follow a normal distribution. Consequently, another student t-test was used, and through the P factor, it was demonstrated that the hypothesis was fulfilled where it was proposed that the OEE indicator had an average increase of more than 5% for the three filling machines analyzed after applying the methodologies lean manufacturing on production lines; specifically, the OEE indicator has an average increase for stuffing machines of 5.9583%. This increase was reflected in savings by the company of approximately 2 million dollars between 2020 and 2021.

When analyzing the present and previous related investigations, it was possible to affirm that the application of lean manufacturing methodologies had a positive effect and generated an increase in the OEE indicator.

References

Almomani, M., Aladeemy, M., Abdelhadi, A. and Mumani, A., A proposed approach for setup time reduction through integrating conventional SMED method with multiple criteria decision-making techniques, *Computers & Industrial Engineering,* vol 66, no. 2, p. 461–469, 2013.

Ameer Issa, LAA and Haddi Hassan, ZA, Use of a modified Markov models for parallel reliability systems that are subject to maintenance, *2nd International Virtual Conference on Pure Science (2IVCPS 2021)* , Diwaniyah, Iraq, April 21-22, 2021.

Andersson, C. and Bellgran, M., On the complexity of using performance measures: Enhancing sustained production improvement capability by combining OEE and productivity, *Journal of Manufacturing Systems,* vol 35, pp. 144–154, 2015.

Bamber, C., Sharp, J. and Hides, M., Developing management systems towards integrated manufacturing: a case study perspective, *Integrated Manufacturing Systems,* vol.11, no.7, pp. 454–461, 2000.

Ben Hassan, A., Assessment of 5S and overall equipment effectiveness contributions towards promoting total productive maintenance implementation, *Proceedings of the Global Joint Conference on Industrial Engineering and Its Application Areas 2016,* Istanbul, Turkey, July 14-15, 2016.

Chaari, F., Schmidt, S., Hammami, A., Heyns, PS and Haddar, M., On the Use of Jerk for Condition Monitoring of Gearboxes in Non-stationary Operations, *Springer Science and Business Media Deutschland GmbH,* Vol. 19, p. 157–167, 2022.

Chen, X., Nophut , C. and Voigt, T., Implementation of the Manufacturing Execution System in the food and beverage industry, *Journal of Food Engineering* , Vol. 115, no. 7-8, p. 2607-2622, 2020.

De Souza, R. and Carpinetti, L., A FMEA-based approach to prioritize waste reduction in lean implementation. *International Journal of Quality & Reliability Management,* vol. 31, no. 4, p. 346–366, 2014.
Gallegos, H., Kaizen system in administration. *Business Innovations Magazine,* Vol. 4, no. 7, 2017.
Grosfeld- Nir, A., Ronen, B. and Kozlovsky, N., The Pareto managerial principle: when does it apply? *International Journal of Production Research,* Vol. 45, no. 10, p. 2317–2325, 2007.
Haddad, T., Shaheen, B. and Németh, I., Improving Overall Equipment Effectiveness (OEE) of Extrusion Machine Using Lean Manufacturing Approach, *Manufacturing Technology,* Vol. 21, no. 1, p. 56–64, 2021.
Hao, H., Sun, Y., Mei, X. and Zhou, Y., Reverse Logistics Network Design of Electric Vehicle Batteries considering Recall Risk, *Mathematical Problems in Engineering,* vol. 2021, p. 1–16, 2021.
Huang, S., Dismukes, J., Shi, J., Su , Q., Wang, G., Razzak, M. and Robinson, D., Manufacturing system modeling for productivity improvement *, Journal of Manufacturing Systems* , Vol. 21, no. 4, p. 249–259, 2002.
Jebaraj , S., Murugaiah , U. and Srikamaladevi , M., The use of SMED to eliminate small stops in a manufacturing firm, *Journal of Manufacturing Technology Management* , vol. 24, no. 5, p. 792–807, 2013.
Jiménez, M., Romero, L., Domínguez, M. and Espinosa, M., 5S methodology implementation in the laboratories of an industrial engineering university school, *Safety Science,* vol. 78, p. 163–172, 2015.
Jonsson, P. and Lesshammar, M., Evaluation and improvement of manufacturing performance measurement systems - the role of OEE, *International Journal of Operations & Production Management,* vol. 19, no. 1, p. 55–78, 1999.
Khamis, N., Abrahman, MN, Jamaludin, KR, Ismail, AR, Ghani, JA and Zulkifli, R., Development of 5S practice checklist for manufacturing industry, *Proceedings of the World Congress on Engineering 2009 Vol I WCE 2009,* pgs. 1-5, London, UK, July 1-3, 2009.
Moxham, C. and Greatbanks, R., Prerequisites for the implementation of the SMED methodology, *International Journal of Quality & Reliability Management,* vol. 18, no. 4, p. 404–414, 2001.
Nakajima, S., *Introduction to TPM,* 1st Edition, Productivity Press, Portland, 1988.
Osteroth, I., Klein, S., Nophut , C. and Voigt, T., Operational state related modeling and simulation of the electrical power demand of beverage bottling plants, *Journal of Cleaner Production* , vol. 162, p. 587–600, 2017.
Oyewobi L., Okel A., Ganiyu B., Shittul A., Isa R. and Nwokobia L., The effect of project types on the occurrence of rework in an expanding economy, *Journal of Civil Engineering and Construction Technology,* vol. 2, no. 6, p. 119–124, 2011
Pötters, P., Schmitt, R. and Leyendecker, B., Effectivity of quality methods used on the shop floor of a serial production – how important is Poka yoke? *Total Quality Management & Business Excellence,* vol. 29, no. 9-10, p. 1200-1212, 2018
Saurin, T., Ribeiro, J. and Vidor, G., A framework for assessing poka-yoke devices. *Journal of manufacturing systems,* vol. 31, no. 3, p. 358-366, 2012.
Schiraldi, M. and Varisco, M., Overall Equipment Effectiveness: consistency of ISO standard with literature, *Computers & Industrial Engineering,* vol. 145, 2020.
Schonberger, R., Japanese production management: An evolution—With mixed success, *Journal of Operations Management*, vol. 25, no. 2, p. 403–419, 2007.
Sri Ngadono , T., Rokhim , M. and Fitri Ikatrinasari , Z., Lean Manufacturing Implementation on Extrude Process with Value Stream Maping : Study Case in Tire Manufacture, *IOP Conference Series: Materials Science and Engineering* , Jakarta, Indonesia, November 21-22, 2019.
Trovinger, S. and Bohn, R., Setup Time Reduction for Electronics Assembly: Combining Simple (SMED) and IT-Based Methods, *Production and Operations Management*, vol. 14, no. 2, p. 205–217, 2009.
Womack, JP, Jones, DT, and Roos, D., The machine that changed the world, *Palgrave Macmillan Journals*, vol. 22, no. 3, p. 533-538, 1991.

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