SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2023
ORGANIZATION AND MANAGEMENT SERIES NO. 188

THE IMPACT OF IMPLEMENTING SELECTED LEAN MANUFACTURING TOOLS ON THE FAILURE RATE OF MACHINES – CASE STUDY

Szymon PAWLAK

Silesian University of Technology in Katowice, Faculty of Materials Engineering, Katowice;
szymon.pawlak@polsl.pl, ORCID: 0000-0002-8896-7966

Purpose: The aim of the research was to present the impact of the use of selected Lean Manufacturing tools on the failure rate of production machines and devices on the analyzed production line. The research was carried out on the basis of data from an electrical industry production plant.
Design/methodology/approach: The article presents a statistical analysis of the impact of the implementation of Total Productive Maintenance on the production process - a case study.
Findings: The obtained results allowed to present the scale of changes taking place in the production process, confirming at the same time the positive impact of the implementation of the TPM tool on the duration of failure and indicators (Mean time to Repair - MTTR and Mean time to Failure - MTTF).
Social implications: The analysis carried out can increase awareness of the importance of the impact of Lean Manufacturing on the production process.
Originality/value: The article contains an original statistical analysis, which indicates a reduction in the failure rate of production machines and devices as a result of the implementation of selected Lean Manufacturing tools.

Keywords: Lean Manufacturing, Total Productive Maintenance, Machine failure rate.

Category of the paper: Case study.

1. Introduction

The progress of civilization, growing expectations and requirements of consumers, as well as the specificity of the market economy mean that one of the main factors determining the effective and efficient functioning of an enterprise is the correct anticipation of the consequences related to decisions made and planning strategy. The ability to plan the production process directly affects the level of organization and the effectiveness of the services provided.

Nowadays, companies strive to develop effective methods of managing and planning production processes, the use of which is intended to shorten the implementation time of individual operations and, consequently, reduce the costs of producing the offered products. One of the most frequently used methods to improve the organization of production processes is Lean Manufacturing (Ghobadian et al., 2020).

In the literature on the subject, Lean Manufacturing is defined as a technique for eliminating waste in production processes (Palange, Dhatrak, 2021). The Lean philosophy distinguishes seven basic types of waste, which include: overproduction, inventories, transport, shortages, unnecessary processing and unnecessary movement.

Proper implementation of the LM philosophy allows to increase the chances of competition in a dynamically developing market (Abreu-Ledon et al., 2018; Galeazzo, Furlan, 2018). The LM philosophy is universal, which means that it can be implemented in many industries, both manufacturing and service (Hopp, 2018), regardless of their size (Hu et al., 2015). The studies described in (Bayou, de Korvin, 2008) and (Narasimhan et al. 2006) present a relationship indicating that lean management enables the reduction of input resources in order to achieve better results expected by organizations. Improving the results achieved concerns many levels, including the quality of manufactured products or services provided and customer satisfaction (Natasya Abdul Wahab, 2013).

In many cases, one of the key tasks of implementing selected Lean Manufacturing tools, in addition to eliminating errors, is to increase the company's productivity while maintaining the quality of manufactured products (Nguyen et al., 2022).

Issues related to lean management have been a frequently discussed topic for many years in the context of improving selected parameters of production processes. It should be noted, however, that in many cases there are still problems related to the correct implementation of the Lean Manufacturing philosophy in production plants (Alefari et al., 2017). Research conducted at production plants in Great Britain (Baker, 2002) and in automotive companies in the United States and India indicate a low level of effectiveness of the results achieved despite the implementation of the Lean concept (Mohanty et al., 2007). However, in the article (Venkat, 2020), based on the analysis of the impact of LM on production efficiency on the assembly line process in the electrical industry, a productivity increase of as much as 23% was found. Also in the article (Samuel, 2021) conclusions are presented indicating the improvement of the obtained parameters as a consequence of the implementation of LM tools. The reason for different results in impact effectiveness depends, among others, on the type of production process, level of automation and correct implementation of LM tools.

2. Total Productive Maintenance

As mentioned in the introduction, dynamic changes on the market and intense competition force producers to introduce actions aimed at preventing situations that destabilize the production process. Therefore, in many cases, the decisive factor in implementing the production process according to the schedule is avoiding failures of machines and production equipment by implementing tools aimed at their correct and systematic maintenance (Adhiutama et al., 2020). One of the Lean Manufacturing tools used to supervise and properly maintain machines and devices is TPM (Total Productive Maintenance).

The TPM tool is defined in the literature on the subject as a concept of maintaining appropriate productivity of the production process by eliminating failures, aimed at achieving comprehensive system effectiveness as a result of the involvement of all people in the organization (Bhasin, Burcher, 2006). The work (Singh et al., 2022) highlights the important role of humans as a factor necessary for the proper functioning of the TPM tool.

In the above-mentioned article, TPM is defined as a strategy aimed at improving production that takes into account the integrity of the company's infrastructure and the efficient operation of human resources through the continuous participation of employees and their empowerment in production, maintenance and industrial efficiency.

The TPM tool includes a number of activities necessary to organize the environment in such a way that it fulfills its purpose, Figure 1. These activities are usually presented in the form of pillars which include, among others: autonomous maintenance, continuous improvement, maintenance planning, quality control planning, interdepartmental communication, staff development and training, safety and environment. However, the 5S tool is considered to be the basis of the TPM tool.

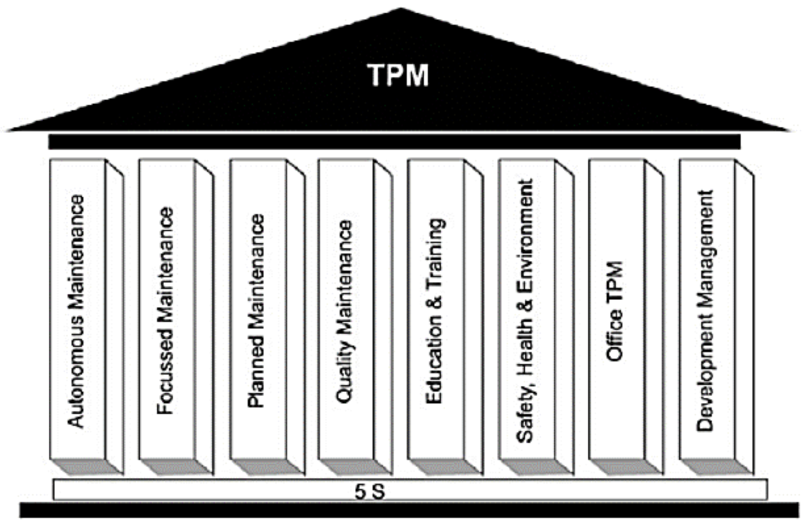

Figure 1. Pillars of TPM.

Source: Ahuja, Khamba, 2008.

Thanks to its comprehensive approach, TPM is becoming one of the most frequently used maintenance techniques used in the manufacturing industry.

3. Methodology and research area

The analysis was carried out on the basis of data collected in a production plant characterized by a high level of automation of production operations in the electrical industry. The work focused on obtaining data related to the failure rate of machines and devices operating on a production line consisting of three stations, i.e. extruders, a device for cutting and bending a metal washer, and an assembly station in the form of a specially constructed station. In the production plant analyzed, production is carried out on a mass scale and the failure of one of the stations on the line causes the entire process to stop. The production process is carried out in a maximum of two shifts or depending on the size of orders in a given period of time. The data analysis was carried out on the basis of obtaining information regarding, among others: production line operating time (operating time), failure time, number of failures, repair time of production equipment and the time and number of maintenance before implementing the techniques included in the TPM tool (data collection period 12 months) and after their implementation (data collection period: 9 months). The scope of activities in the area of implementation of the TPM tool on the production line included, among others:

- Information regarding downtime and operating time was obtained on the basis of failure, stoppage and maintenance reports, as well as data from time devices. Introduction of solutions based on real-time analysis of the wear of active elements at the assembly station in the form of installing vibration sensors. The implementation of the solution allows for continuous monitoring of the technical condition of devices in the area of potentially most critical factors.
- Preparation of standardized maintenance instructions for devices included in the production line, along with a check list. Introduction of a number of training courses to standardize activities related to the maintenance and repair of devices. Detailed repair reports and their periodic analysis, allowing for more precise identification of potential areas of failure and how to remove them.
- Implementation of the 5S tool and its regular internal self-discipline audits.
- Implementation of a formal list of parts and possible substitutes that can be used in a given production device from manufacturers that have been assessed and the level of wear of these parts is known based on a historical analysis of their use.

The next stage of the research was to conduct a statistical analysis to determine the statistical significance of the observed differences in machine and equipment failure times before and after the implementation of the TPM tool. In order to determine the statistical significance of differences between failure times before and after the implementation of the TPM tool, the Mann Withney U test was performed. The non-parametric Mann-Whitney U test is used to verify the hypothesis that the differences between the medians of the examined variable in two populations are insignificant, assuming that the distributions of the variable are close to each other (Więckowska, 2018). The hypotheses concern the mean ranks for the compared populations or are simplified to the medians:

$$H_0 : \theta 1 = \theta 2 \quad (1)$$
$$H_1 : \theta 1 \neq \theta 2$$

where θ1, θ2 - medians of the examined variable in the first and second population. The value of the test statistic is determined, and on its basis the p-value is compared with the significance level α:

if $p \leq \alpha \Longrightarrow$ we reject H_0 accepting H_1,
if $p > \alpha \Longrightarrow$ there is no reason to reject H_0.

Depending on the sample size, the test statistic takes the form:
for a small sample size:

$$U = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - R_1 \quad (2)$$

or

$$U = n_1 n_2 + \frac{n_2(n_2 + 1)}{2} - R_2 \quad (3)$$

where:
n_1, n_2 – number of samples,
R_1, R_2 – sum of ranks for the sample;

for a large sample size:

$$Z = \frac{U - \frac{n_1 n_2}{2}}{\sqrt{\frac{n_1 n_2 (n1 + n_2 + 1)}{12} - \frac{n_1 n_2 \sum (t^3 - t)}{12(n_1 + n_2)(n_1 + n_2 - 1)}}} \quad (4)$$

where t – the number of cases included in the tied rank.

The assumed confidence level α for each of the conducted analyzes was 0.05.

Then, based on the data obtained, indicators were designated to determine the duration of the failure (Mean time to Repair - MTTR) and the length of time until the next failure occurred (Mean time to Failure - MTTF).

$$MTTR = \frac{\sum_{i=1}^{N} T_i}{N} \quad (5)$$

$$MTTF = \frac{T_D - \sum_{i=1}^{N} T_i}{N+1} \quad (6)$$

where:
T_i – failure time,
N – number of failures,
T_D – available time of machines or groups of machines.

4. Results and discussion

As a result of the analysis of the production process carried out over a total period of 21 months, data was obtained regarding operational time and failure time before and after the implementation of the TPM tool. The data are presented in Table 1.

Table 1.
Summary of operational time and failures before and after TPM implementation

Month	BEFORE IMPLEMENTING TPM		AFTER IMPLEMENTING TPM	
	Operating time [h]	Failure time [h]	Operating time [h]	Failure time [h]
1	417,3	29,5	415,5	6,5
2	411,6	25,8	420,1	7,5
3	425,5	21,3	395,5	9,2
4	391,7	31,5	420,5	7,5
5	401,5	29,3	451,5	6,4
6	412,7	26,3	410,5	7,1
7	421,1	20,1	341,7	1,2
8	395,5	31,8	447,4	5,9
9	393,4	19,3	420,7	7,1
10	387,5	31,5		
11	399,5	21,7		
12	352,1	24,9		

Source: own elaboration.

The obtained results indicate a reduction in machine failure time by 5 percentage points, from 7% before implementing the techniques included in the TPM tool in relation to operational time, to 2% after implementing solutions aimed at improving the situation related to maintenance.

Then, based on the obtained results, a statistical analysis of the differences between failure times before and after the implementation of the TPM tool was performed using the Mann Withney U test, the results are presented in Figure 2.

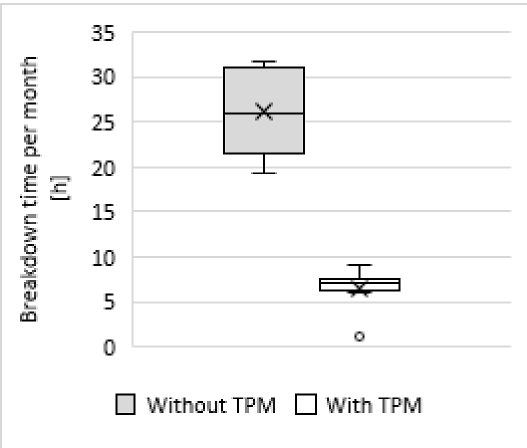

Figure 2. Failure duration.

Source: own elaboration.

As a result of the study, it was found that there are significant differences in the duration of failure compared to the state before the implementation of TPM (p > a). The obtained results seem to confirm the fact that after implementing the solutions included in the TPM tool, the machine failure time is shortened. In the work (Singh et al., 2013), a reduction in failure time and an increase in product quality was observed, which allowed for an increase in production efficiency by 16 points. A similar result of the effectiveness of the TPM tool implementation was described in the works (Pinto et al., 2020) and (Singh et al., 2022). Then, based on the data obtained, the MTTR and MTTF indicators were calculated and their results were compared before and after the implementation of the solutions included in the TPM tool. The obtained values are presented in Figures 3 and 4.

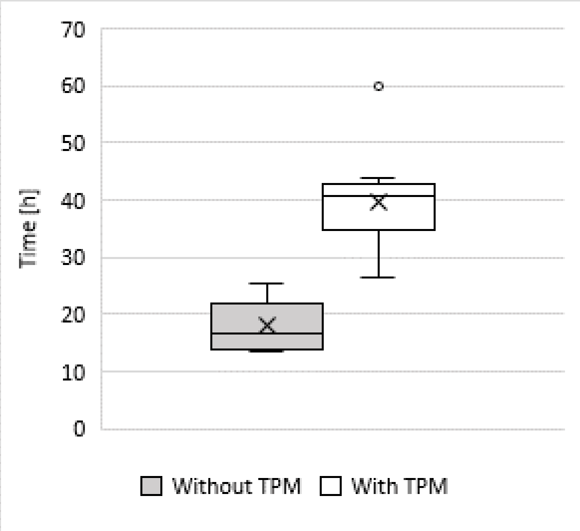

Figure 3. MTTF indicator level.

Source: own elaboration.

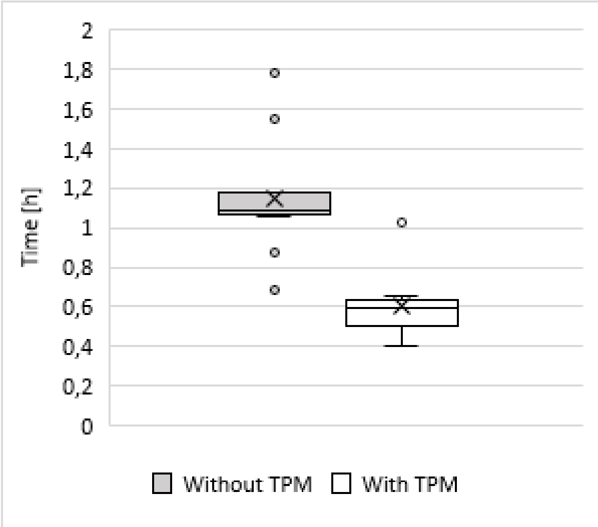

Fig. 4 MTTR indicator level.

Source: own elaboration.

As a consequence of the obtained results, a significant reduction in the duration of a single failure was observed by approximately 34 minutes, which was due to the implementation of standardized procedures regarding device repair and maintenance. The introduced actions allowed for faster identification of failures and their removal in a standardized way. It was also found that the time between the occurrence of subsequent failures increased from an average of 17.9 hours to over 40.5 hours. The reason for such a significant extension of the time between failures was activities related to data analysis in the area of vibration monitoring within active elements, which allows for earlier replacement of key parts with confirmed quality of workmanship. The reduced number of failures and corrective actions contributed to the extension of production line operating periods. The outcomes obtained as a result of the analysis confirm the effectiveness of the implementation of the TPM tool in the production plant, which was also indicated in other literature (Singh et al., 2022). A similar result was described in the work (Pinto et al., 2020), which describes the results of implementing the TPM tool, which allowed for a 38% reduction in the number of repairs and a 23% reduction in the number of interruptions related to failures. It should also be noted that the changes introduced in the field of maintenance of machines and devices did not negatively affect the quality manufactured products.

5. Conclusion

The article presents the results regarding the failure time of machines and devices in a production plant analyzed before and after the implementation of the TPM tool. The obtained results made it possible to present the scale of changes in the scope of, among others, MTTR and MTTF indicators, while confirming the positive impact of the implementation of techniques included in the TPM tool on extending the operating time of machines and devices without failure and reducing the time of failure.

Moreover, as a result of the Mann Withney U test, it was found that there are significant differences in the duration of failure of production machines and equipment compared to the state before the implementation of TPM ($p > a$). The obtained results showed a reduction in machine failure time by 5 percentage points compared to the total production time.

Due to the great popularity of the TPM tool and the results obtained using measurement methods in a real production process, they may encourage decision-makers in other production plants to implement solutions consistent with the LM philosophy. It should be noted, however, that the data on the basis of which the analysis was carried out comes from one production plant (case study), which does not allow defining a clear rule describing the impact of LM tools on production processes. However, the results obtained allow us to confirm the assumptions about the validity of implementing the TPM tool for individual parameters related to maintenance. A detailed analysis of the results obtained and comparison of results from other production plants may allow the identification of reasons for better adaptation of LM tools and their impact on the production process. In further research, in addition to comparing parameters related to machine failure rates before and after the implementation of Lean Manufacturing tools, the factor of assessing the correctness of their implementation and functioning during data acquisition can also be taken into account. Such action will allow to assess not only the impact of the implementation of LM tools on the parameters of the development process, but also the quality and durability of this implementation as a function of time.

Acknowledgements

Silesian University of Technology BKM-564/RM1/2023 (11/010/BKM23/0049).

References

1. Abreu-Ledon, R., Lujan-García, P., Garrido-Vega, B., Perez, E. (2018). A Meta-Analytic Study of the Impact of Lean Production on BusinessPerformance. *International Journal of Production Economics*, pp. 83-102. doi: 10.1016/j.ijpe.2018.03.015.
2. Adhiutama, A., Darmawan, R., Fadhila, A. (2020). Total Productivity Maintenance on the Airbus Part Manufacturing. *Jurnal Bisnis dan Manajemen*, pp. 3-5.
3. Ahuja I.P.S., Khamba J.S. (2008). Total productive maintenance: literature review and directions. *International Journal of Quality & Reliability Management, vol. 25, No. 7*, pp. 709-756.
4. Baker, P. (2002). Why is lean so far off? If lean manufacturing has been around for decades, why haven't more manufacturers got further with it? *Works Management - London then Horton Kirby then Swanley, Vol. 55, No. 10*, pp. 26-29.
5. Bayou, M.E., de Korvin, A. (2008) Measuring the Leanness of Manufacturing Systems: A Case Study of Ford Motor Company and General Motors. *Journal of Engineering and Technology Management.*
6. Bhasin, S., Burcher P. (2016), Lean viewed as a philosophy. *Journal of Manufacturing Technology Management*, pp. 56-72.
7. Galeazzo, A., Furlan A. (2018). Lean Bundles and Configurations: A fsQCAApproach. *International Journal of Operations & Production Management*, pp. 513-533. doi: 10.1108/IJOPM-11-2016-0657.
8. Ghobadian, A.I., Talavera, A., Bhattacharya, V., Kumar, J.A., Garza-Reyes, O'Regan, N. (2020). Examining Legitimatisation of Additive Manufactur-ing in the Interplay between Innovation, Lean Manufacturing and Sustainability. *International Journal of Production Economics*, pp. 457-468. doi: 10.1016/j.ijpe.2018.06.001.
9. Hopp, W.J. (2018). Positive Lean: Merging the Science of Efficiency with the Psychology of Work. *International Journal of Production Research,* pp. 398-413. doi: 10.1080/00207543.2017.1387301
10. Hu, Q.R., Mason, S.J., Williams, Found, P. (2015). Lean Implementationwithin SMEs, A Literature Review. *Journal of Manufacturing Technology Management*, pp. 980-1012. doi: 10.1108/JMTM-02-2014-0013.
11. Jewalikar, A.D., Shelke, A. (2017). Lean Integrated Management Systems in MSME Reasons, Advantages and Barriers on Implementation. *Materials Today: Proceedings, No. 4,* pp. 1037-1044.
12. Mohammad, I.S., Oduoza, C.F. (2019), Interactions of Lean enablers in Manufacturing SMEs using Interpretive Structural Modelling Approach – a case study of KRI. *Procedia Manufacturing, Vol. 38*, pp. 900-907.

13. Mohanty, R., Yadav, O., Jain, R. (2007). Implementation of Lean Manufacturing principles in auto industry. *Vilakshan - XIMB Journal of Management*, pp. 1-32.
14. Mudhafar A., Konstantinos, S., Xu, Y. (2017). The Role of Leadership in Implementing Lean Manufacturing. *Procedia CIRP*, pp. 756-761.
15. Narasimhan, R., Swink, M., Kim, S.W. (2006). Disentangling Leanness and Agility: An Empirical Investigation. *Journal of Operation Management*, pp. 24-44.
16. Natasya, A., Wahab, A., Mukhtar, M., Sulaiman, R. (2013). A Conceptual Model of Lean Manufacturing Dimensions. *Procedia Technology*, pp. 1292-1298. doi: doi.org/10.1016/j.protcy.2013.12.327.
17. Nguyen, D.M., Duong, T.K. (2022). Enterprises Characteristics and Lean Out-come: An Empirical evidence from Vietnam Manufacturing Enterprises. *Management System in Production Engineering*, pp. 98-108, doi: 10.2478/mspe-2022-0013.
18. Palange, A., Dhatrak, P. (2021). Lean manufacturing a vital tool to enhance productivity in manufacturing. *Materials Today: Proceedings, Vol. 46, Part 1,* pp. 729-736, doi: doi.org/10.1016/j.matpr.2020.12.193.
19. Pawlak, S. (2023). Analysis of the impact of selected Lean Manufacturing tools on the parameters of the production process – case study. *Zeszyty Naukowe Politechniki Śląskiej. Organizacja i Zarządzanie*, pp. 379-391. doi: doi.org/10.29119/1641-3466.2023.175.24.
20. Pinto, G., Silva, F.J.G., Baptista, A., Nuno, O., Fernandes, R., Casais, C., Samuel, R. (2020). TPM implementation and maintenance strategic plan – a case study. *Procedia Manufacturing*, *Vol. 51*, pp. 1423-1430, doi: https://doi.org/10.1016/j.promfg.2020.10.198.
21. Rajesh, M., Rajanna, S. (2021). Implementation of lean manufacturing with the notion of quality improvement in electronics repair industry. *Materials Today: Proceedings*, *Vol. 44, No. 10*, pp. 2253-2257.
22. Singh, R., Ashish, M., Gohil, Dhaval, B., Shah, Desai (2013). Total Productive Maintenance (TPM) Implementation in a Machine Shop: A Case Study. *Production Engineering*, pp. 592-599.
23. Singh, S., Agrawal, A., Sharma, D., Saini, V., Kumar, A., Praveenkumar, S. (2022). Implementation of Total Productive Maintenance Approach: Improving Overall Equipment Efficiency of a Metal Industry. *Inventions*, pp. 119. doi: doi.org/10.3390/inventions 7040119.
24. Venkat, B., Jayanth, P., Prathap, P., Sivaraman, S., Yogesh, S. (2020). Implementation of lean manufacturing in electronics industry. *Materials Today: Proceedings, Vol. 33*, pp. 23-28.
25. Więckowska, B. (2018). *Podręcznik Użytkowanika PQStat*. PQStat Software.