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Application of Lean Six Sigma for sustainable maintenance: case study

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Abstract: Increasing the efficiency and effectiveness of maintenance processes is a constant goal of production companies. The elimination of unexpected failures that generate excessive costs and production losses is emphasized. Not only the selection of an appropriate maintenance strategy, but also the use of appropriate methods and tools to support the decision-making process in this area, are also elements that affect the maintenance efficiency. The article presents the possibility of using the Six Sigma methodology to improve the efficiency of the maintenance process. For this purpose, qualitative and quantitative research methods were used to analyze the results obtained from the company's case study. Additionally, the statistical analysis of the obtained results allowed to identify the factors influencing the effectiveness of the maintenance process. the number and duration of the failures, thus increase the availability machines in production process and determination of activities which should be implemented to improve the maintenance processes.

Keywords: maintenance process, TPM, DMAIC, Six Sigma

1. INTRODUCTION

According to EN 13306, 2001 maintenance is defined as the combination of all technical, administrative and managerial actions during the life cycle of an item required to retain or restore it to a state in which it can perform its required function. Maintenance of production equipment is usually associated with maintenance activities such as repair, replacement, inspection, inspection, servicing, adjustment, testing, measurement and fault finding to avoid failures that would lead to interruptions in production processes (Loska and Paszkowski, 2022). Maintenance technology is about finding and applying cost-effective ways to avoid or overcome degradation in machine performance. With the advancement of technology, various maintenance strategies have evolved over the years, which include preventive maintenance, condition based maintenance, predictive maintenance, remote maintenance, etc. (Burduk, 2010; Jasiulewicz – Kaczmarek et. all., 2020; Franciosi et. all., 2020).

Decades ago, maintenance was mainly seen as not necessary process. Nowadays, taking into account the impact of maintenance on other company processes (e.g. production, logistics, occupational health and safety management, environment), the maintenance process is recognized as an important business function supporting the company in meeting the economic, environmental and social challenges of sustainable production (Karuppiah et al., 2021; Hami et al., 2020; Saihi et al., 2022).

Proper maintenance and management of manufacturing equipment has positive effects on the economic, environmental and social performance of company, but poor defined maintenance activities lead to various problems (Jasiulewicz-Kaczmarek et al., 2021). The economic impact of improper maintenance practices is primarily related to costs, downtime, breakdowns, defects, additional inventory, etc., which affect product quality and the company's performance (Zonta et al., 2020). Therefore, efficient and effective maintenance processes will allow not only to improve the condition of the equipment by reducing the failure rate of the equipment, but also to minimize operating costs by maximizing the life of the equipment. From the environmental perspective, improperly defined and executed maintenance processes and activities lead to several environmental impacts, such as hazardous emissions, inefficient energy usage, ineffective resource consumption etc. (Xia et al., 2018; Franciosi et al., 2020; Vrignat et al., 2022). The effects of poor maintenance can also occur at the social level, where unsafe and unhealthy working conditions, accidents and incidents spoil the company's image (Jasiulewicz-Kaczmarek and Drozyner, 2013; Lovrencic et al., 2017; Franciosi et al., 2019).

To meet economic, environmental and social challenges, manufacturers implement various methodologies to improve

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enterprise processes such as Six Sigma, Lean Manufacturing, Theory of Constraints (TOC) and Total Quality Management (Sreedharan and Sunder 2018; Hernandez-Matias et al., 2020; Gastelum-Acosta et al., 2022). Several methodologies are proposed in the literature for process improvement in maintenance, such as Total Quality Maintenance (Al-Najjar, 1997), Lean Maintenance (Antosz et. al., 2019; Ribeiro et. al., 2019), TOC (Faddoul et al., 2018) and Six Sigma (Thomas et al., 2008; Lazgreg and Gien, 2009).

Today, more and more companies are realizing the potential of Six Sigma (SS). The SS methodology was developed and launched by Motorola in 1987. SS can be described as an improvement program aimed at reducing variability by focusing on continuous and innovative improvement. The main goal of reducing variability in the production or service process is customer satisfaction. The SS methodology can be divided into two categories: Design Improvement (DMADV) and Process Improvement (DMAIC) (Patel and Desai, 2018). DMAIC stands for five phases within the methodology, namely Define, Measure, Analyze, Improve, Control. There are many different tools and technologies at different stages of the Six Sigma methodology, and their application depends on the process, resources, and competencies of the people in the teams. The SS methodology is also suggested to improve maintenance processes. Some of these suggestions combine SS methodology with Total Productive Maintenance (TPM) concept. Sharma and Sharma (2014) develop the model centred on the SS and TPM framework that focuses on improved accessibility, increased mean-time-between-failures (MTBF), improved quality and reduced the number of nonconforming products. The proposed model was verified in the paper production industry. According to (Pophaley and Vyas 2015) improving the maintenance process is possible thanks to the use of the TPM and Six Sigma concepts in the maintenance of production equipment, in particular through the Autonomous Maintenance pillar of TPM. Recently, (Tsarouhas, 2021) presents how the SS method and reliability, availability and maintainability (RAM) analysis are helpful in determining maintenance intervals, maintenance activities planning and choosing the appropriate maintenance strategy. Moreover, according to (Seow and Liu, 2006) "SMEs need to consider enabling the fusion of Six Sigma-TPM as a catalyst for corporate sustainability".

That why, the goal of this paper is to explore the using the Six Sigma methodology to improve the efficiency of the maintenance process in the case study company. The paper aims of the economic dimension of maintenance sustainability. The structure of the paper is as follows. Sections *2* presents the research methodology adopted in this study. In Section 3 Six Sigma methodology for process analyses is presented. Finally, the conclusions are presented in Section 4.

2. RESEARCH GOAL AND METHODOLOGY

2.1 Description of the case study company

The research was carried out in a company which is a leader in the production and sale of floor coverings. A production area consisting of 23 machines, was selected for the analysis. The production cells include machines from devices with a very simple structure, such as transporters, to precision machines, which are controlled by precise automatic programs. The following processes are carried out in the analyzed production cell: Granulating (G1), Extrusion I (G2), Extrusion II (G3), Printing (G4) and Finishing (G5) (Figure 1)

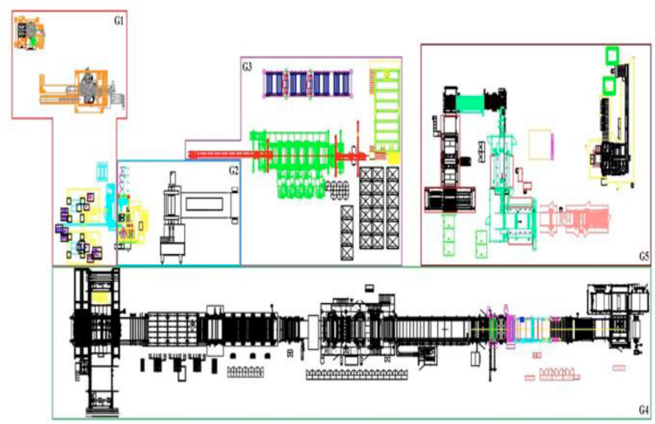

Figure 1. Layout of machines divided into production cells.

2.2 Research problem

The main problem of the case study company is a large number of failures, thus reducing the availability of machines in the production process. The consequences of one machine failure on the production line is the stoppage of the entire production process performed in one production cell. This contributes to an increase in the production costs of the finished product per square meter. Increasing production costs causes customer's dissatisfaction and thus reduces the company's market share. Therefore, the following research problem has been established: Identification of the factors influencing the number and duration of the failures, thus increase the availability machines in production process and determination of activities which should be implemented to improve the maintenance process.

2.3 Description of the case study maintenance process

The activities related to the maintenance of machines in the case study company are carried out by the maintenance departments, which are located centrally at individual production cells. The company uses preventive maintenance (PM) and if its needed corrective maintenance (CM) strategy of machines. Moreover, the company has implemented a modern TPM for almost the all machines. According to TPM assumptions, each employee of the machine should perform autonomous maintenance (AM). The scope of this service and its frequency has been developed for each work station and is located at each production station. Each operator confirms the performance of AM on the stand. In addition, scheduled maintenance (PM) is carried out on the machines.

2.4 Research methodology

In order to analyse the problem, Six Sigma (SS) DMAIC (Define, Measure, Analyse, Improve, Control) methodology was applied. During the Define phase of SS project:

- to understand the process that will be improved, the responsible project leaders the purpose, scope of the project and CTQ (Critical to Quality) have defined,
- the customers' expectations of the process have been identified,
- the timeline and costs of SS project have been established.

During the Measure phase of SS project:

- the information from the process have been collected, so as to fully understand the analyzed process,
- the preliminary analyzed of the collected data have been performed.

During the Analyse phase of a SS project:

- different method and tool of quality management to help spot the problems in the analyzed process and to determine if these problems are the root causes of identified problems have been used,
- different statistical analyses to identify the factors with the highest impact on the CTQ have been performed.

During the Improve phase of a SS project:

- the improvements of the process have been proposed,
- the schedule of the improvements implementation have been developed.

During the Control phase of a SS project:

- re-gathering information from the process to evaluate the results of the implemented improvements,
- introducing methods of continuous monitoring of the results of the process.

3. SIX SIGMA METHODOLOGY IMPLEMENTATION FOR PROCESS ANALYZES - CASE STUDY

3.1 Six Sigma project - Define Phase

The aim of the SS project was to find the possibilities of elimination of one-off and chronic failures, which will have impact on a reduction of the number of failures on machines by 40% within 6 months. In the first phase of the SS project, in order to present the production area, which will be analyses the autonomous maintenance process of machines, a SIPOC (Suppliers, Inputs, Process, Outputs, Customers) diagram was developed. The suppliers for the analyzed process were suppliers of materials used in the maintenance process, e.g. spare parts and media. Inputs were, for example: machines, maintenance workers and machine workers. The analyzed process is a maintenance process. Outputs are available machines for the production process (customers). The following process data were collected: *x1* – operator, *x2* – shift, *x3* – day of the week, *x4*- number of control points in autonomous maintenance (AM), *x5* – range of AM, *x6* - time to perform AM, *x7* - timeliness of PM, *x8* - employee performing PM, *x9* - were the problems reported on the machine after AM, *x10* - were the problems reported on the machine after PM. To identify the critical factors of failures, the CTQ (Critical to Quality) measure was used. CTQ is the factor that directly impacts on the increasing the machines availability. The following CTQs were selected for problem analysis: CTQ (Y1) - failure time (Time of machine unavailability for the production process), CTQ (Y2) - number of failures during the day.

3.2 Six Sigma project - Measure Phase

In the second stage of the SS project the data from the process were collected. In the period from 2018 to 2020 the sample with 1120 observations was taken. Data were collected for all identified *from x1 to x10* in SIPOC and CTQs values. These variables were initially identified as factors that could affect the time and number of failures. The gathered data were the subject of a further analysis. Firstly, in the in preliminary analysis, failures have been assigned to the specific processes: G1, G2, G3, G4 and G5. Figure 2 shows the failure time for each process. It should be noted that the longest failure time for the G5 area was observed.

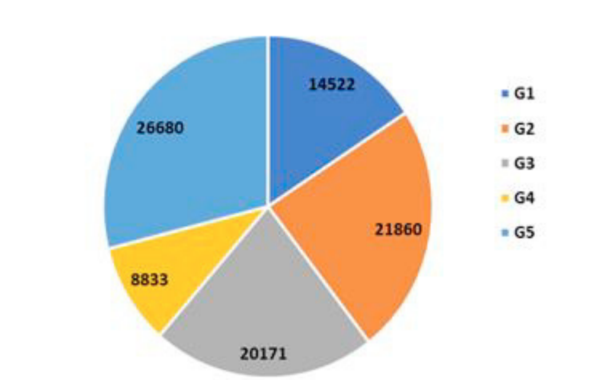

Figure 2. Failure time for each process.

In Figure 3 the failure duration time for G5 is presented.

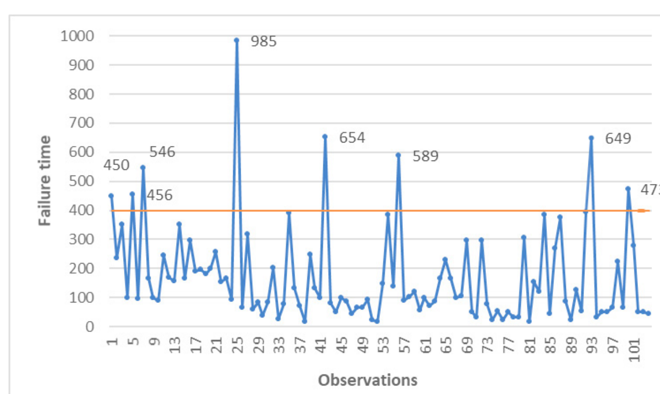

Figure 3. Failure time for G5 process.

It can be seen from the graph that there are 8 points (outliers - marked on the chart) for which the failure time is much longer than the others. These outliers were removed from further analyses. Moreover, the average failure time is 240 [min]. On the other hand, the highest percentage of failures was in the range from 16.5 to 246.5[min].

3.3 Six Sigma project - Analyse Phase

The third stage of the SS project was the analysis stage. The main goal of this stage was to identify the factors that have impact on defined CTQs. In the analyses the normality of distributions, and selecting statistical tests was performed. For the extension of agreement between empirical and normal distributions the Shapiro Wilk test was used. For a significance level of α=0.05, the following statistical hypothesis were verified: H0: the distribution of the tested feature in the population is normal, H1: it differs from normal. The test statistics is of the form: $=|Fn(x)-F(x)|$ (1), where $Fn(x)$ is an empirical distribution function, $F(x)$ is a distribution function of the normal distribution $N(0,1)$. Normality test was performed for Y1 and Y2. The results of the normality test for Y1 and Y2 showed that did not have a normal distribution (p-value < 0.05).Therefore, for the identification of the factors that have the influence on CTQs and corelation between them, due to the type of the analyzed data, the statistical *chi* – square, Kruskal-Wallis test and Spearman tests were performed. The Spearman's rank correlation coefficient was determined by an error according to the formula (1):

$$r_s = 1 - \frac{6\Sigma_{i=1}^{n} d_i^2}{n(n^2-1)} \quad (1)$$

where: d_i^2 - squares of differences between the ranks of the corresponding feature values x^i and y^i; n – a number of data pairs (number of rows in the table).

The *chi*-square statistic was calculated from the following formula (2):

$$\chi^2 = \sum \frac{(O-E)^2}{E} = \sum_{i=1}^{k} \sum_{j=1}^{p} \frac{\left(n_{ij} - E_{ij}\right)^2}{E_{ij}} \quad (2)$$

This statistic has an asymptotic distribution $\chi^2\ with\ (k-1)(p-1)$ degrees of freedom. Where: O – observed values; n_{ij}; E_{ij} – theoretical values obtained from the product of border values. The *chi*-square test is often used to test the independence of two qualitative variables. In this case, a two-way table was created, and the expected frequencies for the cell were determined as the product of the total count in the column, and the total count in the row divided by the total number of observations. For the depended variable (Y1 and Y2) the *chi*-square and Kruskal-Wallis test with null hypothesis: $H_0: x_1 = x_2 = \dots = x_n$, and $H_1: x_1 \neq x_2 \neq \dots \neq x_n$ with confidence level α=0.05 was performed. Table 1 present the results of results of Spearman correlation for inputs variables.

Table 1. Results of Spearman correlation for inputs variables.

Var.	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10
x1	1.000	-0.056	-0.043	0.025	-0.183	-0.086	0.395	0.133	0.073	0.129
x2	-0.056	1.000	-0.036	0.021	-0.266	-0.029	-0.072	0.004	0.007	0.045
x3	-0.043	-0.036	1.000	0.016	-0.280	0.243	-0.055	0.085	-0.029	0.021
x5	-0.183	-0.266	-0.280	-0.057	1.000	-0.228	0.129	-0.051	-0.211	-0.183
x6	-0.086	-0.029	0.243	0.013	-0.228	1.000	-0.045	0.069	-0.125	0.025
x7	0.395	-0.072	-0.055	0.032	0.129	-0.045	1.000	0.170	0.078	0.021
x8	0.133	0.004	0.085	-0.049	-0.051	0.069	0.170	1.000	0.228	0.250
x9	0.073	0.007	-0.029	0.155	-0.211	-0.125	0.078	0.228	1.000	0.016
x10	0.129	-0.045	0.021	0.016	-0.183	0.025	0.021	0.250	0.016	1.000

The results presented in Table 1 were analyzed according to the Cohen scale (Cohen, 1994). According to this scale there is no correlation if the value of R varies around 0.1, the correlation is weak if R varies around 0.3, medium if R varies around 0.5 and large if R is more than 0.5. For most of the analyzed variables there is no correlation or correlation is weak. The highest correlation is between variables x1 and x5 (R=0.395). Although the correlation between the factors was identified, a cause-effect relationship might not exist. That is why in addition the analysis showed a statistical relationship between the variables for which p – value was < 0.05 (highlight in red). Table 2 presents the results of statistical tests for CTQs.

Table 2. Results of statistical tests (chi – square and Kruskal-Wallis test) for CTQs.

Var.	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10
Y1	0.005	0.155	0.151	0.079	0.001	0.003	0.001	0.884	0.000	0.104
Y2	0.018	0.006	0.192	0.580	0.000	0.000	0.000	0.711	0.427	0.284

On the basis of the statistical tests results presented in Table 2, it can be said that the factors which have influence on the CTQs are: x1 – operator, x2 – shift, x5 – range of AM, x6 - time to perform AM, x7 - timeliness of PM, x8 - employee performing PM, x9 - were the problems reported on the machine after AM. These factors are mainly connected with AM.

In the next stage of SS project these factors were detail analyzed. Detailed analysis of these factors allowed to recognized that, the most common failures occurred on machines with:

- work experience of operators less than 1 year,
- on the third shift (22.00 - 6.00),
- the TPM on the machine less than 6 months,
- the largest number of production orders,
- the greatest AM range,
- the shortest AM perform time,
- the largest number of problems reported on the machine after AM.

As part of further analyses, the Ishikawa diagram was used. This tool allowed for the identification of causes of the main identified problem: improper implementation of AM and PM activities. Identification of potential causes affecting the problem allowed for the determination of improvement actions regarding the implementation of maintenance, with particular consideration finding the root causes of not the properly autonomous maintenance. The main identified causes of improper maintenance implementation include:

- Lack of general training for operators in the range of AM.
- Lack of specialized training for the individual checkpoints of AM.
- Lack of monitoring method of performing AM.
- Lack of procedure for solving the problems reported after AM and PM.
- Inadequate scheduled PM actions.
- Overload of machines in production - lack of time to perform AM.
- Different AM standards for the same type of machines.

3.4 Six Sigma project – Improve Phase

In this stage of the SS project the improvements for identified causes were proposed. Table 3 presents the proposed improvement actions (IA), the person responsible (RP) for its implementation and the implementation time (IT) [month] for all identified causes (C)

Table 3. Improvement actions.

C	IA	RP	IT
1.	Development of a periodic training plan for employees	LLMT	1
	Implementation of training for employees	LLMT	3
2.	Development of a training plan for employees	LLMT	1
	Implementation of training for employees	MS	3
3.	Development of monitoring method of performing AM	LLMT	2
4.	Development of procedure for solving the problems reported after AM and PM.	MS	6
5.	Analysis and introduction of changes to the PM.	MS	6
6.	Analysis and introduction of changes to the production planning.	PS	6
7.	Standardisation AM for the same type of machines.	MS	3
8.	Implementation of the periodic audits	LLMT	6
Legend: Leader of Lean Maintenance Team (LLMT), Maintenance Supervisor (MS), Production Supervisor (PS)			

The proposed improvement actions are implemented according to the established schedule.

3.5 Six Sigma project – Control Phase

The main goal of the last stage of SS project is to evaluate, whether the proposed and implemented actions have brought the intended effect. Currently, in the case study company, three out of the six proposed activities have been implemented. These are: a detailed training schedule for employees in the field of AM has been developed, training in this field has been conducted for all production employees (mainly for machines operators) and a method of monitoring the implementation of AM has been introduced. Additionally, the procedure related to reporting problems after AM and PM is at the final stage of development. The changes in the production planning process and scheduled maintenance are also being introduced. Although not all the improvements have been implemented, the company is already noticing some benefits: The number of reported problems after AM has decreased, the standardized AM ranges have significantly improved their implementation, increased awareness of production workers related to machine maintenance. A full assessment of the effectiveness of the implemented measures will be carried out after the implementation of all improvements. Moreover, periodic audits were introduced to check whether the implemented activities are being maintained.

4. CONCLUSIONS

The main goal of the paper was to identify the factors influencing the number and duration of the failures, thus increase the availability machines in production process and determination of activities which should be implemented to improve the maintenance process. To achieve this goal the Six Sigma DMAIC methodology was used. In the first stages of the study the scope of SS project was determined and the data from the process were collected. Then, the statistical analyses to identify potential factors which can have influence on CTQs of the process were performed. On the basis of the statistical results identified factors which have influence the number and duration of the failures were: operator, shift, range of AM, time to perform AM, timeliness of PM, employee performing PM, the problems reported on the machine after AM.. In the next stage of SS project these factors were detail analyzed. Detailed analysis of these factors allowed to identify the most common causes of the failures and propose the improvements activities. Although not all the improvements have been implemented, the cae study company have observed some benefits.

Despite the positive aspects of the used Six Sigma methodology to increase the effectiveness of maintenance processes, it also has some limitations. It is based only on actions implemented in the field of maintenance in one company and results are valid for this companies and can be difference in other companies.

REFERENCES

Al-Najjar, B. Condition-based maintenance: Selection and improvement of a cost-effective vibration-based policy for rolling element bearings. // Doctoral Thesis, Lund: Lund University, Lund Institute of Technology, 1997.

Antosz, K., Pasko, L., and Gola, A. (2019). The use of intelligent systems to support the decision-making process in lean maintenance management. *IFAC-PapersOnLine*, 52(10), 148-153.

Antosz, K., and Stadnicka, D. (2018). Possibilities of maintenance service process analyses and improvement through six sigma, lean and industry 4.0 implementation. In: IFIP International Conference on Product Lifecycle Management (pp. 465-475). Springer, Cham.

Burduk, A. (2010). An attempt to adapt serial reliability structures for the needs of analyses and assessments of the risk in production systems. . *Eksploatacja i Niezawodnosc – Maintenance and Reliability* (3), 85-96.

Cohen, S., Kamarck, T. and Mermelstein, R. (1994). Perceived stress scale. Measuring stress: *A guide for health and social scientists*, 10(2), 1-2.

Faddoul, R., Raphael, W. and Chateauneuf, A. (2018). Maintenance optimization of series systems subject to reliability constraints. *Reliability Engineering & System Safety*, 180, 179-188

Franciosi, C., Di Pasquale, V., Iannone, R. and Miranda, S. (2019). A taxonomy of performance shaping factors for human reliability analysis in industrial maintenance. *Journal of Industrial Engineering and Management*, 12(1), 115-132

Franciosi, C., Voisin, A., Miranda, S. and Iung, B. (2020). Integration of I4. 0 technologies with maintenance processes: what are the effects on sustainable manufacturing?. *IFAC-PapersOnLine*, 53(3), 1-6.

Gastelum-Acosta, C., Limon-Romero, J., Tlapa, D., Baez-Lopez, Y., Tortorella, G., Borbon, M. I. R. and Navarro-Cota, C. X. (2022). Assessing the adoption of critical success factors for lean six sigma implementation. *Journal of Manufacturing Technology Management*. 33 (1), 2022

Hami, N., Shafie, S. M., Omar, S., Ibrahim, Y. M., Sabah, A. S. and Mohd, R. M. (2020). A review of sustainable maintenance in the manufacturing companies. International Journal of Supply Chain Management, 9(3), 935-944;

Hernandez-Matias, J. C., Ocampo, J. R., Hidalgo, A. and Vizan, A. (2020). Lean manufacturing and operational performance: Interrelationships between human-related lean practices. Journal of Manufacturing Technology Management. Vol. 31 No. 2, 217-235;

Jasiulewicz–Kaczmarek, M., Antosz, K., Żywica, P., Mazurkiewicz, D., Sun, B. and Ren, Y. (2021). Framework of machine criticality assessment with criteria interactions. *Eksploatacja i Niezawodnosc – Maintenance and Reliability* 23(2), 207–220.

Jasiulewicz-Kaczmarek, M. and Drożyner, P. (2013). Social dimension of sustainable development–safety and ergonomics in maintenance activities. *In International Conference on Universal Access in Human-Computer Interaction.* Springer, Berlin, Heidelberg. LNCS Volume 8009, Issue PART 1, 175 – 184.

Jasiulewicz-Kaczmarek, M., Legutko, S. and Kluk, P. (2020) Maintenance 4.0 Technologies - New Opportunities for Sustainability Driven Maintenance. *Management and Production Engineering Review*, 11(2), 74-87.

Karuppiah, K., Sankaranarayanan, B. and Ali, S. M. (2021). On sustainable predictive maintenance: Exploration of key barriers using an integrated approach. Sustainable Production and Consumption, 27, 1537-1553;

Lazreg, M. and Gien, D. (2009). Integrating Six Sigma and maintenance excellence with QFD. *International Journal of Productivity and Quality Management*, 4(5-6), 676-690.

Loska, A. and Paszkowski, W. (2022). Geometric approach to machine exploitation efficiency: modelling and assessment. *Eksploatacja i Niezawodnosc – Maintenance and Reliability* 24(1), 114–122.

Lovrencic, V., Brezavscek, A., Pantos, M. and Gomiscek, B. 2017, Contribution of live working to the quality, safety, effectiveness and efficiency of the maintenance processes, *Tehnicki Vjesnik* 24(5), 1619-1626;

Patel, M. and Desai, D. A. (2018). Critical review and analysis of measuring the success of Six Sigma implementation in manufacturing sector. International Journal of Quality & Reliability Management. *International Journal of Quality & Reliability Management* 35(8), 1519-1545.

Pophaley, M. and Vyas, R. K. (2015). Fortification of plant maintenance management practices: role of six sigma approach. Brazilian Journal of Operations & Production Management, 12(1), 56-64.

Ribeiro, D. R. S., Forcellini, F. A., Pereira, M. and Xavier, F. A. (2019). An overview about the implementing of lean maintenance in manufacturing processes. *Journal of Lean Systems* 4(3), 44-59.

Saihi, A., Ben-Daya, M. and As' ad, R. A. (2022). Maintenance and sustainability: a systematic review of modeling-based literature. Journal of Quality in Maintenance Engineering.

Seow, C. and Liu, J. (2006). Innovation in maintenance strategy through Six Sigma: Insights of a Malaysian SME. In 2006 IEEE *International Conference on Management of Innovation and Technology* 2, 793-797.

Sharma, K. and Sharma, G. (2014). Integrating Six Sigma culture and TPM framework to improve manufacturing performance in SMEs. *Quality and Reliability Engineering International* 30(5), 745-765.

Sreedharan V, R. and Sunder M, V. (2018). Critical success factors of TQM, Six Sigma, Lean and Lean Six Sigma: A literature review and key findings. Benchmarking: An International Journal, 25(9), 3479-3504;

Thomas, A., Barton, R., and Byard, P. (2008). Developing a Six Sigma maintenance model. *Journal of Quality in Maintenance Engineering.* 14 (3), 262-271.

Tsarouhas, P. (2021). Reliability, availability and maintainability analysis of a bag production industry based on the six sigma DMAIC approach. International Journal of Lean Six Sigma. Vol. 12 No. 2, pp. 237-263.

Vrignat, P., Kratz, F. and Avila, M. (2022). Sustainable manufacturing, maintenance policies, prognostics and health management: A literature review. Reliability Engineering & System Safety, 218, 108140.

Xia, T., Xi, L., Du, S., Xiao, L. and Pan, E. (2018). Energy-oriented maintenance decision-making for sustainable manufacturing based on energy saving window. Journal of Manufacturing Science and Engineering, 140(5): 051001

Zonta, T., da Costa, C.A., da Rosa Righi, R., de Lima, M.J., da Trindade, E.S. and Li, G.P., 2020. Predictive maintenance in the Industry 4.0: A systematic literature review. Comput. Ind. Eng. 150, 106889.