J. FURMAN, T. MAŁYSA

ISSN 0543-5846
METABK 61(3-4) 848-850 (2022)
UDC – UDK 669.18:658.513.004.4:313.1:438 = 111

AUTONOMOUS MAITENANCE (AM) IN THE ASPECT OF IMPROVEMENT WORK SAFETY IN THE STEEL SECTOR IN POLAND

Received – Primljeno: 2021-12-10
Accepted – Prihvaćeno: 2022-02-28
Preliminary Note – Prethodno priopćenje

Autonomous maintenance is one of the important solutions used in industrial companies where part of the tasks related to the operation of machines is transferred to operators. In the steel sector in Poland, accidents related to the operation of technological machines are still reported. Given the above, this article lists the activities of machine operators in terms of methods and tools that allow for a reduction of the number of accidents at work. It aims to show the significance of the adoption of technical and organizational solutions directed at improving the safety of operators within AM in the steel sector in Poland.

Keywords: steel sector, work safety, accident, autonomous maintenance (AM), Poland

INTRODUCTION

Autonomous maintenance is one of the mail pillars of the TPM system (Total Productive Maintenance), which is defined as a continuous process of operating machinery and equipment in the enterprise by all operators and maintenance workers [1].The main objective of TPM is to achieve the level of three zeros: zero breakdowns, zero defects and zero accidents. A key role in the process of the TPM implementation is played by AM – an increase in the efficiency of the machine park requires the engagement of operators who should become more responsible for their duties, i.e. they should become more aware of their role in ensuring the quality of the manufactured products and the smooth running of the operated machines [2]. AM includes activities aimed at involving operators in maintenance and servicing of the machines they operate, regardless of the maintenance services (inspections, lubrication, simple repairs, replacement of parts, detection of irregularities). AM implies introducing trainings for operators, which will allow them to play a significant role in preventing irregularities during maintenance activities. The AM implementation takes place in seven steps (Figure 1), allowing operators to develop proper skills and making it possible to define expectations towards them [1,3].

The activities performed within AM may not only minimize the number of breakdowns and improve the production process, but they may also be a potential source of danger for operators. Therefore, the key element is to take actions that will improve work safety in the steel sector.

J. Furman: joanna.furman@polsl.pl – Silesian University of Technology, Katowice, Poland
T. Małysa: tomasz.malysa@polsl.pl – Silesian University of Technology, Katowice, Poland

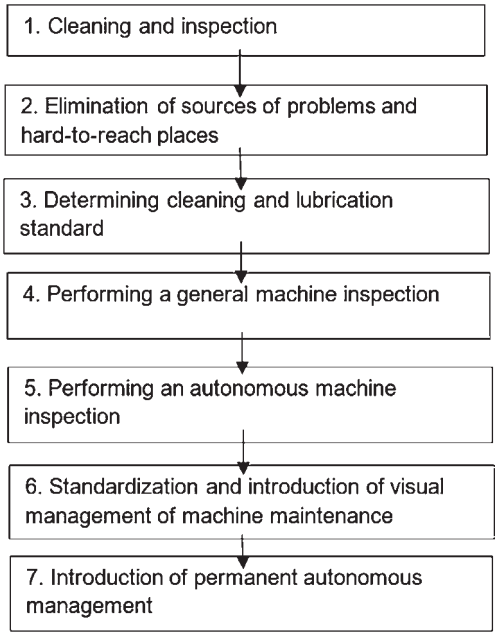

Figure 1 Stages of AM [1,2]

WORK SAFETY AS A PART OF AM

The issue of safety related to the operated machinery in Poland, and in other EU states, is defined in new approach directives, i.e. Machinery Directive 2006/42/EC [4] and Tool Directive 2009/104/EC [5]. These directives are addressed to machine manufacturers and employers, respectively [6]. As regards the steel industry, it is crucial to ensure safety in the workplace, so the machines provided by producers and used at work should not pose a risk to workers' life and safety.

In autonomous maintenance, an operator is engaged in activities connected with machine retooling, minor repairs, maintenance, adjustments, lubrication. Conse-

quently, it is necessary to implement measures aimed at reducing the risk of accidents. They may include: the development of an occupational safety and health culture, activities related to an assessment of occupational risk, staff trainings in the area of OSH, providing instructions in the workstation. Further, the AM implementation requires a job training.

The achievement of the objective pursued by this work was possible through the development of own methodology. The first stage involved compiling a list of the most common causes of accidents. The listed causes of accidents were then referenced to the activities of the operator performed within autonomous maintenance. Moreover, their significance was also determined by assigning appropriate ranks (1-3) to them.

The second stage consisted in a prediction of quantitative data, i.e. the causes leading to accidents in the steel sector in Poland. The conducted prediction made it possible to prepare forecasts (Brown's double exponential smoothing model) and to identify a trend (increasing, decreasing, no trend). A qualitative assessment of the produced forecasts was made for this study. For this purpose, ex post forecast errors were used, i.e. mean relative error of expired forecasts ψ (formula 1), adjusted mean relative ex post error in the verification range Θ (formula 2), Root Mean Square Error RMSE (formula 3) [7-9].

$$\psi = \frac{1}{n-m} \sum_{t=m+1}^{n} \frac{\left| y_t - y_t^* \right|}{y_t} \tag{1}$$

$$\Theta = \frac{1}{n-m} \cdot \sum_{t=m+1}^{n} \left| \frac{y_t - y_t^*}{(y_t + y_t / 2} \right| \tag{2}$$

Table 1 **Causes of accidents at work in the steel sector in Poland [own research based on Statistic Poland]**

Years	2013	2014	2015	2016	2017	2018	Ranks
Total number of people injured in accidents at work	887	889	907	876	995	930	
Causes of accidents in the steel sector in Poland							
Machinery operation	165	167	167	147	182	175	3
Working with hand tools	164	154	159	163	192	181	2
Operations of objects	187	200	224	194	232	206	1
Share in % causes in the number of accidents at work	41,8	41,4	39,4	42,5	39,1	39,6	-

$$RMSE = \sqrt{\frac{1}{n-m} \cdot \sum_{t=m+1}^{n} (y_t - y_t^*)^2} \tag{3}$$

where:

- n – number of time series elements;
- y_t – value of the forecasted variable y for a period of time t;
- y_t^* – forecast of variable y determined for a period of time t;
- m – number of initial time periods t.

The forecasts may be regarded as admissible when the determined error values meet the following conditions: $\psi < 10\%$, Θ is in the range [0% - 200%], RMSE $\leq S_e$ (S_e – standard deviation of model residuals) [7-10].

The third stage involved defining proposed solutions to reduce occupational accidents in the steel industry in Poland and ensuring the safety of operators within autonomous maintenance.

CAUSES OF ACCIDENT AT WORK AND THEIR PREDICTION

With respect to AM, the activities performed by workers injured at the time of accident include:

- machinery operation consisting in starting /stopping the machine, supervising its operation, feeding/receiving materials, semi-finished products and others falling within this scope,
- work with hand tools, both mechanized and non-mechanized,
- operation of objects – these activities include, for instance, assembling /disassembling of bolted connections, bending.

The identified causes of accidents account for approximately 40% of the causes of accidents reported in the steel sector in Poland (Table 1).

In the light of the above, in order to determine their significance for the successive years (2020-2022), a prediction of statistical data was made [11]. The prediction process was carried out using Brown's double exponential smoothing model (k = 2) and Winters' model with a multiplicative trend and multiplicative seasonality. The determined forecasts are shown in Table 2.

The analysis of the compiled data on the forecasts for 2019-2022 leads to the conclusion that the causes of accidents related to the operation of objects will prevail. The values of the forecasts (Table 2, Column 2-5) were determined using Winters' model with a multiplicative trend and multiplicative seasonality, assuming a mini-

Table 2 **Forecasts of causes generating accidents in the steel sector in Poland [own research]**

Years	2019	2020	2021	2022	Ex post forecast errors			Model parameters		
					Ψ, %	Θ, %	RMSE / S_e	α	β	δ
1	2	3	4	5	6	7	8	9	10	11
Brown's double exponential smoothing model (k = 2)										
Machinery operation	168	169	169	169	7,3	2,0	24,8 / 28,6	0,06	-	-
Working with hand tools	184	187	190	193	5,2	1,4	13,5 / 15,6	0,35	-	-
Winters' model with a multiplicative trend and multiplicative seasonality										
Operation of objects	241	155	213	203	9,0	2,3	23,3 / 28,5	0,23	0,34	0,01

mization of the mean relative error of expired forecasts ψ, with parameters $\alpha = 0{,}23$, $\beta = 0{,}34$ and $\delta = 0{,}01$. Work with hand tools was the second significant cause, displaying an upward trend in the period under analysis (2019-2022).The values of the forecasts were obtained using Brown's double exponential smoothing model (k = 2) and parameter $\alpha = 0{,}35$. In that case, the mean relative error of expired forecasts was also minimized. As regards machinery operation, an increase can be seen in 2019, then the cause remained stable (Table 2, Column 3-5). The values of the forecasts of that cause were determined on the basis of Brown model (k = 2) and parameter $\alpha = 0{,}06$. The obtained forecasts may be deemed admissible because the values for the errors meet the criteria adopted in the own methodology.

Given the above, these causes are still considered important and it is proposed that measures aimed at improving work safety in the steel sector should be implemented, namely:

- application of solutions in the field of visual control (in order to quickly detect and respond to irregularities),
- application of rules connected with the organization of the workplace, supporting the process of identification of irregularities (5S/6S method),
- trainings in OSH and work methods in order to identify irregularities and eliminate dangerous behavior during the performance of maintenance activities (TWI program– Training Within Industry, OPL – one point lessons),
- standardization of activities within AM (standards of lubrication, cleaning, inspection of safety devices),
- use of technical measures of protection and personal protective equipment.

Table 3 shows examples of the application of the described solutions for the main causes of accidents at work in the steel sector.

Table 3 **Examples of solutions for the main causes of accidents at work in the steel sector in Poland [own research]**

Causes of accidents	Examples of solutions
Machinery operation	– marking of measuring devices and marking of switches on the machines – light and sound signaling at work stations – use of OPL to provide information to operators in a short time in the field of health and safety, working methods and improvements – LOTO safety system - to protect employees against unexpected power-up or starting the machine during service, adjustment and maintenance works – cleaning, lubrication and inspection standards – use of Red Tags to identify and eliminate problems while working on the machine – pictograms on the machines informing about the dangers – use of guards on machines and protective measures of upper limbs
Working with hand tools, Operation of objects	– marking storage places for work tools – pictograms informing about the dangers – visual work instructions in line TWI – use of OPL in the field of safe working methods – use of protective measures of upper limbs

CONCLUSIONS

The involvement of operators in maintenance activities within AM has an impact on improving the efficiency of machines, but it may also be a potential source of hazard. It is therefore necessary to adopt measures limiting the risk of accidents. The exemplary causes presented above, i.e. machinery operation, work with hand tools and operation of objects, account for approximately 40% of the causes of accidents reported in the steel sector in Poland. The necessity to take preventive actions in their scope is also confirmed by the determined values of ex ante forecasts. Due to the significance of the identified causes of accidents, it was proposed that organizational and technical solutions that can reduce the number of accidents and improve work safety in the steel industry in Poland should be introduced. All activities undertaken within AM should be carried out in a safe manner [12].

Acknowledge

Silesian University of Technology (Faculty of Materials Engineering), supported this work as a part of Statutory Research BK-229/RM1/2021 (11/010/BK_21/0032)

REFERENCES

[1] J. Furman, M. Kuczyńska-Chałada, Management of the machinery in steel companies, In METAL 2016: 25th Anniversary International Conference on Metallurgy and Materials, Ostrava: Tanger, 2016, 1783.
[2] P. Guariente, I. Antoniolii, L. Pinto Ferreira, T. Pereira, F. J. G. Silva, Implementing autonomous maintenance in an automotive components manufacturer, "Procedia Manufacturing", 13 (2017), 1128-1129.
[3] M. Molenda, The autonomous maintenance implementation directory as a step toward intelligence quality management system, "Management Systems in Production Engineering", 2016, 4 (24), 274-275.
[4] Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery.
[5] Directive 2009/104/EC of the European Parliament and of the Council of 16 September 2009 concerning the minimum safety and health requirements for the use of work equipment by workers at work.
[6] T. Małysa, K. Nowacki, J. Furman, The risk management methodology in the metallurgical enterprise, In METAL 2016: 25th Anniversary International Conference on Metallurgy and Materials, Ostrava: Tanger, 2016, 1925-1930.
[7] M. Cieśla, Prognozowanie gospodarcze – Metody i zastosowanie, Wydawnictwo Naukowe PWN, 2001.
[8] S. Krawiec, Adaptacyjne modele wygładzania wykładniczego jako instrument prognozowania krótkoterminowego zjawisk ilościowych, Wydawnictwo Politechniki Śląskiej, 2014.
[9] M. Sobczyk, Prognozowanie – teoria, przykłady, zadania, Wydawnictwo Placet, 2008.
[10] T. Małysa. Application of forecasting as an element of effective management in the field of improving occupational health and safety in the steel industry in Poland, "Sustainability", 14 (2022) 3, 1351.
[11] www.gus.gov.pl (10.12.2021).
[12] M. Jasiulewicz-Kaczmarek, Integrating Safety, Health and Environment into the Autonomous Maintenance Activities, In Stephanidis C. (Ed.) HCII 2014 Posters, Part II, CCIS 435, 2014, 467–478.

Note: M. Gorgol is responsible for English language, Katowice, Poland