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Original scientific paper

TOTAL PRODUCTIVE MAINTENANCE – TOOL TO IMPROVE THE COMPANIES PERFORMANCE

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A b s t r a c t: The research of the paper shows the implementation of TPM methodology on total maintenance and its main tool, Autonomous Maintenance (AM). The goal is to increase the productivity and efficiency of an existing production line for pickling metal sheet. Total analysis of the production line is done by identifying weak points, i.e. assemblies using the Overall Equipment Effectiveness (OEE) indicator. With applying the main tool, autonomous maintenance from TPM methodology, an attempt has been made to identify the anomalies, a system for reporting errors has been created, the number of standards and education of the operators has increased, and in order to reduce the number of delays in the production line. This will improve the efficiency of the employees and the productivity of the company as a whole.

Key words: maintenance; total productive maintenance – TPM; preventive maintenance; autonomous maintenance; overall equipment effectiveness

ЦЕЛОСНО ПРОДУКТИВНО ОДРЖУВАЊЕ – АЛАТКА ЗА ПОДОБРУВАЊЕ НА ПЕРФОРМАНСИТЕ НА КОМПАНИИТЕ

А п с т р а к т: Истражувањето претставено во трудот ја прикажува имплементацијата на методологијата на целосно продуктивно одржување (TPM), како и нејзината главна алатка – автономно одржување (AM). Целта е зголемување на продуктивноста и ефикасноста на постојна производствена линија за лужење на челичен лим. Целосното анализирање на производствената линија е направено преку утврдување на слабите точки, т.е. склопови со помош на индикаторот за севкупна ефективност (OEE).. Со имплементацијата на главната алатка – автономно одржување (AM) на методологијата TPM, направен е обид да се идентифкуваат аномалиите, креиран е систем за информирање за грешки, зголемен е бројот на стандарди и едукации на операторите, а со цел да се намали бројот на застои на производствената линија. Со тоа ќе се подобри ефикасноста на вработените и продуктивноста на компанијата во целост.

Клучни зборови: одржување; целосно продуктивно одржување – TPM; превентивно одржување; автономно одржување; севкупна ефективност на опремата

1. INTRODUCTION

In today's dynamic environment, the reliability of the systems is crucial to creativity. The poor organizational competence in the management of the maintenance functions may have a serious impact on the competitiveness by reducing the progress, increasing the supply and not meeting the deadlines. The equipment, technology and development of its features become a substantial factor that demonstrates the power of the organization and in that manner separates it from the other companies. The maintenance is becoming a strategic tool, unlike before, when the only objective of surveillance was the maintenance cost decrease. The investment in the maintenance is one of the basic functions of the company. It reflects in the quality improvement, the safety, the flexibility and production time. Over the last decade, the opinion that the maintenance is not a separate, isolated function and it needs to be treated as all the other company activities have become predominant. Maintenance is a full partner of the rest of the organizational functions and should strive to realize the company's strategic goals. Therefore, maintenance is becoming a strategic necessity for the manufacturers worldwide. Increase of business pressure put the maintenance as a key role in the company's functions. The modern manufacturing requires that the organization, if it wants to achieve have a World Class Manufacturing – WCM, has both features – *effective* and *efficient maintenance*.

As part of the benchmark ideas for organizational performances and processes improvement, regarding the competition, the TPM has been identified as the best solution to increase the company productivity.

2. OVERVIEW OF THE LITERATURE RESEARCH

The researcher R. Kennedy [5] actualizes total productive maintenance (TPM) in the manufacturing as a revolutionary approach in the maintenance. The main point of the TPM is that it develops outside the lean approach. Its significance goes far beyond the limited view of maintenance because it is a part of a total approach to more productive manufacturing. The TPM concept addresses the maximization of overall plant and equipment effecttiveness through the elimination or minimization of the six machine losses, creating a sense of ownership for plant and equipment operators through a process consisting of training, involvement and promoting continuous improvement through small group activities involving production, engineering and material personnel.

There are several researches carried out by different researchers that review and determine the significance of the development and application of the TPM in the production [3, 7, 8]. It is well known that TPM is introduced in the company, if the application is done when many employees participate. All involved participants need to be focused and need to cooperate at all levels. Team work is the most important factor. There are many approaches in the application of the TPM, but there is no evidence for non-application due to a certain problem.

The total productive maintenance (TPM) is an improvement in the manufacturing, i.e. it is a practical analogy to the total quality maintenance (TQM), while the Japanese researchers explain it as concept for management with the equipment in order to achieve increased productivity by involving all employees. According the researcher S. Nakajima [3], TPM's objective is to continuously improve the equipment and prevent equipment deterioration, in order to achieve maximum efficiency. These objectives require strong management and great support from all involved employees.

TPM may be analyzed in three words [3]:

- *Total*: Meaning involvement from workers to top management employees.
- *Productive*: Meaning no more unnecessary activities or manufacturing delay and focusing on services that satisfy the consumers' needs.
- *Maintenance*: Keeping the equipment and company clean and in an operating condition that is good or even better than the original.

The success of every business improvement is a strategy that rests on a strong and dynamic leadership that has to be presented by winners. The author J. Levitt [6] in his work points out that the key players for the TPM are the machine operators. In this case the maintenance staff has an advisory role. Also, he states that the winning factor of the TPM is to train the operators to an extent that would be sufficient to achieve full AM.

The earliest application of the TPM is in Japan, especially in the fast-growing automobile industry, i.e. in the Toyota Company and its branches. As a result, many Japanese companies, encouraged by the Toyota's success, started to apply the TPM, but at the early beginning there was no noticeable success [9]. All of this changed in 1970 when Japan faced economy decrease. From that moment it started to rapidly adapt TPM in order to improve the manufacturing productivity [10]. The TPM application process has been developed by the researcher S. Nakajima [3]. He developed the process in several stages in order to provide standardized and repeatable methodology.

For comparison, there are two different approaches to define the TPM: the *Japanese approach* presented by the authors S. Nakajima [3], F. Gotoh [9] and K. Shirose [11], and the *Western approach* by the authors P. Willmott [12] and T. Wireman [13]. These two approaches are also supplemented by the approach of the author C. Bamber [14]. The differences between the Japanese and the Western approaches defining the TPM are small compared to the similarities that are much more significant. The Japanese value the team work in small groups and participation of all company employees in the TPM process application, in order to meet the improvements intended for the equipment used. The Western approach is more focused on the equipment, while the employees' involvement in the goal achievement is not crucial. Although it can be noticed that both approaches are very similar, the Japanese approach focuses on the people and the process, while the Western approach starts from the improvement of the equipment efficiency, which does not separate it from the team work, but also does not lead to correct equipment management and equipment use [14].

3. TOTAL PRODUCTIVE MAINTENANCE (TPM)

TPM is an innovative Japanese concept. The origin of TPM can be traced back to 1951 when preventive maintenance was introduced in Japan. However, the concept of preventive maintenance was taken from USA. Nippondenso was the first company to introduce plant wide preventive maintenance in 1960. Preventive maintenance is the concept wherein operators produced goods using machines and the maintenance group was dedicated with work of maintaining those machines, however with the automation of Nippondenso, maintenance became a problem, as more maintenance personnels were required. So the management decided that the operators would carry out the routine maintenance of equipment [1].

TPM is a complex and long process that shows the employees that it is a legitimate methodology which would improve the processes. If the TPM is to be successful in any industry, both teams – the management and workers, must operate in an atmosphere that would be beneficial to the company. The company employees need to truly take action if this methodology is to succeed.

TPM is consisted of eight pillars. Its methodology has a manner of excellent planning, organization, monitoring and practical control applied through the eight pillars. The TPM initiative, as promoted by the Japanese Institute for Plant Maintenance, includes a plan for application of all eight pillars that need to make gradual improvement of the productivity through controlled maintenance, reduction of costs and decreased delays. The methodology core (Figure1) is classified in eight pillars and activities:

- 5S
- Autonomous maintenance (AM).
- Focused maintenance.
- Planned maintenance.
- Quality maintenance.
- Education and training.
- Office TPM.
- Safety, health and environment protection.

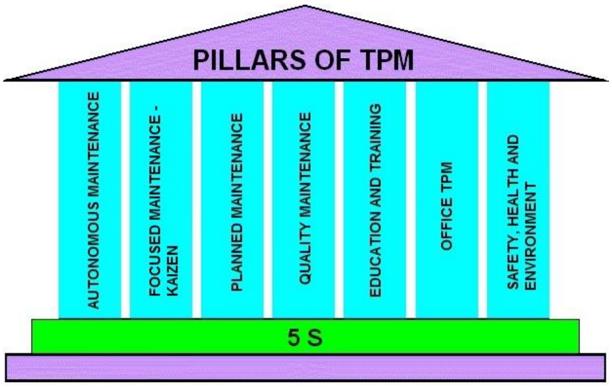

Fig. 1. The pillars of TPM [10]

The mission of each pillar is to reduce losses in order to eliminate all losses in the process.

Prior to the initiation of the TPM application it is necessary for the management to compose a program and inform all employees so that they could understand that it is a matter of long-term program that change the company culture, and not just an initiative intended for the maintenance services.

TPM structure supports the culture changes where the responsibilities and ownership of the processes are clearly defined and supported.

We may also mention that the pillars within themselves change the direction, develop the system, process and standards along with the employees. It enables and motivates the leaders to operate with their employees and teams to decrease the barriers between them in order to create a single and cohesive system where all employees from all levels would work to achieve the same goal. This is a manner of change management and observance of a strict methodology which would provide consistent future results. The manner of establishing of this methodology is the application of all eight pillars. By applying TPM many companies mark productivity increase as well as increase of the reliability of the machines, the malfunction frequency is decreased and the effectiveness of the quality is increased. However, it mostly affects the increase of the productivity. This proactive strategy may contribute to the improvement of the performances stressed in many researches.

4. TECHNICAL DESCRIPTION OF PRODUCTION EQUIPMENT

The application of one of the TPM tools, i.e. the AM, and the need of its application will be displayed in this chapter. The production line for pickling metal sheet is integral part of the company Arcelor Mittal – Skopje. The equipment is composed of several assembly parts and it works as one entirety. During its operation there are often delays that are predictable due to certain events, but some of them cannot be predicted as they occur suddenly. The production pickling metal sheet line is shown on Figure 2 and is made by the British company WEAN LIMITED INC. The production line is for producing the pickled metal sheets in a form of strips, made from the hot rolled materials according to the standards used for cold forming of sheet.

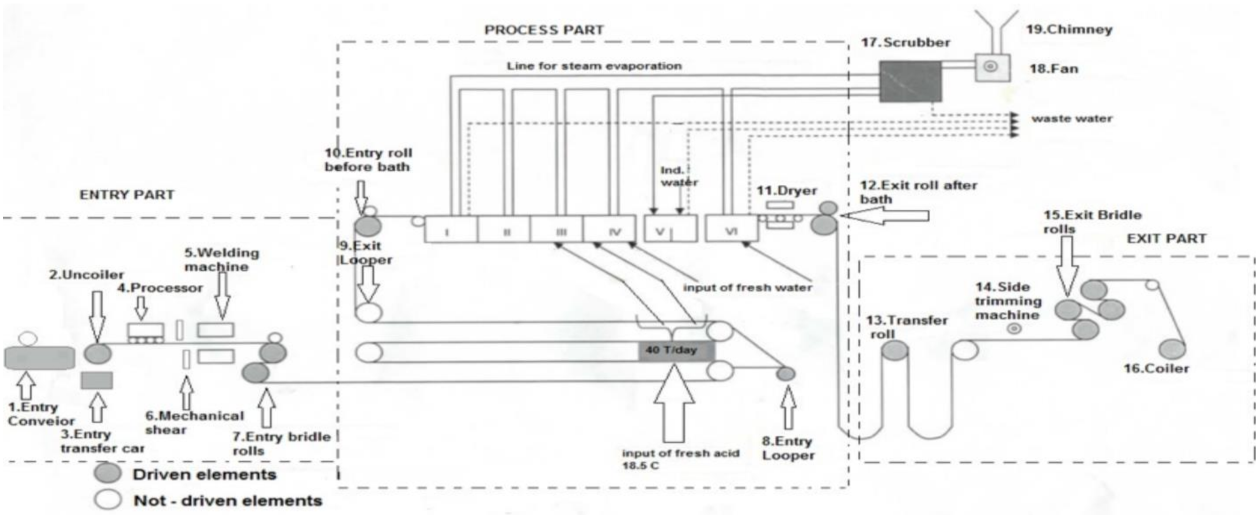

Fig. 2. Production process of pickled metal sheet [2]

4.1. *Overview of delays and problems within the period 2014–2017*

The use of all tools offered by the AM defines the critical equipment of the pickling metal sheet line. The annual reports on the delays, as well as the total line effectiveness are the biggest indication on the major problems. The five most critical pickling metal sheet assemblies are determined through these reports for the period from 2014 to 2017, as well as the analysis of the total effectiveness, but they also determine the year of worst delays. The chart shown on Figure 3 displays the delays in a time interval on the pickling metal sheet assemblies for the period from 2014 to 2017.

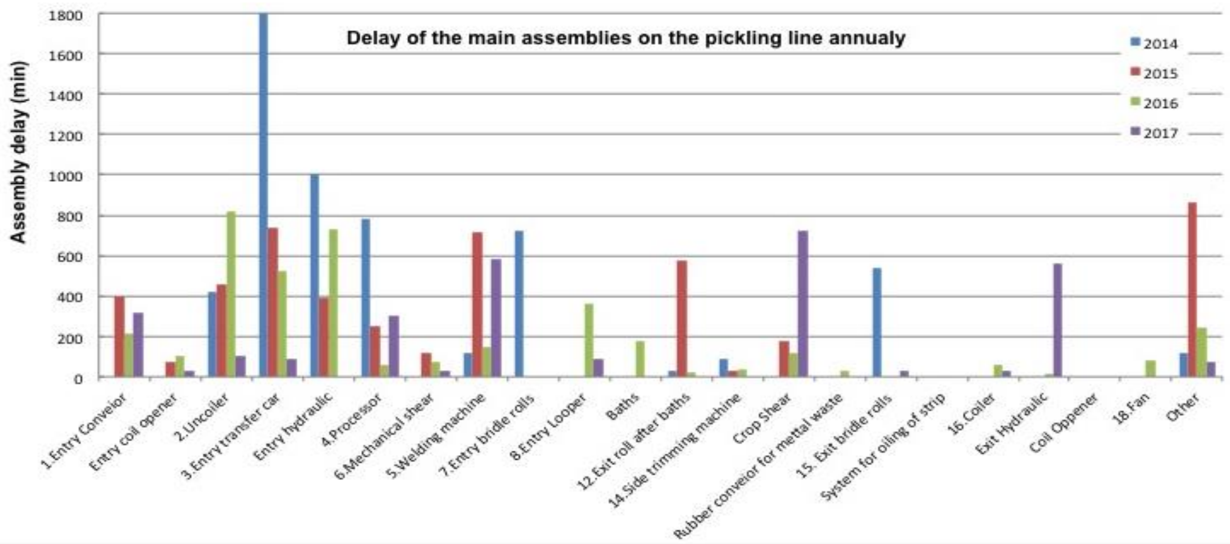

Fig. 3. Duration of delays of the assembly from 2014 to 2017 [2]

The Figure 4 is a graphical display of the total delay period of the pickling metal sheet line assemblies, for each year separately for the period from 2014 to 2017. Based on that, it has been determined that the worst year with the biggest number of delays on the pickling metal sheet line is 2014. This year is taken as a reference for the determination of the overall equipment effectiveness (OEE).

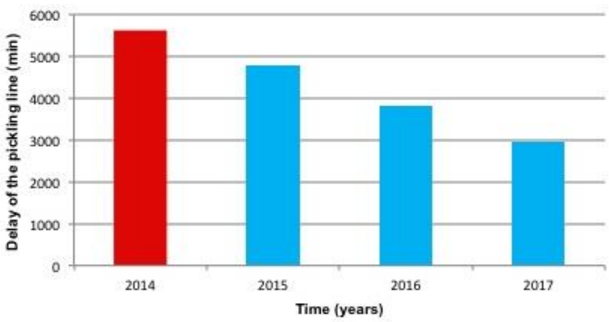

Fig. 4. Total pickling metal sheet delay period by years

5. DEFINITION OF OVERALL EQUIPMENT EFFECTIVENESS INDICATOR

The overall equipment effectiveness (OEE) is a key indicator for the performances of a process or equipment. It may be set as a benchmark for the measuring or analysis of a process and its effectiveness. In other words, the OEE is the full use of time, materials and facilities during the production process [4]. The OEE is calculated based on the following three indicators:

1. *Availability (R)* – is the ratio of actual production time that a machine is working divided by the time the machine is available.
2. *Performances (P)* – is the percentage of total number of parts on that machine to its production rate. In simple words, performance measures the ratio of actual operating speed of the equipment and the ideal speed.
3. *Quality (Q)* – is an indicator calculated as the proportion of the total number of functional products manufactured with the machine and the total number of products manufactured within a period of one year production.

After the three indicators are defined, the OEE can be calculated with the equation (1):

$$OEE = R \cdot P \cdot Q \qquad (1)$$

The calculated values of the OEE with the equation (1) are values between 0 and 1 or expressed in percentage it would be between 0% and 100%. The Table 1 displays the ideal values of the three indicators, as well as the value of the OEE after the application of the recommendations for World Class Manufacturing [3, 4]. It is recommended and acceptable for the OEE to be 60% in which case the companies achieve satisfactory results [4].

The Table 1 displays the calculated indicators and the OEE for each individual year within the reviewed period. According to the data in the Table 1, it is visible that 2014 has the worst effectiveness. The reason due to which 2014 has this result is the system of operation that existed that year, i.e. the small-scale production planned. The occurrence of a large number of delays of the pickling metal sheet line contributed to this outcome. This shows that the pickling metal sheet line in 2014 was at a delay for one fifth of the available time and did not manufacture.

Table 1

Ideal and calculated indicators of the overall equipment effectiveness [3] (%)

Year	R Availability	P Performances	Q Quality	OEE – total efectiveness
2014	82	64	92	48
2015	86	63	91	49
2016	80	71	94	53
2017	84	72	95	57
Ideal values	90	95	99	84,645

5.1. *Determine of critical equipment*

Following the instructions from the research [2], the most critical year within the period from 2014 to 2017 needs to be determined and then also the five most critical assemblies for that year. Figure 3 displays the duration of the delays of the pickling metal sheet line for the period from 2014 to 2017, with 2014 being the most critical one. It also displays the OEE of the equipment for the period from 2014 to 2017 with the results given in Table 1, confirming that 2014 is a critical year when the equipment is less effective. Analyzing the aforementioned, it shall be considered that 2014 defines the five critical pickling metal sheet line most critical assemblies.

The critical assemblies of the pickling metal sheet line are determined using the recommendations [2]. The Table 2 displays the ranked critical assemblies based on special marks indicators for several parameters such as: delays, quality, manufacturing, safety, maintenance costs, average time for repair etc. By expressing the real evaluation of the assemblies in Table 2, the classification of the assemblies can be made. In this manner the assembly with over 15 points are set in the "AA" class, of the most critical assemblies, the assemblies with 10 to 15 points are set in the "A" class, or critical assemblies, the assemblies with 1 to 9 points are set in the "B" class, or problematic assemblies, and with 0 points are set in the "C" class, or defect free assemblies. The evaluation of the steel sheet metal pickling line assemblies is made in the presence of experts from the maintenance and production sectors.

Table 2

Pickling metal sheet line equipment ranking

Assembly	MTTR (min)	Number of delay	Quality impact	Production impact	Safety impact	Maintenance costs	Total points	Class
1 Entry conveior	0	0	0	5	5	5	15	AA
Entry coil opener	0	0	0	2	1	1	4	B
2 Uncoiler	84	5	5	5	5	5	20	AA
3 Entry transfer car	300	6	5	5	5	5	20	AA
Entry hydraulic	250	4	3	5	1	5	14	A
4 Processor	112	7	5	5	1	5	16	AA
6 Mechanical shear	0	0	5	0	0	1	6	B
5 Welding machine	40	3	5	5	5	5	20	AA
7 Entry bridle rolls	360	2	5	5	0	3	18	AA
8 Entry Looper	0	0	1	1	1	2	5	B
Baths	0	0	1	1	1	1	4	B
12 Exit roll after baths	30	1	4	3	1	5	13	A
14 Side trimming machine	45	2	5	5	5	5	20	AA
Crop shear	0	0	1	1	1	1	4	B
Rubber conveior for mettal waste	0	0	1	1	1	1	4	B
15 Exit bridle rolls	540	1	5	5	1	2	13	A
System for oiling of strip	0	0	0	0	0	0	0	C
Coiler	0	0	5	5	1	3	14	A
Exit hydraulic	0	0	5	5	1	5	16	AA
16 Coil oppener	0	0	0	0	0	0	0	C
18 Fan	0	0	0	5	5	5	15	AA
Other	60	2	3	3	2	3	11	A

6. IMPLEMENTATION OF TPM TOOL: AUTONOMOUS MAINTENANCE

The calculations that were done show the production pickling metal sheet line has to be modified regarding the manner of operation. By applying the TPM tool: autonomous maintenance (AM), the decrease of the number of delays will be affected, as well as the productivity increase. The application of the AM will be based on the five critical points. Also, the application of the AM is intended to eliminate the several adverse aspects occurring in the course of operation such as:

- High costs due to excessive number of delays.
- Contaminated and damaged equipment.
- Important quality losses.

- Limited knowledge of the equipment by the operators.
- Very small number of improvement propositions.

By applying the AM, which is a part of the TPM methodology, many good results may be achieved regarding the improvement of the productivity and decrease of the number of delays. This is confirmed by using a line of indicators appearing during the application of the seven steps of the AM. While applying the first step, cleaning, an equipment anomaly notification system has been introduced. The system is composed of two notification manners with blue labels intended for the solution of the problems by the AM-teams and red labels intended for more serious problems solved by the maintenance teams.

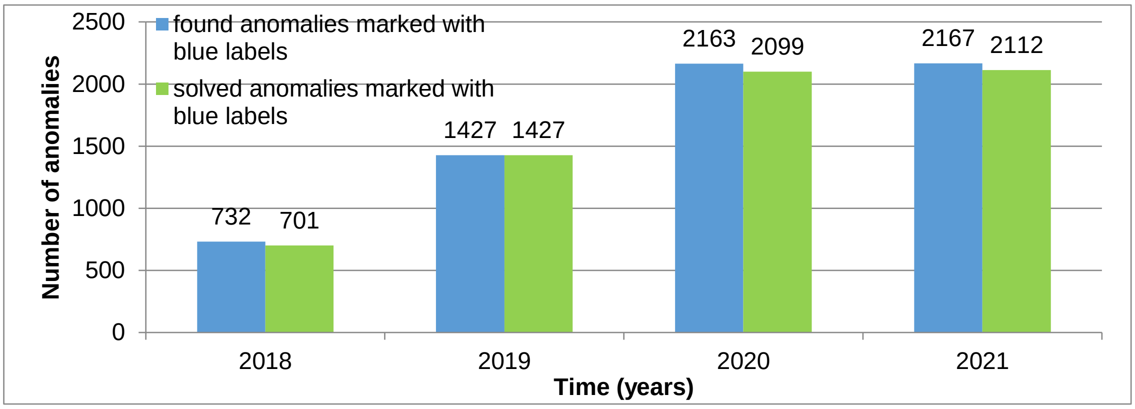

Fig. 5. Expected blue label results

Figure 5 displays the expected results of the blue labels after the application of the first step of the AM. The blue labels mark which of the AM-team members can solve the problems without company maintenance assistance. By analyzing the receive results displayed on Figure 5 it can be expected that the number of found anomalies and solved anomalies will grow each year. The solved blue labels intended for the AM-teams shall mark the defects solved by the AM-teams.

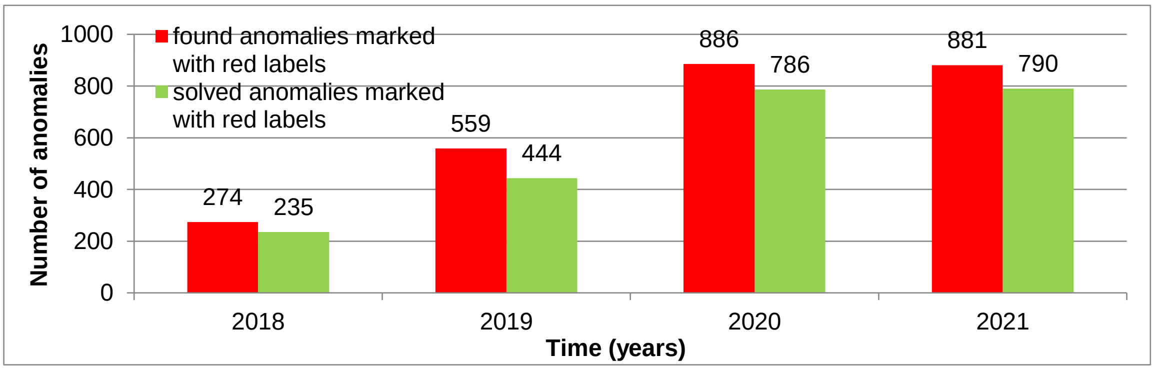

Fig. 6. Expected red label results

The Figure 6 displays the red label results after the application of the first step of the AM. The anomalies marked with red labels are intended for the company maintenance members, i.e. those are anomalies which the AM-teams cannot solve themselves. Analyzing the results displayed on Figure 6, it can be expected that an increase will take place regarding the solved and detected anomalies marked with red labels each year. After the application of the first step of the AM, it is expected that the AM-teams' members will be trained for correct use of the notification system.

While applying the second step of the AM an inspection has been made of the most critical points of the steel sheet metal pickling line, whereby the anomalies detected are divided in several categories and are displayed on Figure 7. After the application of this step, the operators will be one level higher in the familiarization with the equipment and its functioning. In that manner, they are no longer passive observers, but become active participants in the problem prevention.

The Figure 7 displays the critical equipment anomalies prior to the application of the AM. Analyzing the results, it can be noticed that there are too many anomalies of the critical equipment. The anomalies detected refer to all critical points. The Figure 7 also displays that the category of unnecessary openings and damaged protective parts is the most critical.

After the application of the second step, it may be expected that all anomaly categories decrease. This fact is displayed on the Figure 8.

With the application of the third step from the AM, standardization, intended to create standards for the critical points, it can be expected that the number of small delays will decrease. It is due to the insufficient knowledge of the equipment the operators have. The development of the standards for the critical points of the equipment is necessary, as well as the mutual cooperation with the operators, includeing the company maintenance.

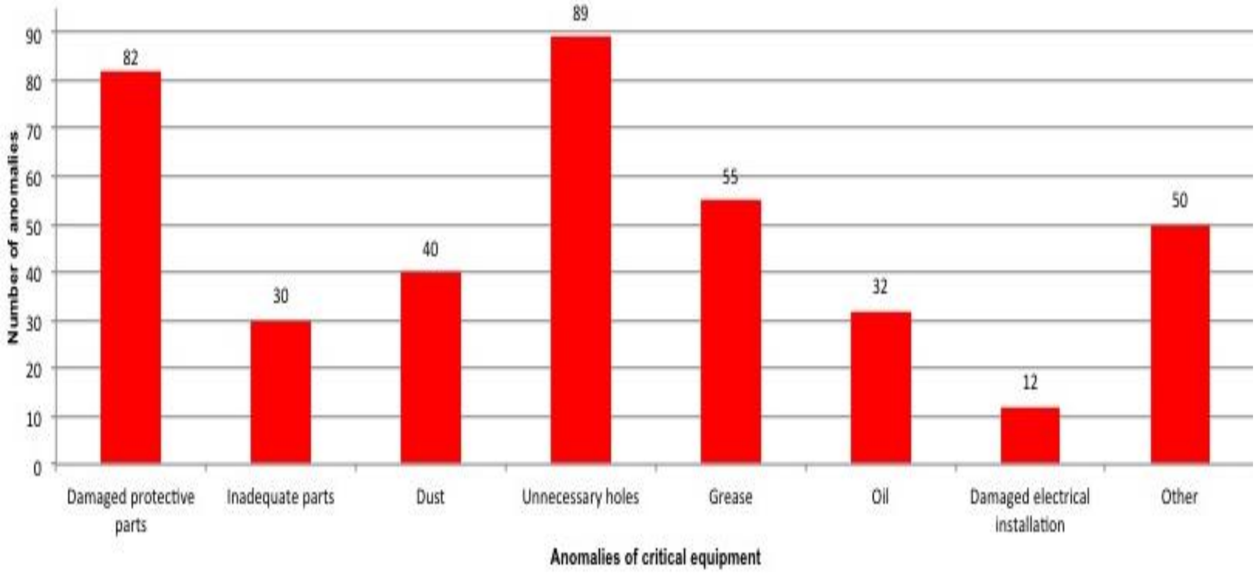

Fig. 7. Critical equipment anomalies prior to the application of the autonomous maintenance (AM)

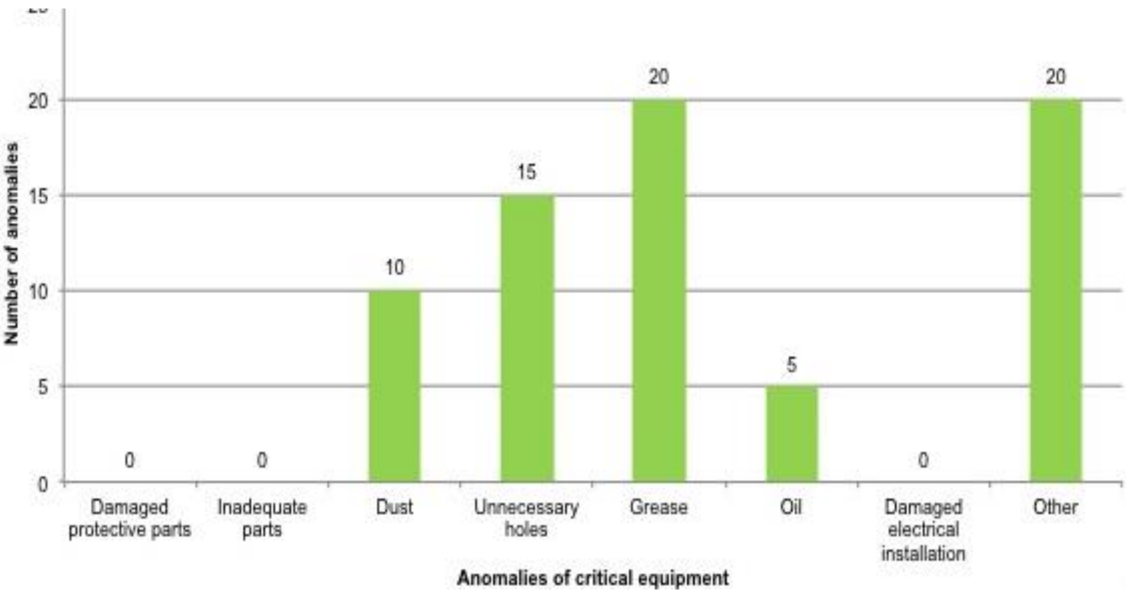

Fig. 8. Critical equipment anomalies after to the application of the autonomous maintenance (AM)

The Figure 9 displays the number of expected developed standards after the first year of application of the AM. Analyzing the obtained results, it can be observed that rapid progress is expected within a year from the application of the AM. This progress is necessary because there are no standards developed for the pickling metal sheet line up until the AM commencement, and with that the entire system is based on the operators' experience.

The Figure 10 displays the number of developed standards after the first year of application of the AM, for each individual critical point of the equipment.

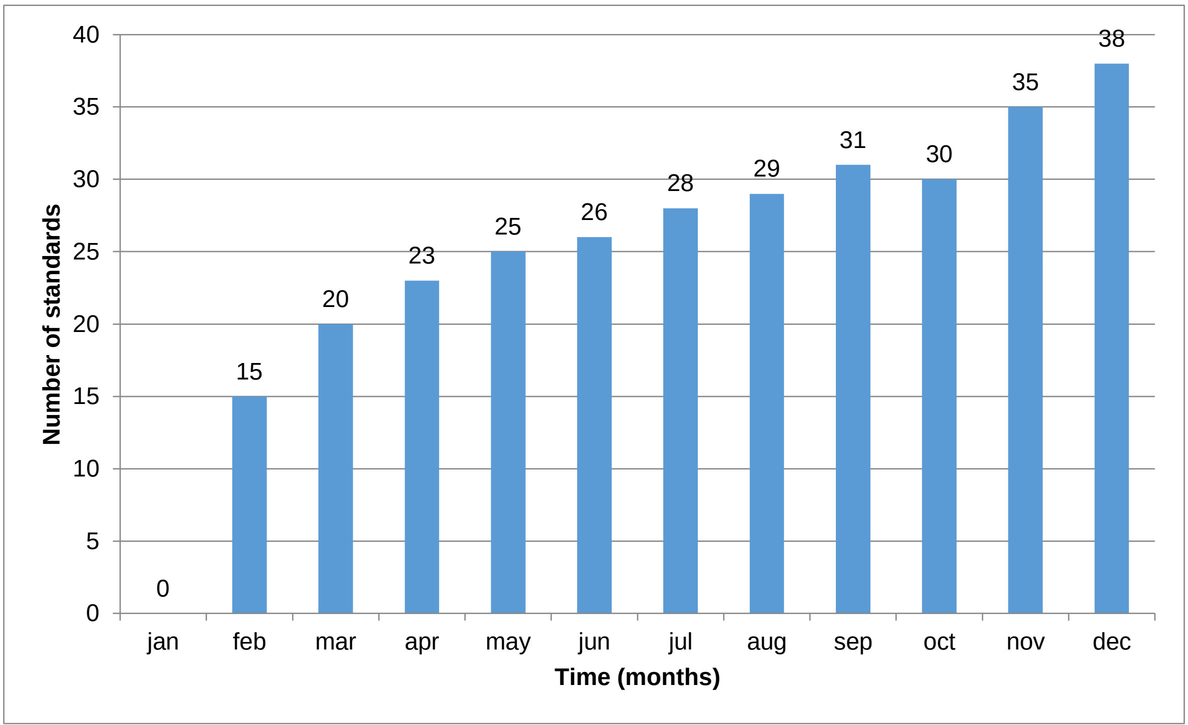

Fig. 9. Number of standards developed after the first year of the AM application

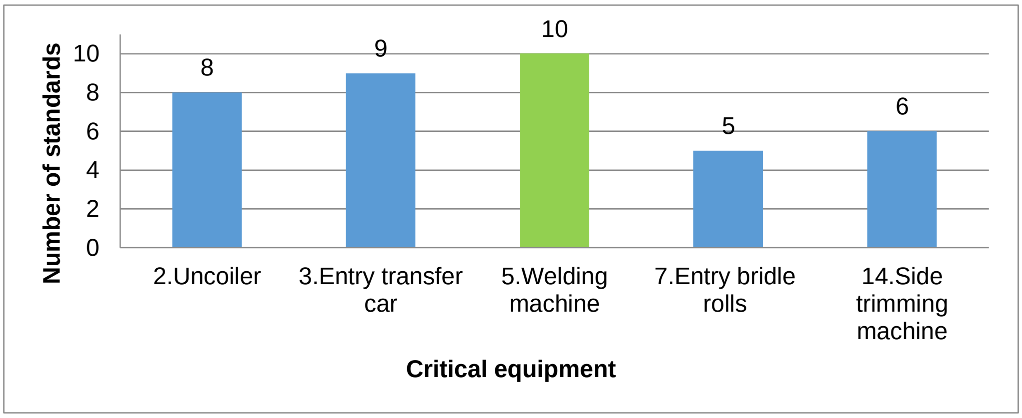

Fig.10. Number of standards developed after the first year of the AM application

The Figure 10 displays the results from which, it can be observed that the most of the developed standards are envisaged for the critical equipment – welding machine. No standards exist for this equipment and therefore the operators face problems such as machine settings that sometimes can take up to two or three hours. After the application of the third step these problems are expected to be eliminated and in the same time the operators' knowledge of the equipment is expected to increase.

The achieving of the objective to decrease the number of delays and increase productivity may be expected to be reached after the application of all seven steps of the AM. The Figure 11 displays the increase of the overall epquipment effectiveness (OEE) of the equipment after the application of the AM of an identical production line in the ArcelorMittal Company, Gent, Belgium. The displayed results on the Figure 11 show the OEE increase trend from the beginning of the application of the seven steps of AM in 2005, until the final application of the AM in 2008.

Analyzing the Figure 11, it can be noticed that the OEE of the equipment is satisfactory, staring from 2005 and finishing in 2008. The achieved results fully justify the correct decision of the ArcelorMittal Company, Gent, to apply AM.

The Figure 12 displays the expected results for the OEE of the pickling metal sheet line in the ArcelorMittal – Skopje company. The columns marked with blue and red color, i.e. the time period by years from 2014 to 2017, give the actual data used in the calculation to prove the need of modification of the AM in the operation manner of the production line. The columns marked with green color, i.e. the time period by years from 2018 to 2021, represent the time during which the AM is to be applied. That is the time period for which there is no particular data, but due to comparison, the data given on the Figure 11 for the period from 2005 to 2008 are used, as comparison values in the application of the AM.

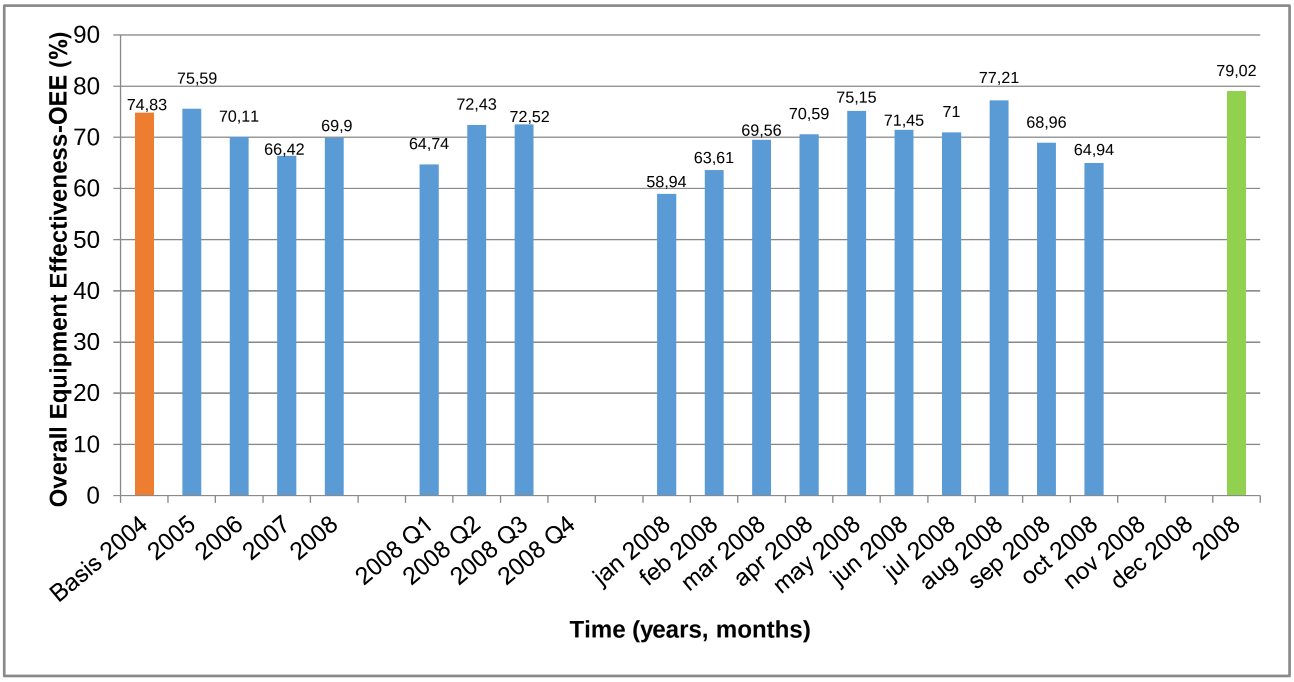

Fig. 11. Overall equipment effectiveness (OEE) after the application of the autonomous maintenance (AM) [9]

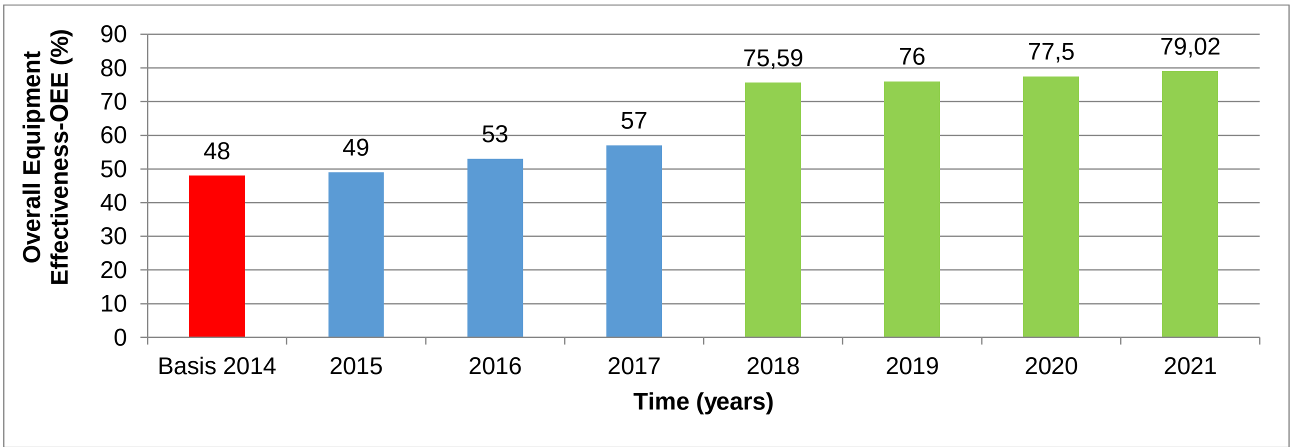

Fig. 12. Envisaging of the overall equipment effectiveness (OEE) for the period from 2014 to 2021

The predictions given in the Figure 12 represent the results from the OEE by years during the application of the AM of the equipment and if in any part of the four year application the results obtained differ from the expected, immediate reaction is needed to detect and solve the problem and correct the course of events in the application.

The Figure 13 displays the comparative analysis of the application of the AM between the expected results from ArcelorMittal – Skopje and the achieved results in ArcelorMittal – Gent. The columns marked with blue color on Figure 13 are the delays from 2014 to 2017 in ArcelorMittal – Skopje. The columns marked with green color are the expected results after the application of the AM in ArcelorMittal – Skopje. The columns marked with orange colour are the results obtained after the application of the AM in ArcelorMittal – Gent. The comparative overview shows that during all years of application of the AM the same results as in ArcelorMittal – Gent are expected. The second and third application years are considered to be exceptions, and in that period the OEE of the production line in ArcelorMittal – Skopje is expected to increase.

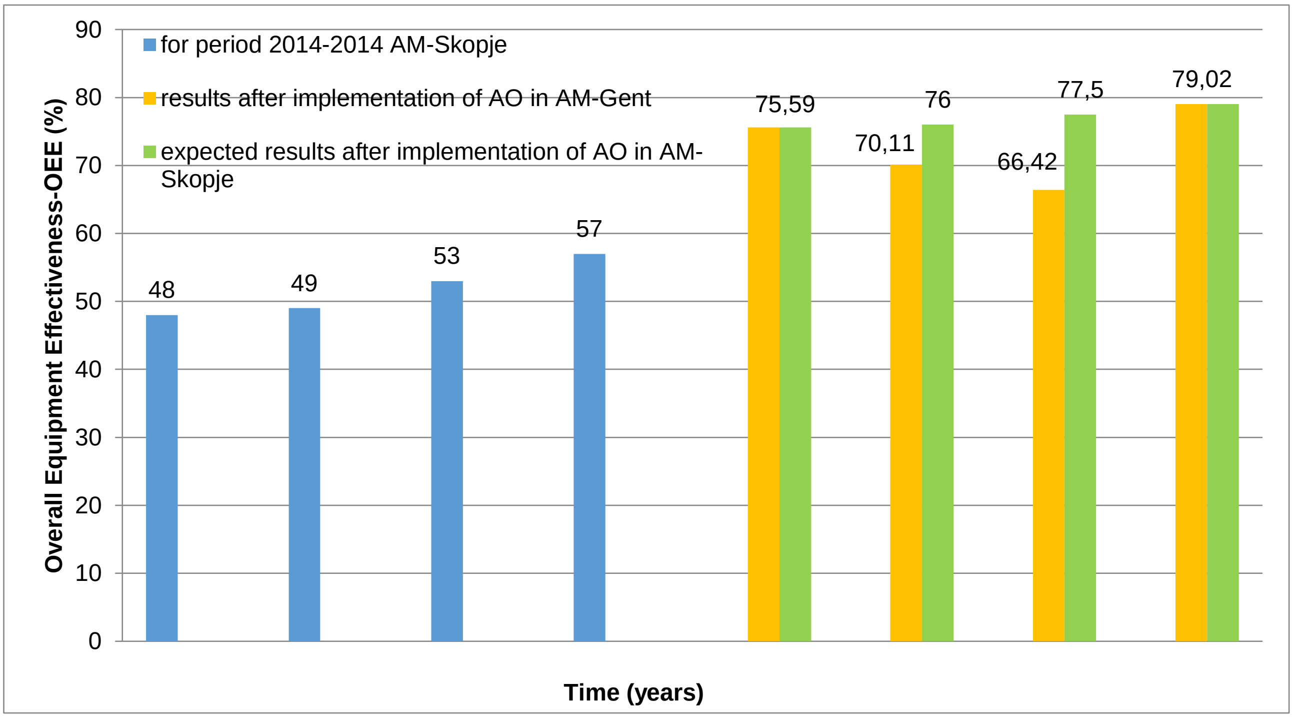

Fig. 13. Comparative overview after the AO application

7. CONCLUSION

The main benefits from the TPM methodology application are the decrease of the number of delays of the equipment, decrease of the clients' complaints, dedicated and educated workers, as well as improvement of the quality of the product. The successful TPM methodology application depends on all involved participants in the company. Mainly, the TPM methodology is helpful in the determination and decrease of the unnecessary costs. According to the obtained results from this research it can be concluded that by applying the TPM methodology the goal is achieved, i.e. the productivity is increased and the number of steel sheet metal pickling line delays are decreased.

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