CONTRIBUTION OF THE MACHINE AVAILABILITY INDICATOR TO THE CALCULATION OF THE MAINTENANCE COST. CASE STUDY: MECHANICAL PRESS MACHINE IN MANUFACTURING INDUSTRY

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Rezumat. *Condițiile concurențiale generate de globalizarea piețelor solicită companiile producătoare din toate domeniile să îşi reducă sau să îşi optimizeze costurile de fabricație. Monitorizarea permanentă a stării de funcționare a maşinilor şi echipamentelor de producție este condiția menținerii şi îmbunătățirii disponibilității acestora, precum şi a controlului costurilor de mentenanță. Lucrarea analizează influența disponibilității maşinilor în managementul costurilor de mentenanță. Aceasta cuprinde prezentarea teoretică a indicatorului de disponibilitate şi a costurilor de mentenanță şi un studiu de caz pentru o maşină de prelucrat prin deformare dintr-o companie producătoare de componente pentru industria auto. Se prezintă date importante privind impactul activității de mentenanță în evaluarea disponilității şi a costurilor de mentenanță.*

Abstract. *The competition conditions generated by the market globalization, force the companies from all areas to reduce or optimize their manufacturing costs. Permanent monitoring of the machines operating process is the condition of maintaining and improving their availability but the control of the maintenance cost as well. The paper analyses the impact of the availability of production equipment in the management of the maintenance cost. The article is composed of the presentation of the basis of the availability indicator and the maintenance cost and a case study on a press machine in a manufacturing company producing components for automotive industry. Are presented important data related to the impact of the maintenance in the calculation of the availability indicator as well as maintenance costs.*

Keywords: Maintenance cost, availability, Mean Time Between Failure (MTBF), Mean Time to Repair (MTTR), failure rate.

1. Introduction

Even is not treated sometime consistent, being considered a "necessary evil" which just "spend money for nothing" the impact of non-applying the maintenance could lead to high expenses, impacting quality, safety, and management relationship with customers. Therefore, set-up the proper

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maintenance activity, with clear purpose and procedure will bring significant benefit to the company. Behind any maintenance activity, there is a solid economic approach gathered in the maintenance cost [1], where can be found internal and external impact of the maintenance and non-maintenance activity.
Melesse&Co [2] stated that during a survey of manufacturers found that full-time maintenance personnel as a percentage of plant employees averaged 15.7 percent of overall staff in a study involving manufacturing organizations, whereas in refineries, the maintenance and operations departments are often the largest and each may comprise about 30 percent of the total staffing. It has been found that in the UK manufacturing industry, maintenance spending accounts for a significant 12 to 23 percent of the total factory operating costs.
The Romanian industry, of course, even if it's mostly private, falls in a period of profound crisis and hard times (financial blockages, a lack of markets both for "inputs" and "outputs", price rises, etc.), a context in which the production capacities usage is an extremely reduced one (30-40% of the capacity, and in some cases even less), the equipment's maintenance isn't a priority in the top managers' concerns. The industrial equipment's maintenance is compulsory for guaranteeing the quality in all the production process' stages, its assignment, in an attempt of warranting quality in all the production stages, the process being one of identifying the equipment that have a direct effect on quality and ensuring that through the performed maintenance works is ensures failure prevention and the prevention of some malfunctions that may affect the production's quality [3]
According to the European standard, EN 13306, Maintenance terminology (2001) [4], the maintenance is defined as „Combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function." If there is no other specification, for the aim of the current paper, the term „maintenance" refers to all types of maintenance (see next paragraph below).
The maintenance activity has different classifications depending on destination, time related, etc. One of the most common ways to classify maintenance is the one related to the action performed and timing. Bengtsson [5] made a comparison between the known types of maintenance – see Fig. 1.
Corrective maintenance. Corrective maintenance is applicable to restore machine/equipments working performance when breakdown occurs. In this case, component, subsystem or system is kept running until failure or breakdown occur. **Preventive maintenance** represents the activities of exchanging components at preset intervals depending on the exploitation period. Thus, is prevented equipment failure during operation or its deterioration to breakdown. **Proactive and predictive maintenance** represents equipment management activities to evaluate, adjust and if necessary exchange equipment components based on their condition. Therewith, is prevented machine/equipment failure. In the predictive

maintenance, the so-called Condition Based Maintenance (CBM), maintenance activities intervals are determined by assessing component, subsystem or system condition.

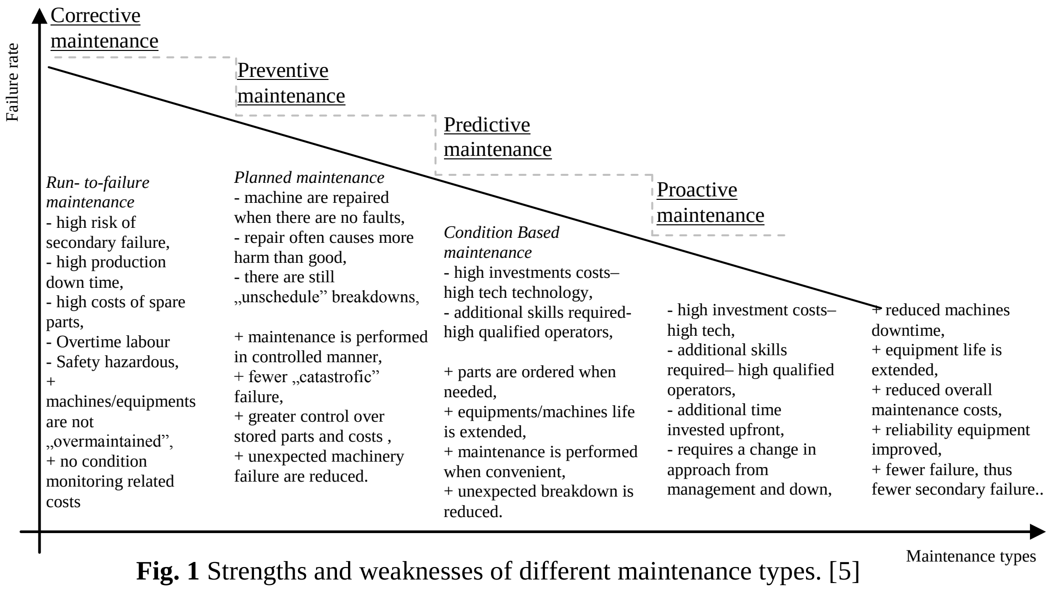

Fig. 1 Strengths and weaknesses of different maintenance types. [5]

Corrective maintenance. Corrective maintenance is aplicable for restoring machine/equipments working performance when breakdown occure. In this case, component, subsystem or system is keep running until failure or breakdown occur. **Preventive maintenance** represents activities of exchanging components at preset intervals depending on exploitation period. Thus, is prevented equipment failure during operation or its deterioration to breakdown. **Proactive and predictive maintenance** represents equipment management activities to evaluate, adjust and if necessary exchange equipment components based on its condition. Therewith, is prevented machne/equipment failure. In the predictive maintenance, so-called Condition Based Maintenance (CBM), maintenance activities intervals are determined by assessing component, subsystem or system condition.

Dekker [6] presented two point of view related to maintenance. First of all, maintenance faces an inherently stochastic deterioration and failure process. The state of affairs in a maintenance organization is often dominated by unplanned events. Failures of important equipment may delay long-planned activities. Major decisions, e.g., choosing between replacement or repair, may have to be taken quickly. The management, being under constant time pressure, lacks time to become familiar with abstract management science techniques. Secondly, maintenance consists of a multitude of different activities. At an individual activity level it is often difficult to quantify the benefits of maintenance. Hence, at a macro level, it is very difficult to balance the maintenance budget with its contribution to company profits. Therefore, maintenance is often seen as a cost function only, with all associated negative implications.

However, the maintenance is a support function and is seen as investment due to the mission of preventive unexpected breakdown. From costs perspective, it can be seen cost to prevent and cost to react and cost of lost production. All these costs are gathered under generic name of maintenance costs and are linked with reliability costs. The more invest in design to increase reliability the less spend with maintenance during the lifetime.

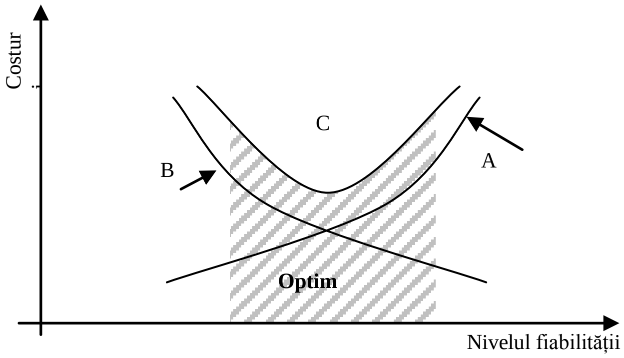

Fig. 2 Realiability of the economic optimum [7]
A- cost of reliability, B- cost of maintenance, C- total cost.

Figure 2 illustrates the relationships between reliability cost and maintenance cost with the aim of finding economic optimum [7]. It shows that the more is invested in reliability the less maintenance is needed. The left side of the pattern shows that if we do not invest in design there will be high maintenance cost while on the right side of the pattern there are less maintenance costs but with unjustified design cost-very expensive equipment against its purpose.

2. Maintainability and Availability of the Mechanical Systems. Uptime and Downtime

The maintenance of a production equipment or device is executed in line with a time schedule, to provide functional at the designed parameters of the machine and to assure the production requirements. The maintenance schedule is planned according to the equipment manufacturer's recommendations. An equipment running as was designed ensures an optimal balance between failure cost and maintenance cost.

Restoring and maintaining production equipment requests both preventive and corrective actions. The fig. 3 introduces the position of the maintenance activity related to operation time frame. As can be easily seen, the preventive maintenance is performed prior to failure, with the aim of avoiding it and the corrective maintenance is applied after the failure occurrence. The classification of maintenance in fig. 3 is based on the EN 13306.

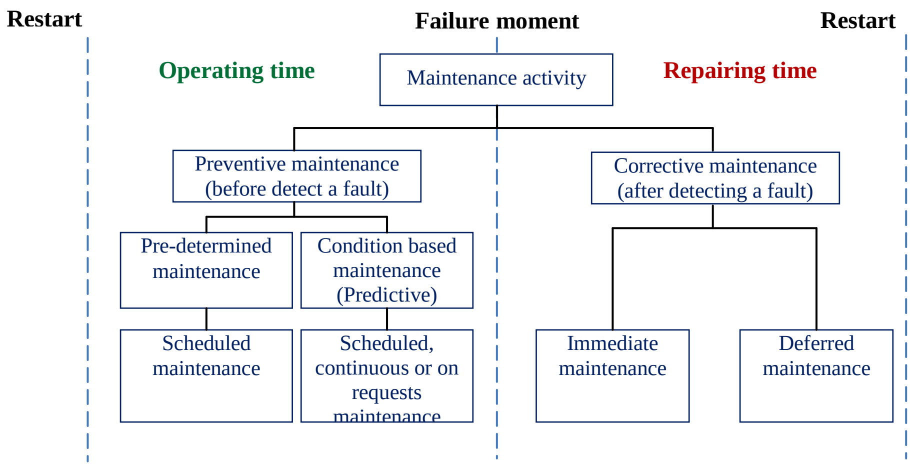

Fig. 3 Type of maintenance and appliance timing

The quantitative expression of the capability of a production equipment or a mechanical system or a system in general to be restored for functionality after a breakdown, it is performed by a time function probability called maintainability. According to EN 13306, Maintainability is „Ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources.” The probability that a failed item will be restored to operational effectiveness within a given period of time when the repair action is performed in accordance with the prescribed procedures. This, in turn, can be paraphrased as ‘The probability of repair in a given time’[8]. The best maintainability is eliminating the need for maintenance [9]. Ţîţu [10] and Burlacu [11] defined maintainability through function of repairing of an equipment, expressing the probability of completing the repair of a system in a defined time frame (0, t_r) by the below equation:

$$M(t_r) = Prob(t_r \leq T_r) \quad (1)$$

where, t_r is the time of restore and T_r a requested limit of restore time frame.

To understand with the concept of the availability of an equipment, it is necessary to define the concepts of uptime and downtime. The uptime is a time period when an equipment is functional or in the state of operating. The downtime is a time period during the normal working period when a production equipment is stopped for reasons of failure, see fig. 4.

Availability [12] deals with the duration of up-time for operations and is a measure of how often the system is alive and well. It is often expressed as (up-time)/(up-time + downtime) with many different variants. Up-time and downtime refer to dichotomized conditions. Up-time refers to a capability to perform the task and downtime refers to not being able to perform the task, i.e., uptime= not downtime.

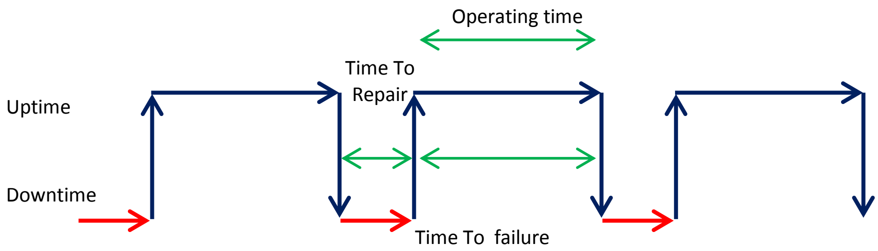

Fig. 4 Uptime and downtime

The performance of an equipment is monthly and yearly monitored, when it is likely to have multiple failure and restart of the operations. The uptime periods are counted by the indicator Mean Time Between Failure (MTBF), while the failure one by Mean Time To Repair (MTTR) or Mean Time to Failure (MTTF).

MTTR expresses a measure of the maintenance performance and represents the average time to repair in the monitored time frame. MTBF represents the average time between two consecutive failures. The MTBF indicator is used for repairable equipments or machines or other systems. MTTF is an indicator applied for non-repairable components (mainly in electronics) and represents the time to first failure. The average is considered for identical components running in the same conditions. The two indicators determine the Availability.

Availability (A) was introduced as a useful parameter which describes the amount of available time. It is determined by both the reliability and the maintainability of the item. It is defined as the ability of a system or equipment to achieve its function taking into account the combined aspect of Reliability, Maintainability and Maintenance activity at a certain moment or during a time frame.

$$A(t) = Prob(t_r > T_r) \qquad (2)$$

and after calculation, the availability expression is:

$$A = \frac{Uptime}{Total\ time} = \frac{Uptime}{Uptime + Downtime} = \frac{MTBF}{MTBF + MTTR} \qquad (3)$$

Maintainability also contributes to the availability of a system, since it is the combination of failure rate and repair/down time which determines unavailability.

3. Costs of maintenance. Definitions and structure

Dhillon defined the cost of maintenance as costs that include lost opportunities in uptime, rate, yield, and quality due to non-operating or unsatisfactorily operating

equipment in addition to costs involved with equipment-related degradation of the safety of people, property, and the environment or simply described as the labour and materials expense needed to maintain equipment/items in satisfactory operational state. In other papers, Niebel and Cavalier [13] and [14] stated that the costs associated with maintenance have been classified into four areas: direct costs, lost production costs, degradation costs, and standby costs. Direct costs represents the costs of maintaining the machine or equipment operable and include costs of periodic inspection and preventive maintenance, repair cost, and outsourced maintenance related cost. Lost production costs represent the costs of loss of production due to primary equipment breakdown and unavailability of standby equipment. Degradation costs are associated with deterioration in the equipment life due to unsatisfactory/inferior maintenance. Standby costs are associated with operating and maintaining standby equipment. Standby equipment is used when primary facilities are either under maintenance or inoperable.
Based on the above definition, the following mathematical formulas for the maintenance cost were developed:

$$C_m = C_d + C_{lp} + C_d + C_{sb}, \quad (4)$$

where, C_m- cost of maintenance, C_{dc},- direct costs, C_{lp} – cost of lost production, C_{dg} – degradation cost, C_{sb} – stand-by cost.

All these costs are collected by the Controlling of every company and analyzed with the aim of mitigating the expenses and maximising the profit.

4. The Impact of the Availability in Calculating Maintenance Cost. Case Study - Calculation Matrix on the Production Equipment

When looking at the theoretical aspects of the production machines or equipment, we can see a link between Availability, as indicator, and cost of maintenance. To be more specific, the Availability directly contributes to the cost of maintenance performance.
To understand the connection between Availability and the cost of maintenance, we shall consider a case study based on a production machine running in a stamping shop in a company working in the automotive industry. The machine runs five days per week in three shifts if there is no unexpected breakdown. Therefore the scheduled Operation time will be 7 hours and 40 minutes per shift or 22 working hours per shift. The number of the maintenance operators is of 20 in an unequal shift distribution. Details of the case study:

- stamping press, originated in France, BRET 320T with the characteristics presented in the table below
- number of shifts: 3
- working time per shift: 7h and 20 min

- total breaks: 40 min
- number of working days per month: pending on the monthly days
- number of people in the maintenance team: 20
- time scheduled for preventive maintenance: see table below

- **Table 1.** Press BRET 320T Technical Characteristics

Press type	BRET 320T		
Manufacturing year	1973	Eclairage zone travail	oui
Force	320T	Ecran mobil	Avant et arrière
Force/PMB	320T at 9mm	Cellule protection	non
Tool dimension max (mm)	1700x1200	Poids	50 tT
Distance between beams	700	Armoire électrique climatisée	non
Speed	35at100cp /min	Puissance consommée	110kW
Manufacturing press mode	Mecano-welded	Hauteur de défilement	300+ /- 50
Number of stations mobile	2	Press length	
Displacement	150	Alimentare	Dimeco
Adjusting displacement	150	Latime	610
Suprasarcina	Hydraulique	Grosime material de lucru	0.5 à 4.5 mm

The collection of the data took one year and these are related to the unexpected breakdown. Based on past experience, for the current case study, the total breakdown time is: detection of the failure, alert the maintenance team, repairing and re-set the parameters and the machine.

The data is composed of the defect date, description of the defect, shift, total time of failure, monthly number of failure and the system affected by the failure: mechanical system, hydraulic system, mechanical-hydraulic system, pneumatic system, and electrical system. The machine was considered as well composed of: the machine itself and the feeder with metal sheet. The operations performed on the machine are stamping using a progressive stamping tool with tree operations and using manual transfer executed by three operators. Blanking operations, bending and punching are executed. A matrix was designed that will calculate, monthly and yearly, the performance of the following maintenance parameters: MTBF, MTTR, Failure rate (λ), Repairing rate (μ). The matrix is presented in the table below.

Fig. 5 Stamping press BRET 320T

It already contains the parameters for the machine and is referred only to few month due to space available.

The input data for cost of maintenance analyze is: number of people in the maintenance department, hourly labour cost, total labour executed per month, machine hourly rate and for the stand-by machine the rate of capacity non-utilize. Based on the input, it was created a similar matrix. Need to be added to the total maintenance cost, the value of the stock of components for maintenance of the press 15,000.0 EURO/year.

Table 2. Calculation matrix of maintenance parameters

Month/Defect	January	February	March	April	May	June	July	August	September	October	November	December
Monthly working days	15	21	23	20	22	22	21	5	22	21	22	17
Monthly operating time (hours)	336	470.4	515.2	448	492.8	492.8	470.4	112	492.8	470.4	492.8	380.8
Preventive maintenance scheduled time (hours)	24	0	0	72	0	0	24	0	24	0	0	24
Effective operating time (hours)	312	470.4	515.2	376	492.8	492.8	446.4	112	468.8	470.4	492.8	356.8
Monthly effective planned time - w/o preventive maintenance (hours)	271.8	451.8	469	363.4	477.8	465.8	409.2	95.2	452	424.8	470.6	323.8
Monthly unexpected breakdown (min)	2412	1116	2772	756	900	1620	2232	1008	1008	2736	1332	1980
Monthly unexpected breakdown (hours)	40.2	18.6	46.2	12.6	15	27	37.2	16.8	16.8	45.6	22.2	33
Monthly unexpected breakdown (days)	1.8	0.8	2.1	0.6	0.7	1.2	1.7	0.8	0.8	2.0	1.0	1.5
Rate of monthly unexpected breakdown to monthly operating days (%)	12.0%	4.0%	9.0%	2.8%	3.0%	5.5%	7.9%	15.0%	3.4%	9.7%	4.5%	8.7%
Rate of monthly unexpected breakdown to effective operating time (%)	14.8%	4.1%	9.9%	3.5%	3.1%	5.8%	9.1%	17.6%	3.7%	10.7%	4.7%	10.2%
Number of monthly breakdown	20	12	24	13	8	17	17	9	14	24	16	18
MTBF	**13.6**	**37.7**	**19.5**	**28.0**	**59.7**	**27.4**	**24.1**	**10.6**	**32.3**	**17.7**	**29.4**	**18.0**
MTTR	**2.0**	**1.6**	**1.9**	**1.0**	**1.9**	**1.6**	**2.2**	**1.9**	**1.2**	**1.9**	**1.4**	**1.8**
Failure rate - λ=1/MTBF	**0.074**	**0.027**	**0.051**	**0.036**	**0.017**	**0.036**	**0.042**	**0.095**	**0.031**	**0.056**	**0.034**	**0.056**
Repairing rate - μ=1/MTTR	**0.498**	**0.645**	**0.519**	**1.032**	**0.533**	**0.630**	**0.457**	**0.536**	**0.833**	**0.526**	**0.721**	**0.545**
Operational Availability of the machine - A=MTBF/(MTBF+MTTR)	**0.871**	**0.960**	**0.910**	**0.966**	**0.970**	**0.945**	**0.917**	**0.850**	**0.964**	**0.903**	**0.955**	**0.908**
Operational Unavailability of the machine- U=MTTR/(MTBF+MTTR)	**0.129**	**0.040**	**0.090**	**0.034**	**0.030**	**0.055**	**0.083**	**0.150**	**0.036**	**0.097**	**0.045**	**0.092**

In fig. 6 it is shown the primary result of the calculation of MTBF, MTTR and in fig 7, the Availability (A) and Unavailability (U) during one year as stated above.

Logically, A abd U make together 100%. There is a significant variation of A and U and if is not considered August, which is the plant's shut down period, Availability varies between 87% and 98% and U between 3% and 15%.

The Unavailability impact will be reflected below in the calculation of the total cost of maintenance and becomes the main responsible for the poor performance of the maintenance cost.arewe shacnit .

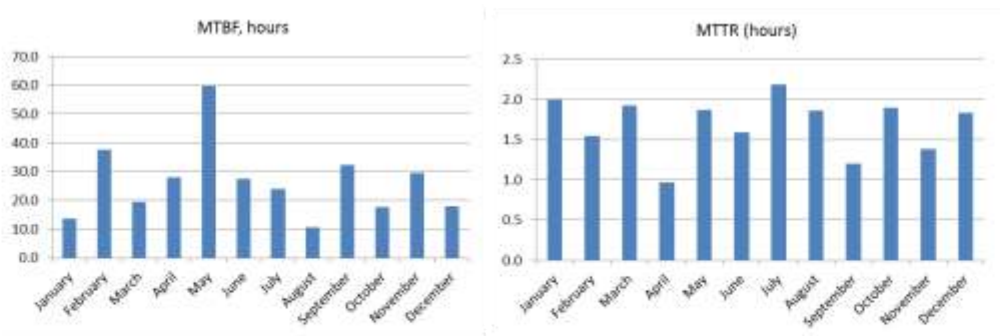

Fig. 6. Calculation of the maintenance indicators: a. MTBF; b. MMTR

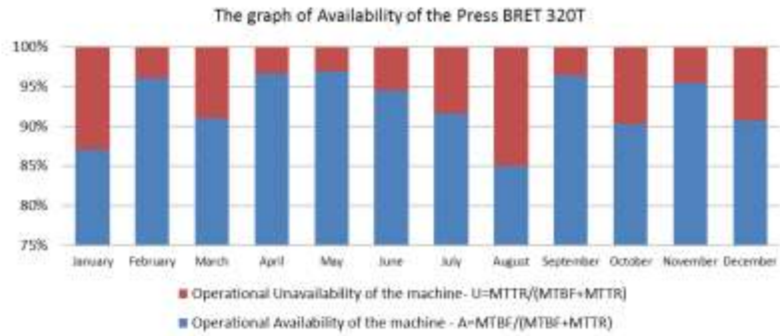

Fig. 7. Calculation of the Availability (blue) and Unavailability (red)

Table 3. Calculation matrix of cost of maintenance

Month/Costs	January	February	March	April	May	June	July	August	September	October	November	December	Year to date (YTD)
Monthly working days	15	21	23	20	22	22	21	5	22	21	22	17	
Monthly operating time (hours)	336	470.4	515.2	448	492.8	492.8	470.4	112	492.8	470.4	492.8	380.8	
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Rate of monthly unexpected breakdown to monthly operating days (%)	12.0%	4.0%	9.0%	2.8%	3.0%	5.5%	7.9%	15.0%	3.4%	9.7%	4.5%	8.7%	
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Number of monthly breakdown	20	12	24	13	8	17	17	9	14	24	16	18	
Number of people in the maintenance department	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**
Maintenance labour cost (EUR/hour)	**4.5**	**4.5**	**4.5**	**4.5**	**4.5**	**4.5**	**4.5**	**4.5**	**4.5**	**4.5**	**4.5**	**4.5**	**4.5**
Total labor hour in Maintenance department (hours)	**2400**	**3360**	**3680**	**3200**	**3520**	**3520**	**3360**	**800**	**3520**	**3360**	**3520**	**2720**	
Percentage from total labor hours alocated for press machines (hours)	**1800**	**2520**	**2760**	**2400**	**2640**	**2640**	**2520**	**600**	**2640**	**2520**	**2640**	**2040**	
Alocated labor hours for BRET 320T press 20 (hours)	**51**	**72**	**79**	**69**	**75**	**75**	**72**	**17**	**75**	**72**	**75**	**58**	
Cost total manopera de mentenanta (EUR/lu	**231**	**324**	**355**	**309**	**339**	**339**	**324**	**77**	**339**	**324**	**339**	**262**	**3564**
Press machine hourly rate (EUR)	**40**	**40**	**40**	**40**	**40**	**40**	**40**	**40**	**40**	**40**	**40**	**40**	**50**
Monthly cost of machine stoppage (EUR)	**1608**	**744**	**1848**	**504**	**600**	**1080**	**1488**	**672**	**672**	**1824**	**888**	**1320**	**13248**
Monthly cost for stand-by press (EUR)	**624**	**940.8**	**1030.4**	**752**	**985.6**	**985.6**	**892.8**	**224**	**937.6**	**940.8**	**985.6**	**713.6**	**10012.8**
Monthly total cost of maintenace (EUR)	**2463**	**2009**	**3233**	**1565**	**1925**	**2405**	**2705**	**973**	**1949**	**3089**	**2213**	**2296**	**26824.8**

It is obviously the impact the Availability of the machine has it in the total cost of maintenance for this machine. It goes to almost 27,000.0 EURO and need to be added another 15,000.0 EURO blocked in the spare parts stock.

5. Conclusions

The paper presented a process flow to determine the availability of an equipment and then to calculate its impact on the cost maintenance. It can be observed from the value in Table 2 that the missing availability is the main responsible for the cost of maintenance. Therefore it can be concluded that the availability is the main driver for the cost of maintenance.

If it is desirable to keep under control the cost of maintenance, the plant management, especially the maintenance management team must act to maximize the availability. At the same time, the companies' management has to balance the cost of preventive maintenance, cost of corrective maintenance and the lost production cost and to find the optimum of these expenses.

The team can use the Continuous Improvement and TPM techniques to maximize the availability by autonomous maintenance and innovation processes.

Regarding the maintenance indicators analyzed in the paper, MTBF and MTTR, the monthly variation of the MTBF, in this case, is not predictable. The variation from month to month is high and the root cause identification is part of maintenance team activity. The analyze team can use standard tools for analyze, Ishikawa diagram, 5 Why, histogram, statistical process tools to identify the errors in the processes and to set-up corrective actions and action plans as well. The same for MTTR with the mention that MTTR is more stable, between 1.5 to 2 hours. As long as the maintenance is executed properly and the unplanned breakdown are mitigate or reduced at minimum the value of inventory can be planned to avoid blocking cash as well.

As a conclusion, the maintenance is not a "necessary evil" but a mandatory act for the company's own benefit. Avoiding good practices could lead to high costs but respecting it will reduce the cost and release the cash for another important activity of the company.

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