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DEVELOPMENT OF A MAINTENANCE POLICY FOR A PRODUCTION LINE AT THE HAMMA BOUZIANE CEMENT FACTORY, ALGERIA

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РОЗРОБКА ПОЛІТИКИ ТЕХНІЧНОГО ОБСЛУГОВУВАННЯ ВИРОБНИЧОЇ ЛІНІЇ НА ЦЕМЕНТНОМУ ЗАВОДІ HAMMA BOUZIANE, АЛЖИР

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The object of research is the process of the maintenance used in the HAMMA BOUZIENE cement factory (Algeria), where an attempt was made to devolope a new maintenance policy based on preventive maintenance instead of corrective maintenance. The maintenance of industrial systems has become an essential element for companies seeking to conquer an increasing number of markets.

In this study, we focus on examining the necessary maintenance policy for the production line of the HAMMA BOUZIENE cement plant. The policy used in the HAMMA BOUZIENE cement plant is corrective maintenance which costs 3.9 million euros in year, and creates approximately 5 months of downtime at grinding workshop level. This article describes the evaluation of Reliability, Availaility and Mainenability of various subsystems within the production line. Our system is divided into five subsystems (kk1 grinding mill, kk2 grinding mill, raw mill 1, raw mill 2 and cement kiln). It was proposed a systematic preventive maintenance which reduces the costs of corrective maintenance. to determine the most problematic subsystem, we used Pareto and FMECA methods, The calculation of the reliability of the most critical system was done using the Weibull distribution.

The results of this evaluation showed that the subsystem with a very high failure rate was kk1 grinding mill (with an excessively long downtime…). To reduce this failure rate and increase the reliability and availability of the grinding mill, we conducted an RAM study. The analysis results indicated that the mill's reliability reaches 80% if systematic maintenance is performed every 23 hours. when we use this maintenance policy, the avalabilitty will increase from 87% to 95%.

This work contributes to reducing maintenance costs for the Hamma Bouziane cement company by following the maintenance policy proposed in this research.

Keywords: *reliability, cement factory, grinding mill, maintainability, availability, Pareto method, FMECA methods.*

Об'єктом дослідження є процес технічного обслуговування, що застосовується на цементному заводі HAMMA BOUZIENE (Алжир), де було зроблено спробу розробити нову політику технічного обслуговування, засновану на профілактичному обслуговуванні замість коригувального. Технічне обслуговування промислових систем стало важливим елементом для *компаній, які прагнуть завоювати все більше ринків.*

Це дослідження зосереджено на вивченні необхідної політики технічного обслуговування виробничої лінії цементного заводу HAMMA BOUZIENE. Політика, що застосовується на цементному заводі HAMMA BOUZIENE, полягає у коригувальному технічному обслуговуванні, яке коштує 3,9 мільйона євро на рік і створює приблизно 5 місяців простою на рівні цеху подрібнення. У цій роботі описано оцінку надійності, доступності та ремонтопридатності різних підсистем виробничої лінії. Запропонована система поділена на п'ять підсистем (подрібнювальний млин kk1, подрібнювальний млин kk2, млин для сировини 1, млин для сировини 2 та цементна піч). Було запропоновано систематичне профілактичне технічне обслуговування, яке зменшує витрати на корекційне технічне обслуговування. Для визначення найбільш проблемної підсистеми використано методи Парето та FMECA. Розрахунок надійності найбільш критичної системи було проведено за допомогою розподілу Вейбулла.

Результати цієї оцінки показали, що підсистемою з дуже високим рівнем відмов була шліфувальна машина kk1 (з надмірно тривалим часом простою…). Щоб зменшити цей рівень відмов і підвищити надійність та доступність шліфувального млина, проведено дослідження RAM. Результати аналізу показали, що надійність млина досягає 80%, якщо систематичне технічне обслуговування проводиться кожні 23 години. При застосуванні цієї політики технічного обслуговування доступність збільшиться з 87% до 95%.

Ця робота сприяє зниженню витрат на технічне обслуговування цементної компанії HAMMA BOUZIANE завдяки дотриманню політики технічного обслуговування, запропонованої в цьому дослідженні.

Ключові слова: *надійність, цементний завод, млин, ремонтопридатність, експлуатаційна готовність, метод Парето, методи FMECA.*

1. Introduction

The efficiency of maintenance of industrial systems constitutes a major economic issue for commercial operations. The main difficulties and sources of inefficiency lie in the timely choice of maintenance measures to be taken, especially when the machine plays a vital role in the production process (the condition of our system). These shortcomings can have serious consequences. Therefore, in order to avoid unplanned production shutdowns and the major economic repercussions that result, it is necessary to constantly monitor this equipment and detect any warning signs of defects before it is too late.

Preventive maintenance is the solution that has been integrated into management systems and has proven itself. It helps reduce downtime, reduce maintenance costs and production downtime, and improve resources, production and profitability in the case of the cement industry. Effective condition monitoring requires accurate and reliable measurements. Furthermore, since the equipment used in cement plants is typically large and needs to be available and ready for use at all times, presenting a high level of reliability and availability, there must be a well-defined maintenance plan. A new Reliability Centered Maintenance Method (RCM) was proposed, which was used in the field of electricity transmission (high voltage), this method is based on the optimization of maintenance by analyzing failure modes, and the main recommendation is the reintegration of this maintenance strategy, particularly through the optimal and rational implementation of the RCM approach. This work has demonstrated the feasibility of optimizing maintenance using this method in electrical grids. The main recommendation is the reintegration of this maintenance strategy, particularly through the optimal and rational implementation of the RCM approach. His work has demonstrated the feasibility of optimizing maintenance using this method in electrical grids [1]. A new method for planning stocks of electrical capacitors linked in series with each other and which are applied to power lines. Which take into consideration the fundamental principles of reliability analysis; it has been applied to the planning and design of series capacitor (SC) banks, applied to power lines. It takes into account the cost of power outages, the decision process for new and existing electrical equipment in multiple systems, It was realizing as a study case, with successfully improve in the network reliability and it reduces the operation cost of the grid [2]. A new approach to evaluate maintenance strategies in the oil industry by comparing the new RAMS results with the old ones, the results of the RCM study applied on reciprocating compressor API 618 showed that the preventive maintenance proposed tasks and planning are generated [3]. A study examines a system configured in parallel with components connected in series, called a series-parallel system. Decision-makers seek to estimate the reliability of the subsystems as well as the number of connections required between the components to guarantee the performance and reliability of the overall system. To address this issue, we propose two methods for estimating the reliability function, based on the maximum likelihood estimator (MLE) and the unbiased uniform minimum variance estimator (UMVUE). These methods are applied to the reliability estimation of the components and the system for different lifetime distributions, in order to illustrate, through simulation, the estimation procedure using MLE and UMVUE [4]. The authors classified the study of reliability into three categories: problem type, configuration and optimization techniques, while the last two are active research problems in the design of sophisticated systems [5]. An analysis of the reliability of the material transport system of an earth pressure balance tunnel boring machine (EPBTBM) was conducted. For this purpose, data on failures and repairs of the main conveyor system of Line 2 of the Tabriz Metro in Iran were collected. The results of the analysis indicate that the reliability of conveyor subsystems 1, 2, and 3 reached zero after 267, 58, and 300 hours of operation, respectively, furthermore, the availability results showed that all subsystems were available for more than 89% of the time [6]. A very thorough study aimed at integrating RAMS aspects into the Murthy model demonstrated that this approach falls within the safety lifecycle of the IEC 61508 standard. This lifecycle covers the development of a Safety Instrumented System (SIS), including all phases from design to decommissioning. However, the model lacks detail regarding the product development stages [7]. The study of reliability, availability, maintainability and supportability (RAMS), whose role is to increase the work rate of industrial systems, The authors have tried to make it reasonably comprehensive, but those papers which are not included were either inadvertently overlooked or considered peripheral to this survey. In the present work the authors have only considered those articles which have included two or more aspects of RAMS [8]. A new method for calculating reliability based on the Markovian approach with the aim of determining the behavior of industrial systems in a more realistic and regular manner, the maintenance schedule can be prepared which might help the maintenance managers to improve the system effectiveness by adopting suitable preventive maintenance actions. FMEA analysis of the system can be carried out by listing all possible failure modes with reference to different sub-systems [9].

The object of this research is the process of the maintenance used in the HAMMA BOUZIENE cement factory, where an attempt was made to develop a new maintenance policy based on preventive maintenance instead of corrective maintenance.

The aim of the research is to evaluate the performance of the maintenance applied in the company, based on the fundamental concepts of Reliability, Maintainability and Availability (RAM), as well as modern analytical tools such as the Pareto and AMDEC methods.

To achieve the set aim, the following objectives were solved:

1) to apply the Pareto method to identify the most critical equipment failure modes;

2) to propose an effective maintenance policy aimed at reducing maintenance costs;

3) to determine the optimal period for systematic preventive maintenance to reduce downtime for plant equipment.

2. Materials and Methods

2.1. Reliability

2.1.1. Definition

Reliability is the probability that a primary part, device or complete piece of equipment will be used without failure for a specified period of time, under specified operational conditions [10]. In the system design phase it is very important to have the different anomalies recorded in previous versions, the aim of which is to improve the operating modes as well as the use and non-use of sub-systems, systems, including system, equipment, components, etc. [11]. The statistical analysis method is the most used method to quantify the reliability of repairable (MTBF) or non-repairable (MTTF) systems. The main causes of repairable system failure include poor design, vibration, incorrect use and corrosion, but in the case of non-repairable system failure, it is necessary to replace the part without repairing it. The probability distribution functions for the different subsystems are better determined, by the Weibull model. It is the most widespread law, and it is used in several fields (electronics, mechanics, etc.). It makes it possible to model in particular many situations of material wear.

It makes it possible to characterize the behavior of the system in the three phases of life, period of youth, period of useful life and period of wear or aging. In its most general form, the Weibull distribution depends on the following three parameters: β, γ and η [12]. The probability density of weibull distribution has the expression

$$f(t)=\frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1}\cdot e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}, \tag{1}$$

where β – shape parameter ($\beta > 0$); η – scale parameter ($\eta > 0$); γ – position parameter ($-\infty \le \gamma \le +\infty$).

The distribution function is written

$$F(t)=1-e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}. \tag{2}$$

The reliability function is written

$$R(t)=e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}. \tag{3}$$

The failure rate given by

$$\lambda(t)=\frac{f(t)}{R(t)}=\frac{\frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1}\cdot e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}}{e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}}=\frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1}. \tag{4}$$

2.1.2. Statistical analysis method

The main reason the IID assumption is important is that it allows the use of probability distributions to model subsystems. If the data is not IID and probability distributions are used for modeling, this can lead to erroneous results and conclusions in the analysis. The assumption that the data is independent means that the failures are not related to each other and that the parameters of the chosen distribution do not change over time. In contrast, the assumption that the data is identically distributed means that each data point follows the same distribution. Fig. 1 explains the different steps of the IID method.

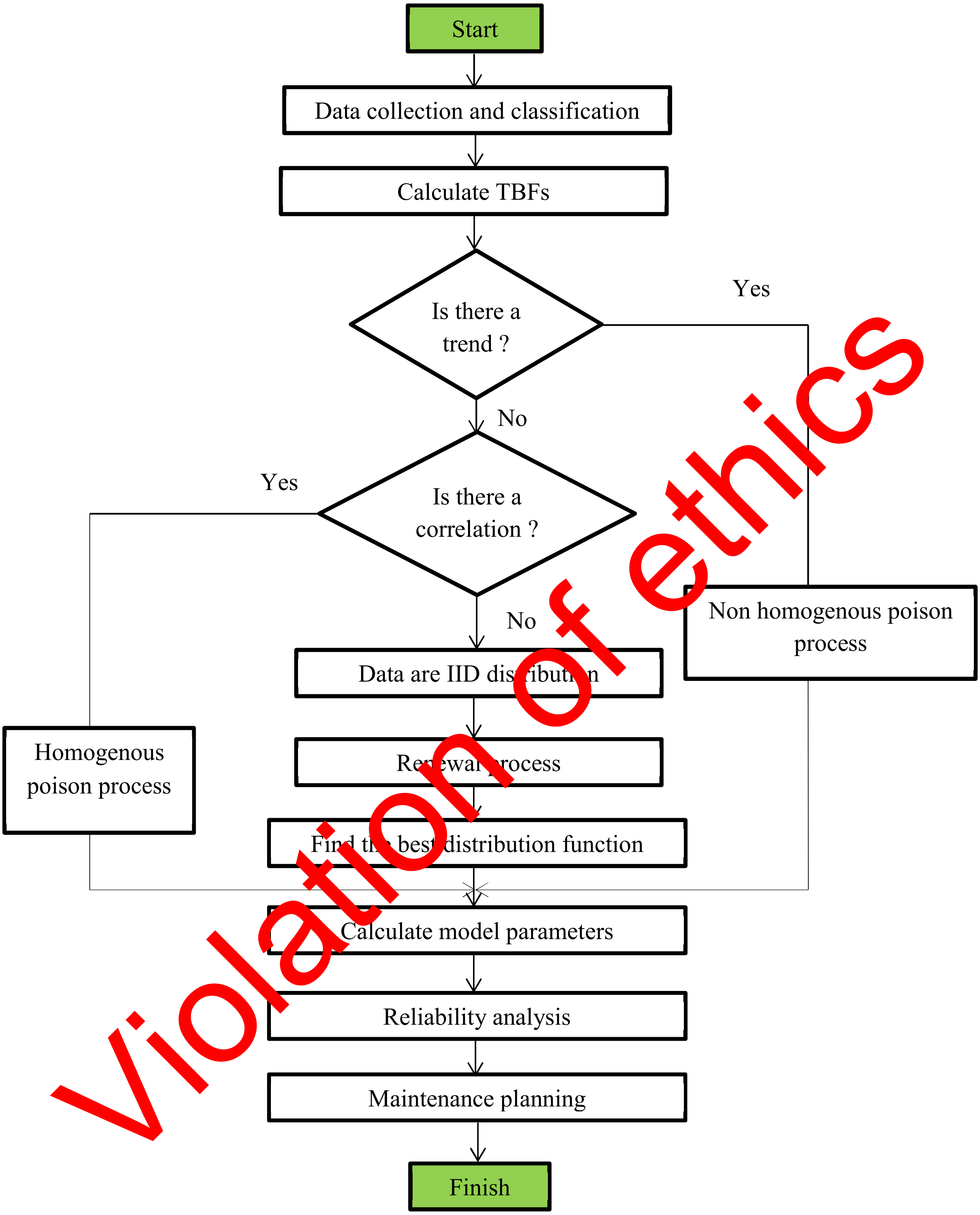

Fig. 1. Flowchart of statistical analysis method

It is important to emphasize that verifying the IID hypothesis is crucial to ensure accurate data analysis. If this assumption is not met, the analysis results can be biased, which can lead to inappropriate decisions regarding maintenance and reliability management of the systems.

2.1.3. Pareto analysis

The Pareto diagram is a graphical analysis tool used to highlight the main causes of occurrence of a phenomenon.

We usually say that 20% of the causes lead to 80% of the effects, while these percentages are only an order of magnitude; they illustrate the fact that, in most cases, a small number of causes lead to the majority of consequences. In the case of causes of failure, priority must be given to eliminating the 20% of causes which lead to 80% of failures.

This rule also applies to costs, because the 20% of maintenance costs will require 80% of financial costs, etc. This tool will make it possible to improve maintenance by targeting the most critical causes which will require greater attention in terms of monitoring and actions taken by the maintenance department.

To perform rigorous statistical and probabilistic analysis of data, it is crucial to select appropriate techniques by verifying the assumption that the data is independent and identically distributed (IID).

This hypothesis should be evaluated using statistical tests such as the trend and serial correlation test.

2.1.4. Trend testing

Trend testing is a commonly used method to assess whether a system is stable, improving, or deteriorating. This method involves plotting the cumulative TBF or TTR against the number of cumulative failures or repairs and determining the overall trend of the data. If the data trend is concave upward, this indicates that the system is improving, that is, the time between failures or repairs is increasing over time. If the trend is concave downward, this indicates that the system is deteriorating, that is, the time between failures or repairs is decreasing over time. However, if the trend is approximately linear, this means that the data is identically distributed; indicating that the system is stable and the time between failures or repairs remains relatively constant over time. Trend testing can be a useful method for assessing the condition of a system and deciding whether it needs to be overhauled or replaced based on its current state.

In 1981 the military school evaluated the trend using the method of calculating statistical indices based on the following equation

$$U = 2\sum_{i=1}^{n-1} \ln\left(\frac{T_n}{T_i}\right). \quad (5)$$

where i is the number of failures, T_n is the last failure time and T_i is the time of failure.

In this method, if i is greater than the critical number in the standard table, the null hypothesis is accepted. If this hypothesis is rejected, the data has a trend.

2.1.5. Serial correlation test

In the serial correlation test, the (i–1)-th TBF/TTR is plotted against the i-th

TBF/*TTR*. If the data points are scattered randomly without any clear pattern, this implies a data set exempt from serial correlation, implying that the data points in the data set are independent of each other. The objective of serial correlation tests is to verify the relationship between two variables; the scatterplots between the two variables (TBF_i and TBF_{i-1}) show the correlation between the two variables.

2.2. Availability

Availability is the probability that a piece of equipment/system is functioning satisfactorily at time when used according to specified conditions and in an ideal environment. Inherent *t* availability is the most common definition used in reliability literature [13]. The average availability of an item can be determined from the following equation

$$D(t) = \frac{\mu}{\lambda+\mu} + \frac{\lambda}{\lambda+\mu} e^{-(\lambda+\mu)t}, \tag{6}$$

where $\lambda = \frac{1}{MTBF}$ and $\mu = \frac{1}{MTTR}$.

2.3. Maintainability

Maintainability is a design parameter intended to reduce repair time, as opposed to maintenance, which is the act of repairing or servicing an item or equipment [14].

The probability of ending system repairs at a time less than *t* can be defined as follows

$$M(t) = \int m(t)dt. \tag{7}$$

2.4. Description of the studied element

The Hamma Bouziane cement factory has a large production line which is distinguished by different types of grinders, a large rotary kiln with a diameter of 5500mm, a cooler etc. Fig. 2 illustrates the different steps in the manufacturing of cement.

These latter elements work in series, when a subsystem fails, it causes a halt in production. It is for this reason that it is necessary to ensure the maintenance of these machines in order to guarantee them better availability.

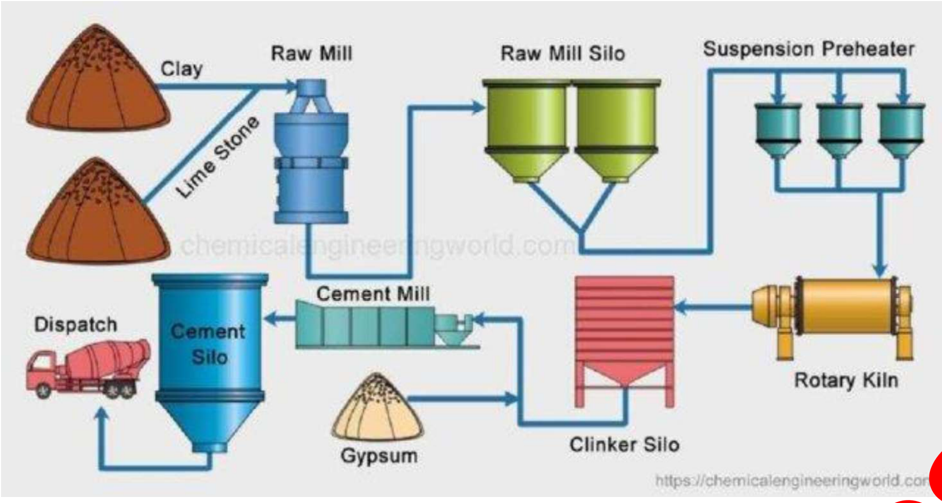

Fig. 2. General layout of the cement plant [15]

The division into one or more workshops is therefore unique to each company, depending on its activity. Consequently, there is no standard model. To illustrate how workshops can be defined and divided at the company level, the Hamma Bouziane cement plant offers the division presented in Fig. 3.

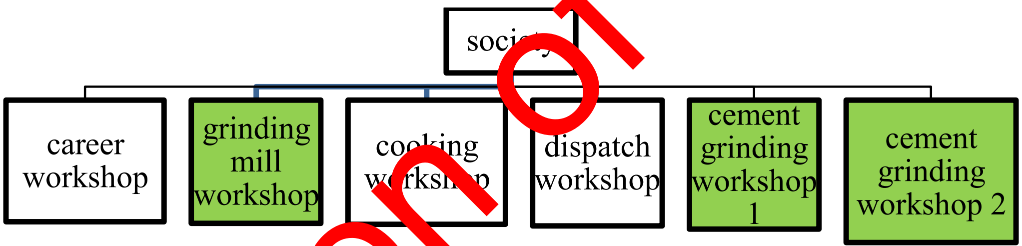

Fig. 3. Organisation of the cement plant company

The study will focus on only five subsystems, in order to determine their behavior over the years and to propose solutions for those which have proven to be more critical in the face of breakdowns.

3. Results and Discussion

3.1. Pareto Analysis

3.1.1. Analysis according to the downtime of the factory

System failure and repair data are found from different sources such as operation and maintenance information, daily maintenance reports and sensor data for reliability modeling have been used.

The implementation of a preventive maintenance policy requires the identification of critical workshops which must therefore be treated as a priority. Fig. 4 shows the different percentages of downtime for the Hamma Bouziene cement plant.

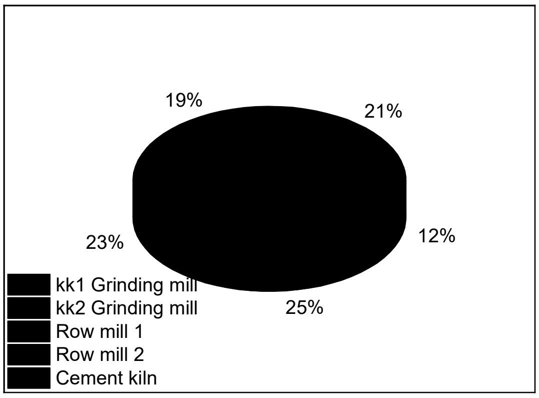

Fig. 4. Stop rate of the "SCHB" Cement planet workshops

The a posteriori analysis method which produces results from (historical) data is based on the Pareto chart which allows us to select critical equipment, it can be seen that the KK1 grinding mill has a rate of 25%.

3.1.2. Analysis according to the frequency of breakdowns

In this step, a classification of the subsystems according to the frequency of occurrence of breakdowns was carried out, thus making it possible to obtain an idea of the reliability of the equipment. To do this, a table is constructed in which we can see the (annual) frequency, its percentage and the cumulative percentage of the equipment frequency.

In our study the number of workshops analyzed is equal to five. We construct a table in which the workshops are classified in descending order of the number of failure and the intervention time are presented in Table 1.

Table 1

Rankings of the company's workshops

Workshop	Frequency	% percentage	% accrual
kk1 Grinding mill	814	26.61	26.6
kk2 Grinding mill	774	25.30	51.9
Raw mill 1	677	22.13	74.0
Raw mill 2	571	18.67	92.7
Cement kiln	223	7.29	100.0

The classification of critical subsystems based on the frequency of failures during the year 2021 is presented in Fig. 5 and provides an indication of the reliability of the equipment.

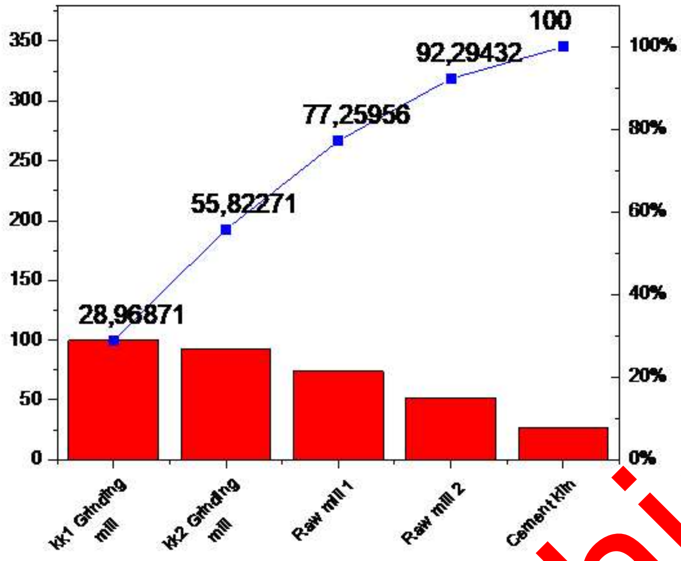

Fig. 5. Classification of equipment according to frequency of failures

Following the Pareto analysis of the subsystems, which was carried out based on the frequency of downtime, it was found that the equipment, kk1 Grinding mill, kk2 Grinding mill, and Raw mill 1; represent 80% of the recorded shutdowns during the study period. Therefore priority action must be taken to address the root causes that directly impact these machines in order to ensure better machine reliability.

3.1.3. Analysis according to the average failure time

The mean time between breakdowns is the ratio of the total breakdown time to the number of breakdowns. The calculation of the total breakdown time during the year 2021 is presented in Table 2.

Table 2

Classification of machines according to the total failure time

Workshop	Total time(h)	% percentage	% accrual
kk1 Grinding mill	4983.82	25.09	25.09
kk2 Grinding mill	4601.3	23.17	48.26
Raw mill 1	4149.8	20.89	69.15
Raw mill 2	3673.64	18.49	87.64
Cement kiln	2454.54	12.36	100

The resulting classification of machines, in relation to production is presented in Fig. 6.

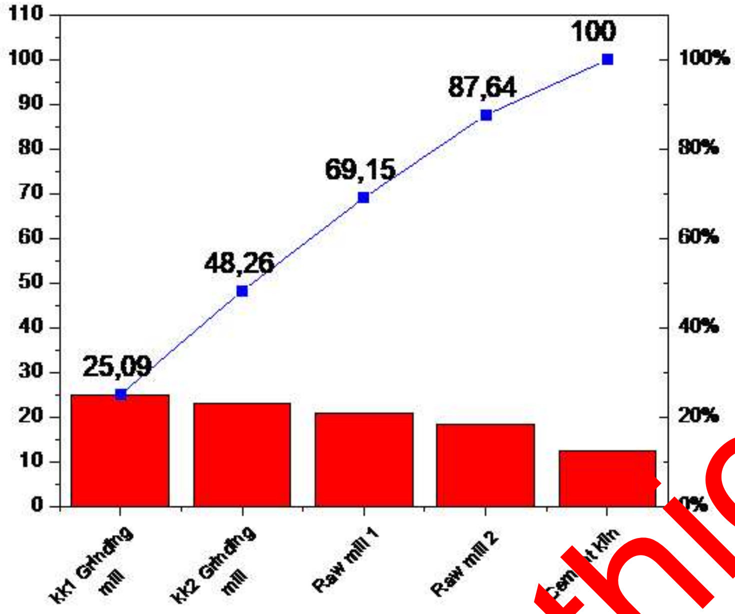

Fig. 6. Classification of machines according to the total breakdowns time

The results show that the most detrimental (or critical) are the kk1 Grinding mill, kk2 Grinding mill, and Raw mill 1.

3.1.4. Analysis of unavailability time (TI)

Fig. 7 illustrates the results of the preceding Pareto analysis, which revealed that three out of the five machines studied accounted for 71.02% of the total repair time. Action can be taken on these three pieces of equipment to significantly improve overall machine maintainability.

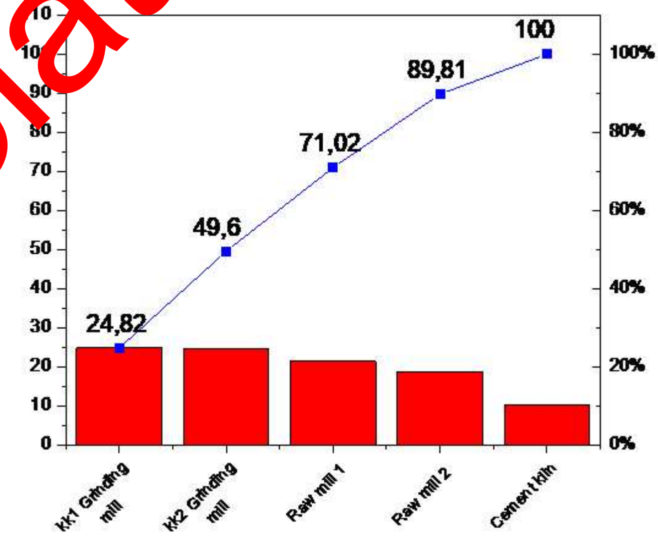

Fig. 7. Classification of mechines according to the unavailibility time

The Pareto diagram above established according to the "unavailability time" criterion highlights that the three first machines classified in order of importance. The results show that the kk1 Grinding mill contains most of the breakdowns recorded in the maintenance department.

3.1.5 kk1 grinding mill analysis

The division of the company will be followed by a second who allows us to go down to the level of critical equipment. Fig. 8 shows the layout of the kk1 Grinding mill workshop.

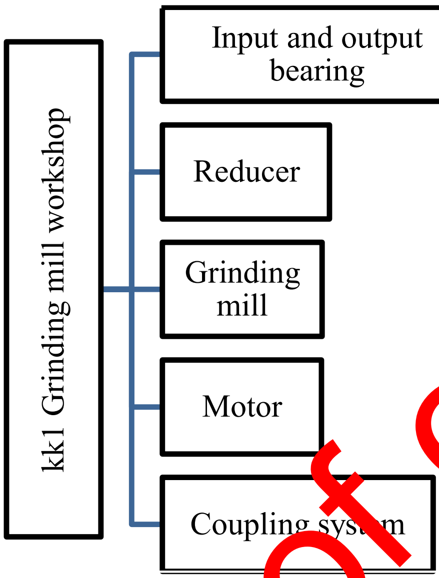

Fig. 8. Division of kk1 grinding mill workshop

To determine the main reasons for failures in the most penalizing subsystem (grinding mill workshop), the Pareto diagram for each element were plotted according to the number of failures and breakdowns illustrated in the Figs. 9 and 10. According to these values, the input/output bearing is the faultiest element in the kk1 grinding mill workshop with 370 failures.

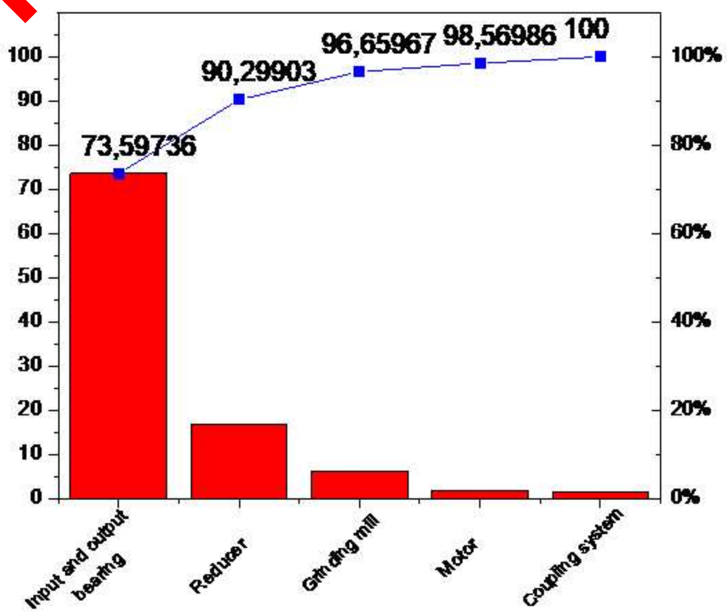

Fig. 9. Classification of subsystems according to average failure time

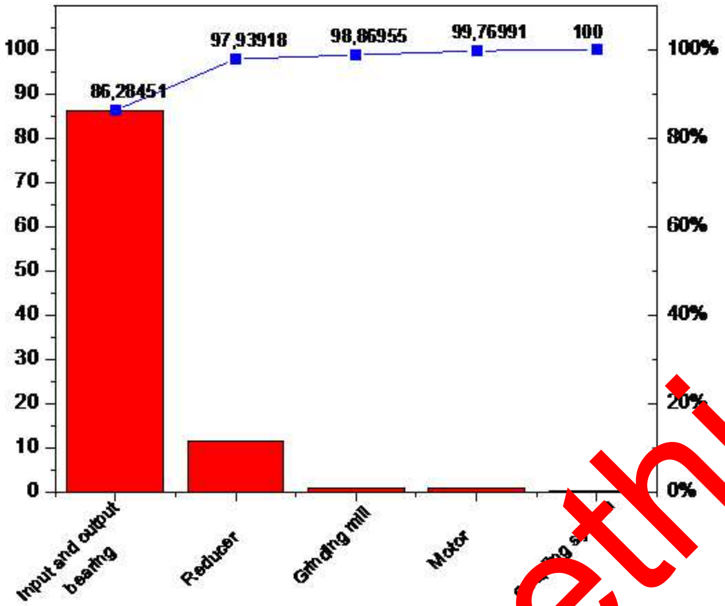

Fig. 10. Classification of subsystems according to the frequency of failures

The top priority for improving system reliability must be the "Input/Output bearing" subsystem. Any maintenance action, design improvement, or investment in spare parts must focus on this component, as efforts focused on other components (Motor, Coupling, Grinding mill) will have a negligible impact on overall failure reduction.

3.2. Maintenance policy according to the FMEA method

Table 3 presents the application of the FMEA method for the kk1 Grinding mill workshop. The various pieces of information (failure modes, possible causes and effects, etc.) presented in the following FMEA tables were collected through real-time observations of the system and through discussions with operators and maintenance engineers on site.

Table 3

Analysis according to the FMEA method

Organs	Status function	Failure mode	Cause	Effect on the System	Detection	Criticality				Action of maintenance
						Fr	Gr	Dé	C	
Grinding mill	Grinding of materials	Fracture of the armor plate. Lack of fixation. Cracking body	Foreign body at the front of the system. Bad tightening	Bad function	Control	1	3	4	12	Change. Welding. Tightening
Input	Greasing	Heating	Lack of	Grinding	Control	4	2	2	16	Change

bearing		friction	oil. Pump broken	mill body. Cushion and Valves						
Output bearing	Greasing	Heating friction	Lack of oil. Pump broken	Grinding mill body. Cushion and Valves	Control	4	2	2	16	Change
Reducer	Adjust speed and power	Change the bearing and gears	Wear. Alignment	Reducer shutdown	Control	1	4	3	12	Repair
		Electrical control	Reducer broken	Reducer shutdown	Visual	3	1	1	3	Change Tightening.
Motor	Motion generator	Change the brush. Cabling. Cushion heating	Carbon brush Wear. Cable tears. Oil lacking	System shutdown	Control	2	1	3	6	Connection. Change
Coupling system	Motion transmission	Gear tooth breakage	Grease lacking	System shutdown	Visual	1	4	3	12	Repair

According to the FMEA study, the input and output bearings are the most critical components, with a criticality of 16.

3.3 Period of systematic preventive maintenance

3.3.1. RAM analysis

The trend test in this study was conducted using analytical and graphical methods on the cumulative TBFs and TTRs data. The analytical methods of Military and the Laplace were used to perform the trend test. A graphical method was also used to detect the trend in the data. After performing all three trend tests on the data, the decision was made about the existence or absence of trend. The Figs. 11 and 12 respectively shows the graphical test for TBFs and TTRs data of kk1 crasher, from these figures, the decision on whether or not the trend is present in the data was made. So the TBFs and TTRs for kk1 Grinding mill not trend.

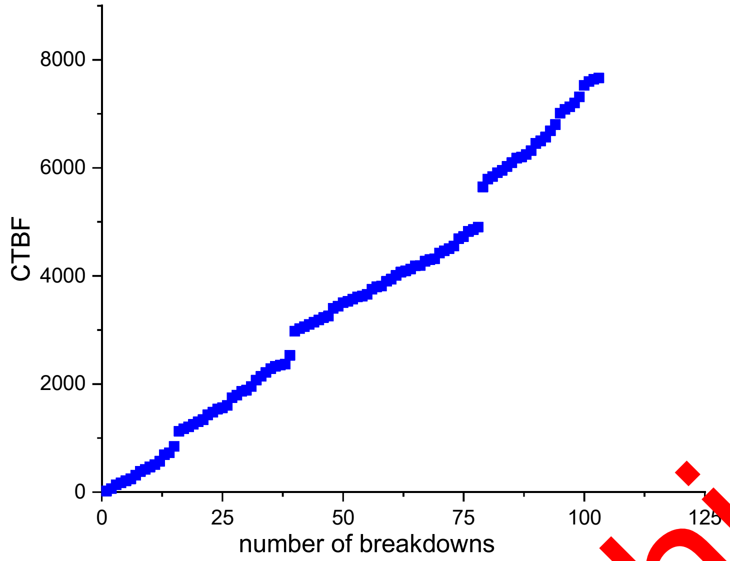

Fig. 11. Trend test for TBF.

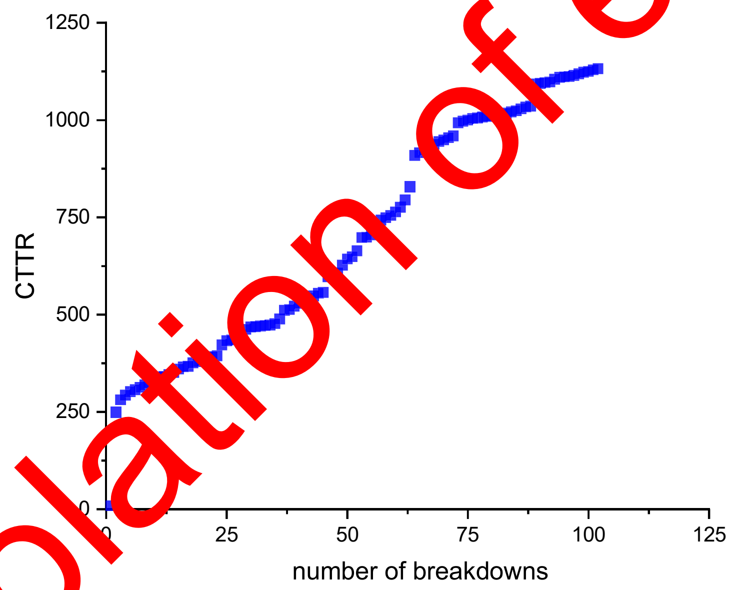

Fig. 12. Trend test for TTR

Figs 13 and 14 present the Time between Failures (*TBF*) and Time to Repair (*TTR*) data from the plant's correlation tests, respectively. The scatter plot between the two variables (TBF_i and TBF_{i-1}) shows that the data are widely dispersed. This observation indicates that there is no correlation between the data from two consecutive failures. This validates the assumptions of IID of *TBF* and *TTR*.

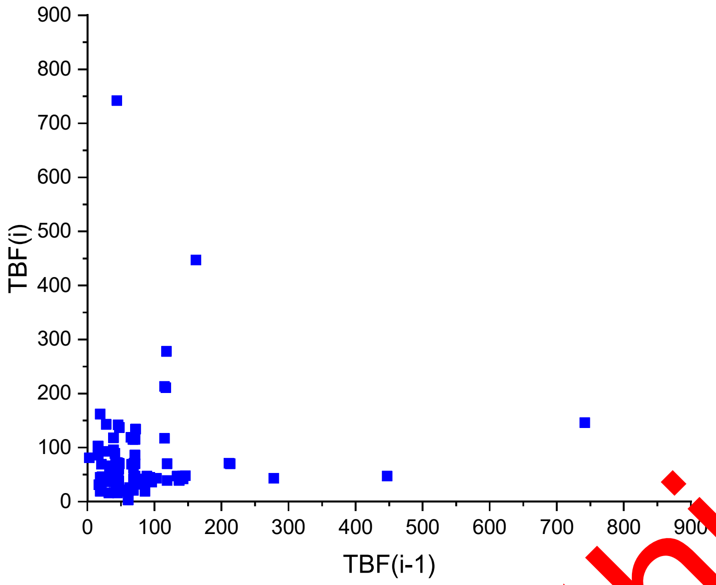

Fig. 13. Correlation test for TBF

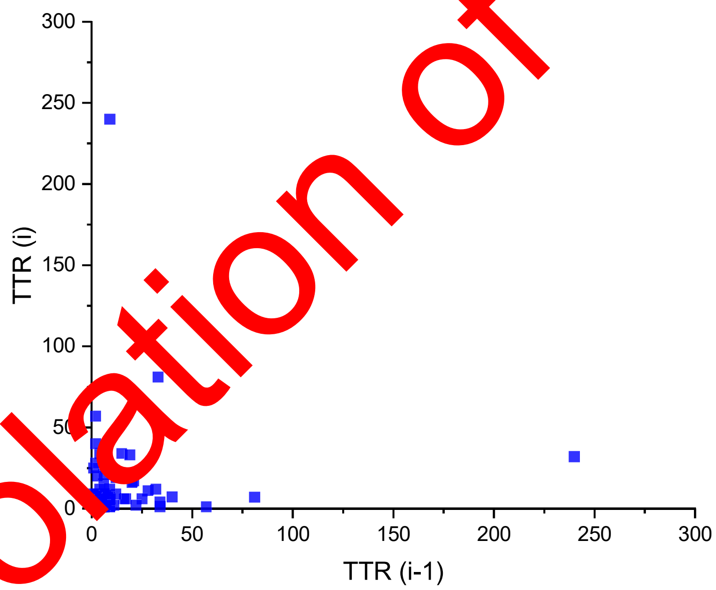

Fig. 14. Correlation test for TTR

3.3.2. Reliability analysis

Subsequent to data analysis, best distribution functions of the TBFs and TTRs data were selected by goodness of fit tests. In the case of existence trend in the data, the non-homogeneous Poisson process and PLP was used. On the other hand, in the absence of trend in the data, the renewal process was used to select the best distribution function. In the case of renewal process, the classic method was used to fit the data.

Based on the obtained results, the reliability functions for kk1 Grinding mill for TBFs data are as follow

$$R(t) = e^{-\left(\frac{t}{79.76}\right)^{1.18}}. \quad (8)$$

The reliability of kk1 Grinding mill was determined by the best probabilistic distribution function. The reliability of each sub-system for TBFs data was calculated individually and its reliability charts was plotted. The reliability diagrams are shown in Fig. 15; we note that the diagrams of (R_{est} and R_{th}) are very close to each other with minimal error.

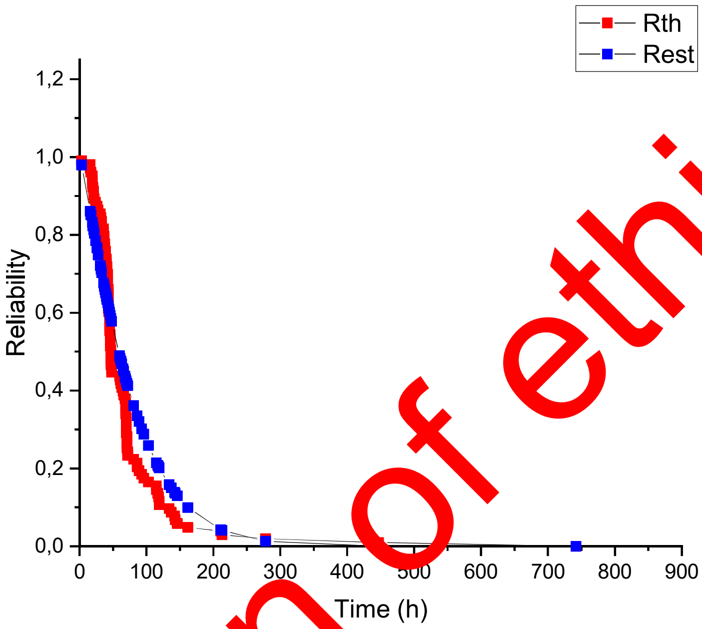

Fig. 15. Estimated and theoretical reliability curves of the kk1 Grinding mill

This allowed us to validate our diagnostic and expert work on the faultiest element in order to optimize maintenance on this machine.

To improve the reliability of the system and with the aim of minimizing maintenance costs, we tried to estimate the systematic period of maintenance to achieve higher reliability, preventive maintenance is required for the system. Table 4 shows the maintenance period required for different reliability values.

Table 4

Reliability intervals for the system

Reliability (R)	Time (t)
90%	12 h
80%	23 h
70%	34 h
60%	46 h
57%	48 h

3.3.3 Maintainability

Using this distribution function, the maintainability of kk1 grinding mill subsystems was determined by equation (7) and their associated graphs are plotted in Fig. 16. According to this figure, the failure repair time of the kk1 Grinding mill is about 1071 minutes with 80% probability.

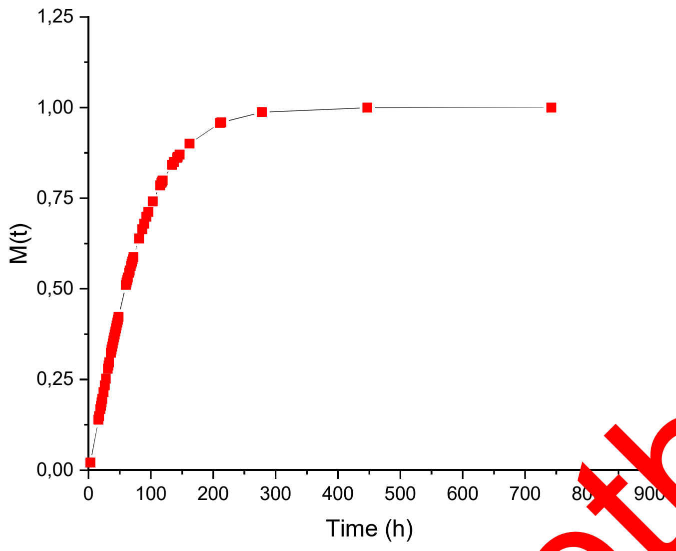

Fig. 16. The maintainability graph of the kk1 grinding mill

3.3.4. Availability

The availability of each sub-system was calculated by using equation (6). The MTBF value for each sub-system was obtained through dividing the cumulative time between failures (CTBFs) by the total number of sub-system failures. Similarly, the MTTR value for each sub-system was determined through dividing the cumulative time to repair (CTTR) by the total number of failures. According to Fig. 17, we observed that the availability curve $A(t)$ decreased from 99% to 87% in the first 20 hours of operation.

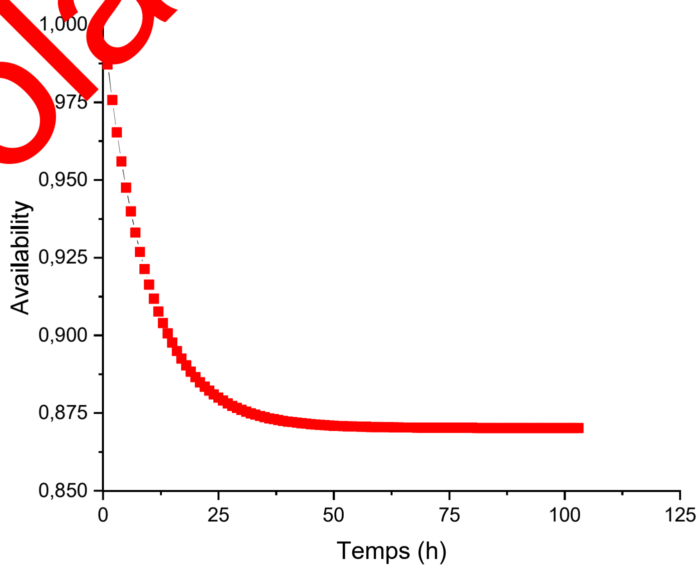

Fig. 17. Evolution of availability

3.4. Discussion of results

To increase the availability of the subsystem, it is important to reduce the number of failures (i. e., increase its reliability) and reduce the time required to resolve the causes of these failures (improve its maintainability).

To improve the reliability of the system, preventive maintenance is required for each sub-system.

These results are recommended for the Hamma Bouziane cement company. We were able to propose a maintenance action plan for the production plant of the studied system.

In the future, an experimental study will be conducted to determine the most penalizing element using mixed Weibull law.

4. Conclusions

1. The Pareto method shows that the most detrimental system is the KK1 Grinding mill. According to this study, the input and output bearings are the two most deficient elements in the KK1 crushing workshop.

2. According to this study, we proposed using a preventive maintenance policy instead of corrective maintenance. This proposal will benefit the HAMMA BOUZIENE cement plant by 3.9 million euros.

3. According to the results, found the high reliability level up to 57%, and to achieve a reliability of 80% it requires a systematic maintenance period of 23 hours. Additionally, the Availability results indicate that the system is available more than 87% of the operating time.

Conflict of interest

The authors declares that they have no conflict of interest in relation to this study, including financial, personal, authorship or other, which could affect the study and its results presented in this article.

Financing

The study was performed without financial support.

Data availability

There is no data associated with the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies in creating the submitted work.

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Authors contributions

Redouane Zellagui: Conceptualization, Methodology, Software, Validation,

Visualization; ***Leila Khammar***: Investigation, Resources, Data Curation, Writing-original draft.

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