

Analysis of the operational sustainability of a production line at the CHLEF cement plant

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Abstract: A cement plant production line reliability study is an in-depth analysis designed to assess the resistance and performance of a specific production process in a cement plant. Our work consists of assessing the reliability of a specific production line. Using statistical analysis methods and probabilistic modelling, we identify the main causes of failures and propose improvements to increase the overall reliability of the production line.

Keywords: Maintenance, Reliability, Stability, Availability, Production.

1. INTRODUCTION

Positioning as a leader in a given market is a crucial issue, and this quest for excellence implies mastering multiple concepts, mainly productivity, availability, quality and meeting deadlines. These concepts are closely linked to the quality of production lines and processes. Inevitably, the effects of manpower, obsolescence and depreciation will have an impact on production equipment, reducing both productivity and profitability.

It is therefore essential to carry out a reliability study based on probabilistic models and equipment history. This approach will make it possible to estimate and assess the future behaviour of equipment and to take preventive action upstream, thereby avoiding any disruption to the production cycle (breakdowns, etc.).

1.1 History of the company

The ECH-CHLEF cement and derivatives company (ECDE) is located in the Oued Sly industrial zone, about 9 km south-west of the town of CHLEF, 40 km from the port of Ténés, 10 km from CHLEF airport and adjoining Route Nationale 4 and the East-West motorway. Covering an area of more than 40 hectares [1], it comprises three production lines. Société des Ciments de Chlef (ECDE) is a 100% subsidiary of Groupe Industriel des Ciments d'Algérie (GICA). It takes the legal form of an SPA (joint stock company). ECDE has a 16% share of the national market.

1.2 Choice of channel to study

The cement plant in the wilaya of Chlef comprises 3 production lines, each with 6 zones and a range of equipment. It should be noted that each line produces cement in the same way and at the same stages. For our reliability study in this

Given the large number of machines that make up the 1st line, the statistical study of each of them will prove very time-consuming. It is therefore advisable to target only the critical

work, we chose the first line because it is the oldest and contains a lot of information and documents.

2. PROBLEMATICS

2.1 Failure history of the first line

At the heart of the ECH-CHLEF (ECDE) company is a production unit made up of several production lines. It is complicated to pinpoint the critical sectors that cause production stoppages.

The degree of complexity increases as the number of pieces of equipment and their components increases.

To deal with this situation, a breakdown analysis is needed to target the sectors, reducing the focus on those sectors that are not actually frequent causes of production stoppages. This analysis involves a history of the equipment as well as knowledge of the statistical and diagnostic methods most widely used in the industrial sector: ABC Pareto method, Ishikawa method, FMECA analysis, etc.

The breakdown history of the first line supplied by ECH-CHLEF (ECDE) is the history recorded from 03/08/2023 to 21/02/2024.

Given the large number of machines making up the 1st line, a statistical study of each of them will take a very long time. It is therefore advisable to target only the critical equipment. We based our study on the "number of stoppages" criterion. An ABC (Pareto) analysis was used to determine the class of equipment.

2.2 Application of the Pareto method

equipment. We based our study on the "number of stoppages" criterion.

To this end, we carried out an ABC (Pareto) analysis to determine the class of equipment.

The table in the appendix shows the number of suitable breakdowns for each piece of equipment in decreasing order, their percentage of the total and their cumulative total.

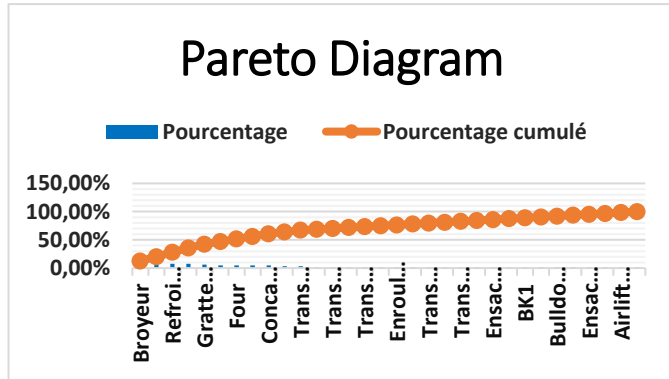


Figure 1. Graphic representation of zones A, B and C as a function of stop frequency.

Interpretation:

From the results of the table and the figure we propose that :

Zone "A" : is the area corresponding to the equipment (Crusher, Preheater tower1, Cooler, Gypsum crusher (2MJ100), Scraper, Recovery bridge, Kiln, Homo1 silo booster, Limestone-clay crusher, Stacker, BC hopper feed belt conveyor (2MD070 /2D107), Additives belt conveyor (B122), Mixing hall extraction belt conveyor (B113) (1MB021), BK2 belt conveyor, Belt conveyor (IMG 030 / 1G122), Clinker storage conveyor 1, Rewinder, Additive hall storage belt conveyor (1MA210/A137), T01 metal conveyor) with a cumulative percentage of 79.69%, this zone represents equipment with poor reliability.

Zone "B": The equipment (Homo silo distributor 1, Crusher feed belt conveyor (BAEG/1MD082), Bulk truck, Bagger 2, Gypsum hopper feed belt conveyor N°03 (2MJ150), BK1, Diesel truck (SNVI K66), KOMATSU D375 6R bulldozer (MR 9235), CAT 773G dumper (MR 9963)) represent a cumulative percentage of around 15%.

Zone "C": The rest of the equipment is found in this zone, accounting for 5% of the cumulative percentage.

We conclude:

From the results of applying the Pareto method, it is clearly noticeable that the Shredder is the equipment with the worst reliability compared to the other equipment.

2.3 History of the "Shredder" equipment

Table 1. History of "Shredder" equipment

Equipment	Start of fault	Start date of repair	End date of repair	Downtime
Shredder	15/08/2023 11:00	19/08/2023 08:00	19/08/2023 16:00	101:00:00
Shredder	24/10/2023 09:00	24/10/2023 09:08	24/10/2023 10:00	1:00:00
Shredder	26/10/2023 16:00	29/10/2023 08:00	29/10/2023 11:00	67:00:00
Shredder	07/11/2023 09:13	07/11/2023 11:00	07/11/2023 12:00	2:47:00
Shredder	07/12/2023 09:00	07/12/2023 09:00	07/12/2023 15:00	6:00:00
Shredder	17/12/2023 09:36	20/12/2023 09:00	20/12/2023 12:00	74:24:00
Shredder	03/01/2024 09:38	17/01/2024 13:00	18/01/2024 12:00	362:22:00
Shredder	06/02/2024 10:02	06/02/2024 13:00	06/02/2024 20:00	9:58:00

2.4 Calculation of uptime :

TBFs represent the time between two successive failures. Each TBF can be calculated using the following relationship:

TBF : Next stop start date - previous stop end date

Table 2. Shredder uptime.

Number of TBF	TBF(H)
1	54
2	214,216
3	234,6
4	333,633
5	454,033
6	717
7	1577

2.5 Calculation of functions F(ti), R(ti) :

In our case the total number of elements in the sample N = 7 < 20 so we apply the Median ranks method:

$$F(ti) = \frac{\sum ni - 0.3}{N + 0.4}$$

With:

$$R(ti) = 1 - F(ti)$$

Note: the TBFs must be ordered in ascending order.

Table 3. Calculation of functions F(ti), R(ti).

TBF	Rank	F(ti)	F(ti) %	R(ti)	R(ti) %
54	1	0,094594595	9,46%	0,905405405	90,54%
214,216	2	0,22972973	22,97%	0,77027027	77,03%
234,6	3	0,364864865	36,49%	0,635135135	63,51%
333,633	4	0,5	50,00%	0,5	50,00%
454,033	5	0,635135135	63,51%	0,364864865	36,49%
717	6	0,77027027	77,03%	0,22972973	22,97%
1577	7	0,905405405	90,54%	0,094594595	9,46%

Estimation of the theoretical repair function F(t) :
 In this section, we imported the previous TBF data into Minitab and estimated it using the Weibull model, as it is the most appropriate for our case.
 Plotting the Weibull line :
 The following figure shows the Weibull line that was drawn using Minitab software.

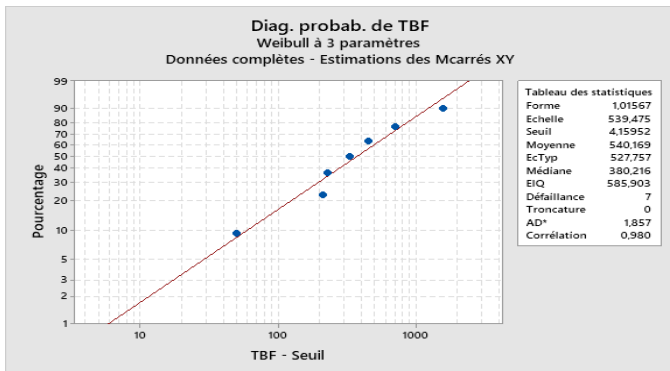


Figure 2. The Weibull line.

Estimation of the parameters of the Weibull distribution:

The parameters obtained from the Weibull distribution.
 Interpretation:
 $\beta=1.01567 \approx 1 \Rightarrow$ the failure rate is constant, Characteristic of the mature zone.
 $\gamma = 4.15952 > 0 \Rightarrow$ The probability of failure is zero in the first uses of the system.
 Estimation of F(t):
 Calculated by the following relationship:

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

The values of F(t) estimated by the Weibull model.

Table 4. The values of F(t) estimated by the Weibull model.

Rank	TBF	F(t)
1	54	0,085156678
2	214,216	0,318636499
3	234,6	0,343938759
4	333,633	0,454487186
5	454,033	0,564621596
6	717	0,734765811
7	1577	0,948429221

3. Kolmogorov-Smirnov test :

Before validating all the reliability laws, we need to test the hypothesis to find out whether we should accept or reject the model proposed by the Minitab software, by applying the Kolmogorov-Smirnov test.

Calculating Dn.

Table 5. Calculating Dn.

Rank	TBF(H)	F(t)	F(ti)	Dn= F(t)-F(ti)
1	54	0,08515667 8	0,09459459 5	0,00943791 7
2	214,216	0,31863649 9	0,22972973	0,08890676 9
3	234,6	0,34393875 9	0,36486486 5	0,02092610 6
4	333,633	0,45448718 6	0,5	0,04551281 4
5	454,033	0,56462159 6	0,63513513 5	0,07051354
6	717	0,73476581 1	0,77027027	0,03550445 9
7	1577	0,94842922 1	0,90540540 5	0,04302381 6

According to the Kolmogorov-Smirnov table, for a confidence level $\alpha = 0.05$ and a number of samples $n=7$, we find: $D7.0.05 = 0.486$

From the table above, we find that: $D7, \max = 0.088906769$
 By comparison: $0.088906769 < 0.486 \Rightarrow D7, \max < D7,0.05$
 The weibull model is therefore acceptable.

Theoretical reliability function R(t), failure rate $\lambda(t)$ and probability density f(t) :

Calculate By the following laws:

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

Reliability R(t) :

The failure rate $\lambda(t)$:

$$\lambda(t) = \frac{\beta}{\eta} \left(\frac{t - \gamma}{\eta}\right)^{\beta-1}$$

Probability density: $f(t) = \lambda(t).R(t)$

Estimation of the functions R(t), $\lambda(t)$ and f(t).

Table 6. The probability density

Rang	TBF	R(t)	Y(t)	f(t)
1	54	0,91484332 2	0,0018137 3	0,00165927 8
2	214,216	0,68136350 1	0,0018550 8	0,00126398 3

3	234,6	0,65606124 1	0,0018577 7	0,00121881 3
4	333,633	0,54551281 4	0,0018682 1	0,00101913 2
5	454,033	0,43537840 5	0,0018773 5	0,00081735 8
6	717	0,26523418 9	0,0018909 4	0,00050154 2
7	1577	0,05157077 9	0,0019145 4	9,87341E- 05

Graphical representation of functions and interpretations :
Failure function $F(t)$:

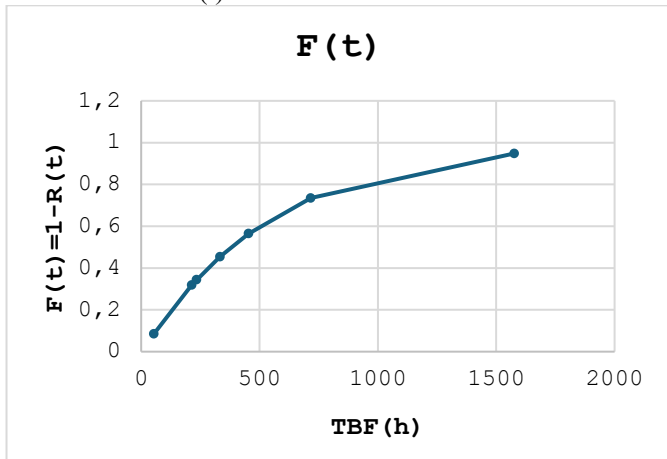


Figure 3. Failure function curve $F(t)$.

The figure above illustrates how the failure function $F(t)$ varies as a function of uptime, showing that its increase is proportional to the increase in uptime.

Reliability function $R(t)$:

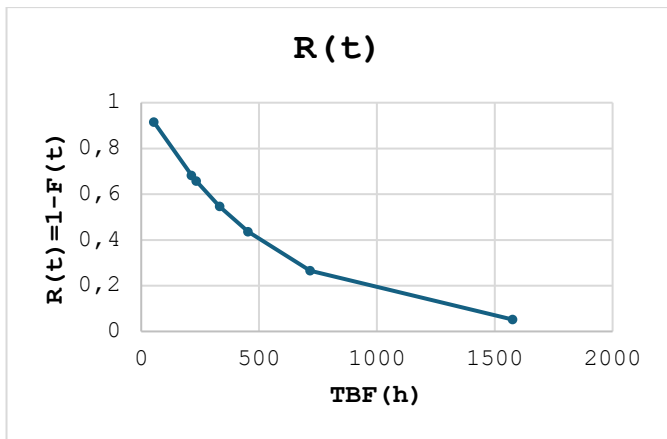


Figure 4. Reliability curve $R(t)$.

This representation shows the decreasing curve of the reliability function $R(t)$, which decreases in proportion to the increase in uptime.

Failure rate function

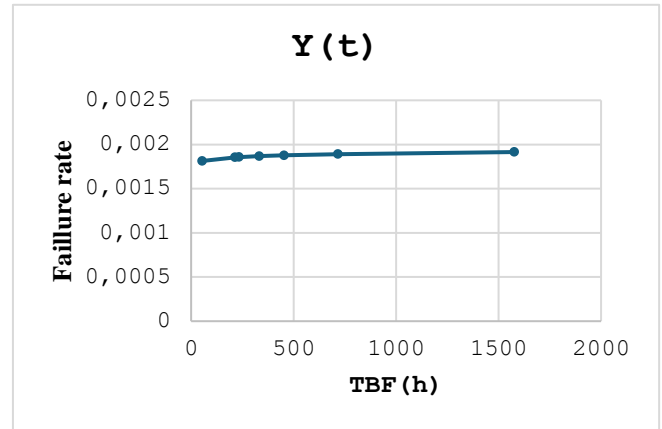


Figure 5. Failure rate curve $\lambda(t)$.

This figure shows the failure rate curve. We can see that the failure rate is almost constant, with a shape parameter equal to 1, so we are in the second phase of the "mature" bathtub curve.

Density function $f(t)$:

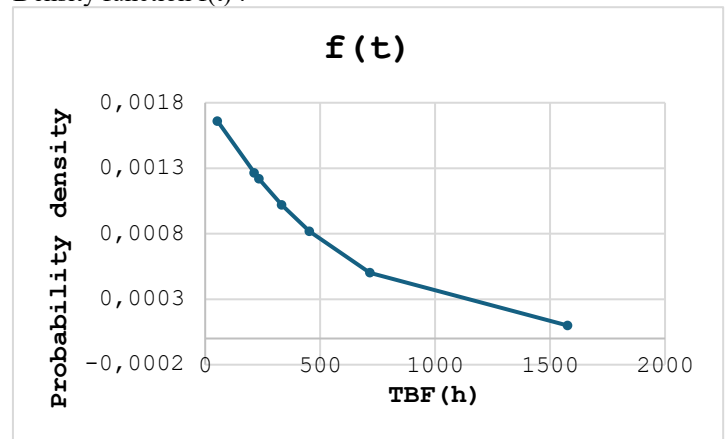


Figure 6. Probability density curve $f(t)$.

Calculation as a function of MTBF :

MTBF :

$$\beta = 1.01567 \Rightarrow \text{From the table } A = 1$$

$$\text{MTBF} = A \times \eta + \gamma$$

$$\text{MTBF} = 1 \times 539.475 + 4.15952 = 543.63452 \text{ h.}$$

From MTBF we can deduce λ :

$$\lambda = 1/\text{MTBF}$$

$$\lambda = 1/(543.63452) = 1.84 \times 10^{-3} \text{ Failure/hour}$$

Maintainability:

Maintainability $M(t)$ Expressed as: $M(t) = 1 - e^{-\mu t}$

Where: μ is the repair rate calculated by the relation :

$$\mu = 1/\text{MTTR}$$

Knowing that: MTTR is the mean time to repair

$$MTTR = (\sum TTR)/N$$

In our case $\sum TTR = 51.866$ hours in 8 interventions.

Therefore : $MTTR = 6.48325$ hours / job

With a repair rate $\mu = 0.154$

The table below illustrates the different values of $M(t)$:

The different values of $M(t)$ as a function of TTR.

Table 7. The different values of $M(t)$ as a function of TTR.

Rank	TTR(H)	M(t)
1	0,866	0,124853519
2	1	0,142727979
3	3	0,36997766
4	3	0,36997766
5	6	0,603071851
6	7	0,659724604
7	8	0,708291423
8	23	0,971044642

The following graph shows the evolution of maintainability as a function of repair time TTR :

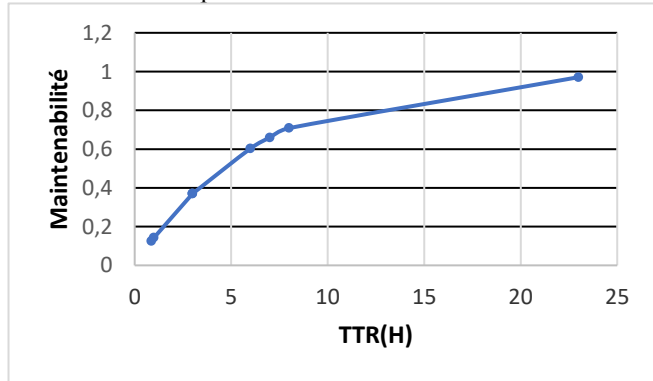


Figure 7. The $M(t)$ curve.

An improvement in maintainability $M(t)$ can be seen with increasing repair times TTR.

Availability :

Intrinsic availability :

Expressed by the expression:

$$D = MTBF/(MTBF+MTTR) \Rightarrow D = 0.98$$

Instantaneous availability :

This is given by the relationship:

$$D = \mu / (\mu + \lambda) \lambda / (\mu + \lambda) e^{-(\lambda + \mu)TTR}$$

The table below illustrates the different values of $D(t)$:

The Different values of $D(t)$ as a function of TTR. de $D(t)$:

Table 8. la the availability curve $D(t)$

Rank	TTR(H)	$D(t)$
1	0,866	0,9985094052
2	1	0,9982962064
3	3	0,9955907323
4	3	0,9955907323
5	6	0,9928280871
6	7	0,9921592286
7	8	0,9915868890
8	23	0,9885207276

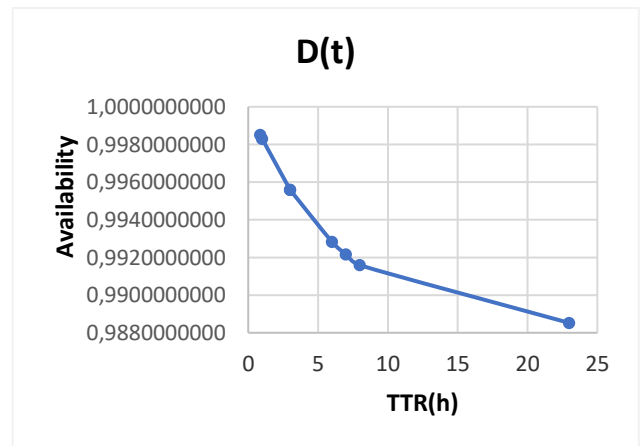


Figure 8. The $D(t)$ curve.

We can see that availability $D(t)$ decreases with increasing repair times TTR.

Intervention time T :

The desired time for a systematic intervention T can be calculated for different values of $R(t)$: 80%, 85%, 90%, 95%.

$$T = \eta (-\ln R(t))^{\frac{1}{\beta}} + \gamma$$

Intervention time

Table 9. Intervention time.

$R(t)$:	80	85	90	95
Intervalle pour intervention (H)	127,358	94,327	63,007	33,128

3. CONCLUSIONS

In conclusion, this work has enabled an in-depth exploration of the reliability of the production line at the Chlef ECDE cement plant. In the first theoretical part, we presented the company and the fundamental notions of industrial maintenance and the FMD

(Reliability, Maintainability, Availability), thus laying the foundations for our study.

In the practical part, selecting the first production line as the object of study, we used the Pareto method to identify the crusher as the equipment with the lowest reliability. By analysing its reliability, maintainability and availability, we were able to highlight the challenges facing the company and propose concrete solutions

to improve the reliability of this production line.

This research has therefore made it possible to combine theoretical knowledge with a practical approach, providing the company with tools and recommendations for optimising its production line and guaranteeing better long-term performance. It also paves the way for future in-depth studies in the field of industrial reliability, contributing to the development and efficiency of companies in the cement sector.

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