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Reliability Optimization in the cutting area

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Abstract: *This Work is the result a study that aims to optimize reliability in the cutting area in the context of a re-locating.The works presented in this paper joins within the project of reliability optimization in the cutting area; they focus on the detailed internal and external problems of this area, where we have proposed solutions to improve the availability of equipment, by using the PRCM approach, integrated into the general work methodology DMAIC. In fact, with a large number of failures, industrial companies must produce and improve their production and ensure the operational maintenance of their equipment with an optimal maintenance cost, thus practical solutions are essentials. Therefore, our efforts in this project focus on the analysis of current down time and optimize it by using the basic concepts of PRCM to be framed by the steps of the DMAIC methodology of work in order to achieve the objectives set by the maintenance department.*
Keywords: *Reliability Optimization, DMAIC, down time, Equipment availability, optimal maintenance cost, PRCM,*

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I. Introduction

Technical development has contributed to the improvement of companies working in the automotive industry in term of reliability, however, “zero failure” remains impossible to achieve. To ensure their competitiveness, companies must achieve low costs, high quality, and continuous manufacturing, for that reason a company is forced to perform high-quality maintenance in order to respond to the need of its customers.

This study is given in the context of a re-locating company and aims to reduce the down time in the cutting zone using methods of probabilistic reliability which is based on the technical analysis of the equipment using the DMAIC approach to reduce the down time.

II. Methodology

2.1 DMAIC METHODOLOGY

DMAIC (define, measure, analyze, improve, control) is an approach to problem-solving defined by Motorola as part of the Six Sigma management philosophy.

The purpose of the Six Sigma DMAIC methodology is to resolve problems with unidentified answers. The issue or (“Y”) must be well-defined in tangible quantifiable terms with a working description. The group dedicated to the Six Sigma assignment will determine a project by choosing options that reflect the organizational goals, as well as the consumers of the process based on their requirements. This will be accomplished during the Define phase. The group is looking for CTQs (critical to quality characteristics) which have a dramatic effect on quality. From this selection, the “vital few” are distinguished from the “trivial many”. The result is a map of the process that will be improved.[1]

DMAIC, which is pronounced "de-may-ick," is a tool for improving an existing process. The steps can be summarized as follows.

Define: State the problem, specify the customer set, identify the goals, and outline the target process.

Measure: Decide what parameters need to be quantified, work out the best way to measure them, collect the necessary data, and carry out the measurements by experiment.

Analyze: Identify gaps between actual and goal performance, determine the causes of those gaps, determine how process inputs affect outputs, and rank improvement opportunities.

Improve: Devise potential solutions, identify solutions that are easiest to implement, test hypothetical solutions, and implement actual improvements.

Control: Generate a detailed solution monitoring plan, observe implemented improvements for success, update plan records on a regular basis, and maintain a workable employee training routine.

2.2 RCM

Reliability-centered maintenance (RCM) is a process to ensure that systems continue to do what their users require in their present operating context.[2] It is generally used to achieve improvements in fields such as the establishment of safe minimum levels of maintenance. Successful implementation of RCM will lead to increase in cost-effectiveness, reliability,[3] machine uptime, and a greater understanding of the level of risk that the organization is managing. It is defined by the technical standard SAE JA1011, [4] Evaluation Criteria for RCM Processes. [5]

2.3 FMEA

Failure Modes and Effects Analysis (FMEA) is a methodology for analyzing potential reliability problems early in the development cycle where it is easier to take actions to overcome these issues, thereby enhancing reliability through design. FMEA is used to identify potential failure modes,[6] determine their effect on the operation of the product, and identify actions to mitigate the failures. A crucial step is anticipating what might go wrong with a product.[7] While anticipating every failure mode is not possible, the development team should formulate as extensive a list of potential failure modes as possible.[8]

The early and consistent use of FMEAs in the design process allows the engineer to design out failures and produce reliable, safe, and customer pleasing products. FMEAs [9] also capture historical information for use in future product improvement. [10]

III. Implementation of DMAIC and RCM

3.1 DEFINE

The goal of this study is to reduce the down-time, however; we will start by finding the global time where machines are not in productivity

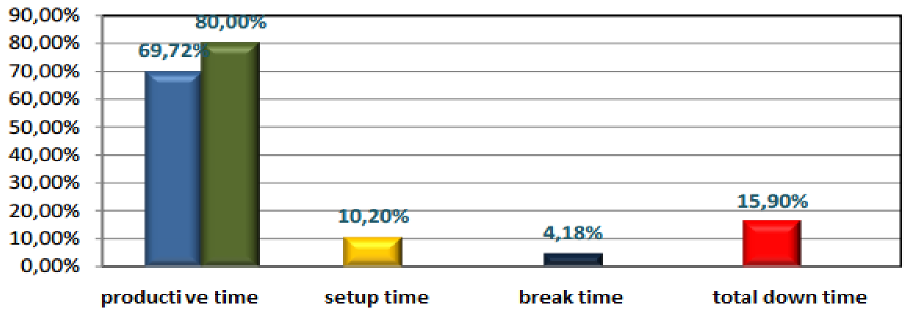


Figure 1: percentage of opening time

Where:

Productive time: time during the production process

Setup time: time during production change (change of tools, change of terminal)

Break time: operator breaking time

Total down time that includes the following parts:

Maintenance time: time during the intervention of maintenance team

Dead time: a time when the operator is looking for tools.

Logistic time: time of bringing the raw material.

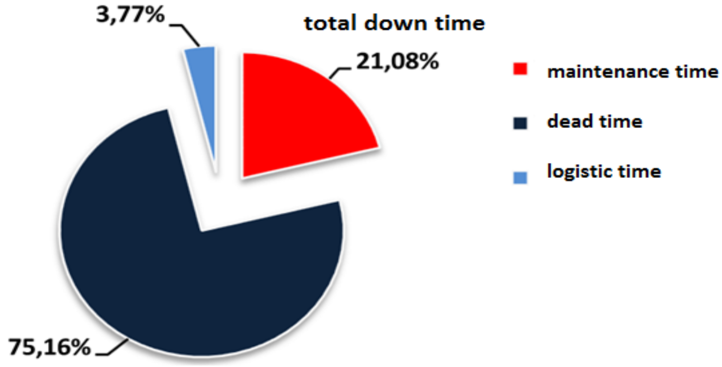


Figure 2: Total down time distribution

From the diagram above, we find that the maintenance down time represents an important percentage of the total down time, that is why we must consider it during improvement.

Most of the machines in of the company are located in the cutting zone , these machines have the downtime of maintenance that is caused mainly by the subsets (the machine base, the crimping tool, seal station, and applicator, inkjet) .the down time sometimes exceeded 7% during one month, while it is very high compared to the target which is 2.5% .So our goal is to achieve the lower down time, and improve the working environment and also have a long-term maintenance management strategy.

- **Identification of gains and costs**

If the costs are difficult to estimate in the beginning, it is not easier to estimate the gains. Indeed, some of the gains are easily identifiable. But a large part of gains is difficult to quantify, such as improving the image of the company among customers. That is why we have separated the measurable and non-measurable gains.
The gains and costs associated with this project are:
• Reduce the cost of maintenance.
• Reduce the frequency of down time.
• Improve the effectiveness of the interventions.
• Optimize the preventive maintenance plan.
• Improve machine availability and ensure the quality of interventions.
• Avoid customer complaints.
• Have a good image with customers.
• Improve the reliability of the work system and make it effective.

3.2 MEASURE

Data collecting will last for one month; the down time of the critical equipment is measured by a minute of unit time.
The cutting machine is composed of four subsets.
- The crimping tool
- The station and seal applicator
- The Base machine
- The inkjet

we realized the Pareto diagram of maintenance down time for the four subsets of the cutting machine. The following table shows the components of the cutting machine with their downtime in minutes and as it frequency relative to the other components:

Process	*Total down time (min)*	*Total cumulative (min)*	*Fi Cu*
OUTIL	14243	14243	50,65%
SEAL	6808	21051	74,85%
MACHINE	4647	25698	91,38%
Jet d'encre	2425	28123	100,00%

Table 1: Down time-frequency during one month for every machine sub-assembly

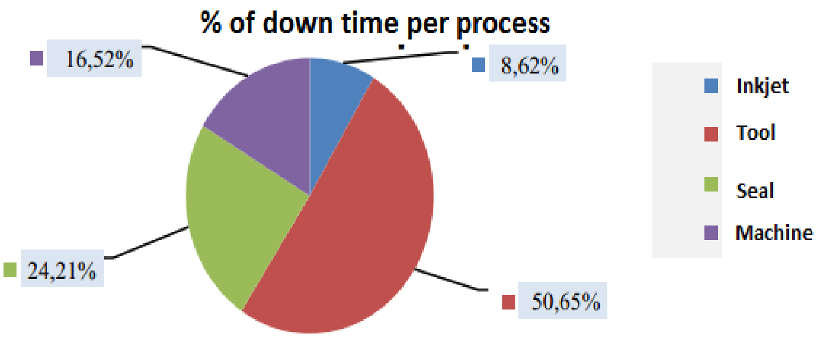


Figure 3: Down time rate of the machine sub-assembly

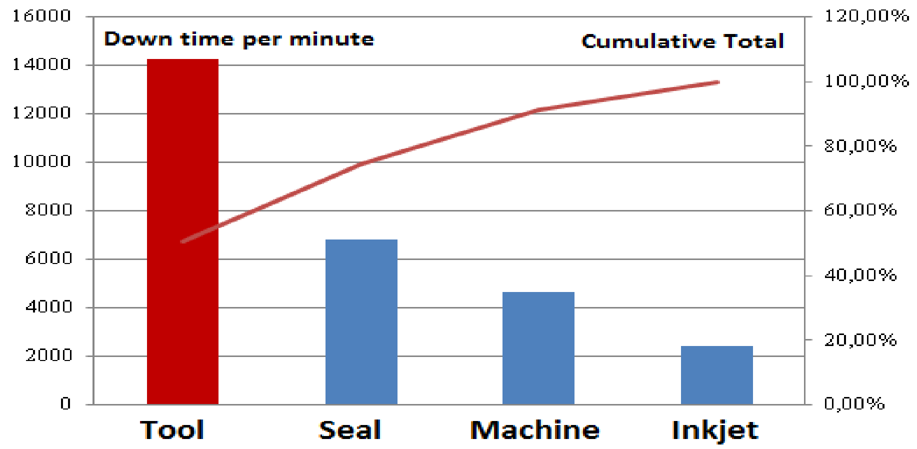


Figure 4: Pareto diagram of the machine sub-assembly

According to the table and previous diagram, we find that the most critical equipment, and has over 50% of downtime is the crimping tool, so we will focus our work on this subset. So in order to collect more information about the behavior of this equipment, we will make a more detailed follow so that we can at the end establish an action plan.

To follow the problematic tools, we defined a list with the reference tool broken down it machine, the technician who did the operation, the shift in which we had the breakdown, date, the down time, and description of the problem.

When the technician made an intervention on the tool, it must be mentioned in the report to the end of each shift, monitoring begins after the execution of preventive maintenance for the tool.

- **The monitoring results**

The monitoring carried out for problematic tools allowed us to treat them in a way to get the uptime for each reference and downtime, so it remains to use these two indicators for the analysis of studies in the next section.

The table containing the data obtained during monitoring with uptime for each critical reference tool is shown.

- **Viewing uptime monitoring tools**

The following figure shows the uptime in the crimped wire of numbers on each tool followed during a cycle of 190000 crimped wires. Each curve represents the uptime one tool among the 22 samples observed.

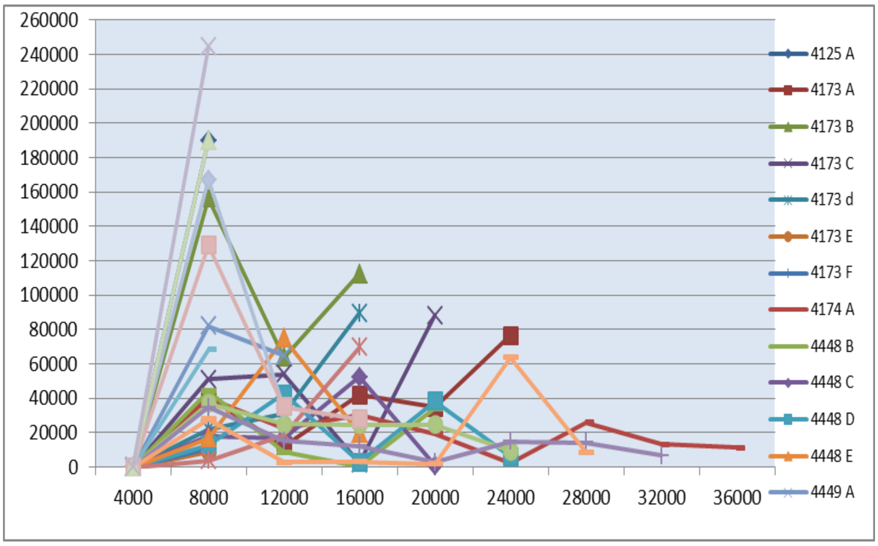


Figure 5: TBF of crimping tool in function of cramped wires

Raw material	• Lack of Spare parts
Machine	• The problem of lead system • Punch • Anvil • lack of tools • fitting problem • broken parts • Lack of maintenance means • Problem of gap • Deformation • Pb head degradation • lack of spare parts • Low reliability and maintainability of equipment
Method	• Lack of data • No tracking of repetitive problems • No priority during interventions • No feedback interventions
People	• Not important
Environment	• No working comfort • Work Risk • Too much stress • dirty environment • No application of 5 S
Management	• Preventive maintenance not adequate
Financial means	• Lack of spare parts

Table 2: the result of the fishbone diagram

The fishbone diagram allowed us to understand quickly and effectively the root causes of downtime, the various causes are grouped into 7 categories and will help our pursuit of actions during our analysis in the next section.

3.3 ANALYZE

We have elaborated a failure Modes and Effects Analysis for the crimping tool and designed a functional analysis of its components, in this step the crimping tool to be analyzed is defined and partitioned into an indentured hierarchy, such as systems, subsystems, units, and piece parts. Functional descriptions are created for the crimping tool, covering all operational modes and mission phases. In the end, a criticality analysis is designed.

Frequency: F		Level of criticality	corrective actions
1	1 failure per year	1 ≤ C ≤ 10 negligible Criticality	No modification in design needed Corrective maintenance
2	1 failure per trimester		
3	1 failure per month		
4	1 failure per week		
non-detection: N		10 ≤ C ≤ 20 medium Criticality	Improvement of unit performance Systematic preventive maintenance
1	Operator detection		
2	Maintenance agent detection		
3	Difficult detection		
4	Undetectable	20 ≤ C ≤ 40 high Criticality	Design review of sub-assembly Preventive conditional maintenance
Gravity: G			
1	There is no down time		
2	Downtime for 1 hour		
3	1 h ≤ Downtime ≤ 1day	40 ≤ C ≤ 64 forbidden Criticality	A complete review of design
4	Downtime more than 1day		

Table 3: Criticality ranking

Element	**Criticality Number**
Punch die	16
Setting screw pitch	16
Terminal screw setting	16
Dip screw setting	16
Running shank	16
PVC punch	12
Carcass	12
Anchor screw	12

Table 4: Classification of criticality

We use the Weibull law

The density of probability f (t): $f(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{(\beta-1)} e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}$ Avec t > γ

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

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

Failure rate λ (t) : $\lambda(t) = \frac{f(t)}{1-F(t)}$

$\lambda(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{(\beta-1)}$ while: $t > \gamma, \beta > 0, \eta > 0$

- β is the shape parameter, also known as the Weibull slope
- η is the scale parameter
- γ is the location parameter

We calculate the unction Fi= i/N with N≥50 it will be calculated in function of TBF value, the following table shows the Fi values for 73 TBF

Order i	TBF	Fi=i/N	Order i	TBF	Fi=i/N	Order i	TBF	Fi=i/N
1	600	0,013513514	**26**	16830	0,351351351	**51**	41930	0,689189189
2	1000	0,027027027	**27**	17000	0,364864865	**52**	42570	0,702702703
3	1900	0,040540541	**28**	18000	0,378378378	**53**	44120	0,716216216
4	2190	0,054054054	**29**	18830	0,391891892	**54**	50930	0,72972973
5	2500	0,067567568	**30**	19480	0,405405405	**55**	52330	0,743243243
6	2730	0,081081081	**31**	19910	0,418918919	**56**	53970	0,756756757
7	2800	0,094594595	**32**	22060	0,432432432	**57**	63680	0,77027027
8	2800	0,108108108	**33**	22540	0,445945946	**58**	63770	0,783783784
9	3050	0,121621622	**34**	24750	0,459459459	**59**	64600	0,797297297
10	3800	0,135135135	**35**	24770	0,472972973	**60**	68360	0,810810811
11	6050	0,148648649	**36**	24980	0,486486486	**61**	69550	0,824324324
12	6650	0,162162162	**37**	26030	0,5	**62**	74860	0,837837838
13	8580	0,175675676	**38**	27800	0,513513514	**63**	76440	0,851351351
14	8610	0,189189189	**39**	27920	0,527027027	**64**	82050	0,864864865
15	9150	0,202702703	**40**	30200	0,540540541	**65**	88110	0,878378378
16	9210	0,216216216	**41**	30830	0,554054054	**66**	89480	0,891891892
17	11000	0,22972973	**42**	34030	0,567567568	**67**	112310	0,905405405
18	11200	0,243243243	**43**	34100	0,581081081	**68**	128850	0,918918919
19	12300	0,256756757	**44**	34710	0,594594595	**69**	156370	0,932432432
20	12300	0,27027027	**45**	34880	0,608108108	**70**	166930	0,945945946
21	12920	0,283783784	**46**	35250	0,621621622	**71**	190000	0,959459459
22	13350	0,297297297	**47**	36900	0,635135135	**72**	190000	0,972972973
23	14130	0,310810811	**48**	38400	0,648648649	**73**	244310	0,986486486
24	15030	0,324324324	**49**	40430	0,662162162			
25	15140	0,337837838	**50**	40700				

Table 5: Cumulative probability failure Fi for every TBF

After that, the Weibull diagram designed and will allow us to find the parameters β, γ, η

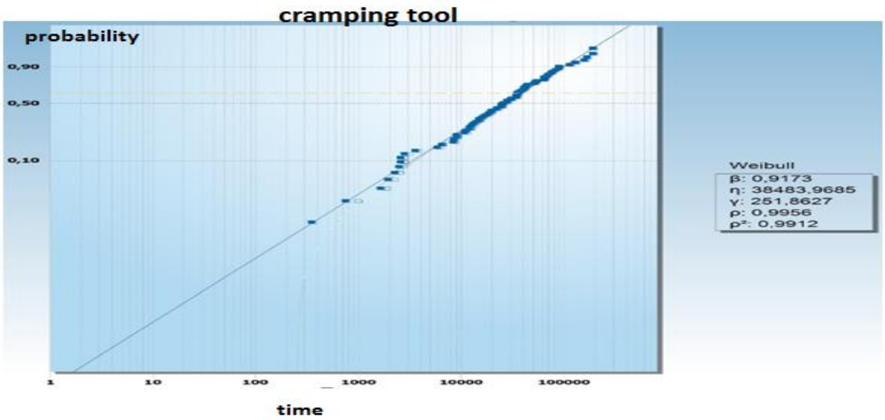


Figure 6: Visualization of TBF using Weilbul diagram

Now we can easily find the functions R(t), F(t) and λ(t) in the following table for 73 TBF.

TBF	**F(t)**	**R(t)**	**λ(t)**	**TBF**	**F(t)**	**R(t)**	**λ(t)**
600	0,013261	0,986739	3,5175E-05	27800	0,52093	0,479074	2,45E-05
1000	0,02657	0,9734299	3,3018E-05	27920	0,52233	0,477667	2,45E-05
1900	0,054058	0,9459421	3,0931E-05	30200	0,5482	0,451805	2,434E-05
2190	0,062447	0,9375527	3,0519E-05	30830	0,55506	0,444937	2,429E-05
2500	0,071221	0,9287795	3,0147E-05	34030	0,58821	0,411792	2,409E-05
2730	0,077612	0,922388	2,9905E-05	34100	0,5889	0,411098	2,409E-05
2800	0,079539	0,9204614	2,9836E-05	34710	0,59489	0,405105	2,405E-05
2800	0,079539	0,9204614	2,9836E-05	34880	0,59655	0,403452	2,404E-05
3050	0,086352	0,9136479	2,9606E-05	35250	0,60012	0,39988	2,402E-05
3800	0,106214	0,8937857	2,903E-05	36900	0,61563	0,384369	2,393E-05
6050	0,161543	0,8384566	2,7875E-05	38400	0,62916	0,370837	2,385E-05
6650	0,175393	0,8246072	2,7649E-05	40430	0,64665	0,353345	2,375E-05
8580	0,217771	0,7822294	2,7052E-05	40700	0,64891	0,351087	2,374E-05
8610	0,218405	0,7815949	2,7044E-05	41930	0,659	0,340997	2,368E-05
9150	0,229707	0,7702929	2,6905E-05	42570	0,66413	0,335872	2,365E-05
9210	0,230949	0,7690508	2,689E-05	44120	0,6762	0,3238	2,358E-05
11000	0,266816	0,7331836	2,6488E-05	50930	0,72396	0,276036	2,33E-05
11200	0,270687	0,7293128	2,6447E-05	52330	0,73281	0,267187	2,325E-05
12300	0,291516	0,708484	2,6239E-05	53970	0,7428	0,257205	2,319E-05
12300	0,291516	0,708484	2,6239E-05	63680	0,79432	0,205676	2,287E-05
12920	0,302925	0,6970753	2,613E-05	63770	0,79475	0,205254	2,287E-05
13350	0,310702	0,6892976	2,6058E-05	64600	0,7986	0,201396	2,284E-05
14130	0,324538	0,675462	2,5934E-05	68360	0,81514	0,184858	2,274E-05
15030	0,340081	0,6599195	2,5799E-05	69550	0,82007	0,179927	2,27E-05
15140	0,34195	0,6580499	2,5783E-05	74860	0,84045	0,159551	2,257E-05
16830	0,369884	0,6301157	2,5555E-05	76440	0,84603	0,153967	2,253E-05
17000	0,372615	0,6273853	2,5534E-05	82050	0,86426	0,135739	2,239E-05
18000	0,388394	0,6116065	2,5411E-05	88110	0,88144	0,118561	2,226E-05
18830	0,401134	0,5988659	2,5316E-05	89480	0,885	0,115002	2,223E-05
19480	0,410894	0,589106	2,5244E-05	112310	0,93043	0,069565	2,182E-05
19910	0,417248	0,5827518	2,5198E-05	128850	0,95141	0,048592	2,157E-05
22060	0,447849	0,5521515	2,4982E-05	156370	0,97303	0,026969	2,123E-05
22540	0,454424	0,5455758	2,4937E-05	166930	0,97843	0,021566	2,111E-05
24750	0,483565	0,5164347	2,4743E-05	190000	0,98671	0,013285	2,089E-05
24770	0,483821	0,5161792	2,4741E-05	190000	0,98671	0,013285	2,089E-05
24980	0,486495	0,5135052	2,4724E-05	244310	0,99568	0,004325	2,046E-05
26030	0,499631	0,5003686	2,4639E-05	244310	0,99568	0,004325	2,046E-05

Table 6: Calculation of F(t), R(t) and λ(t) functions using the Weibull Law

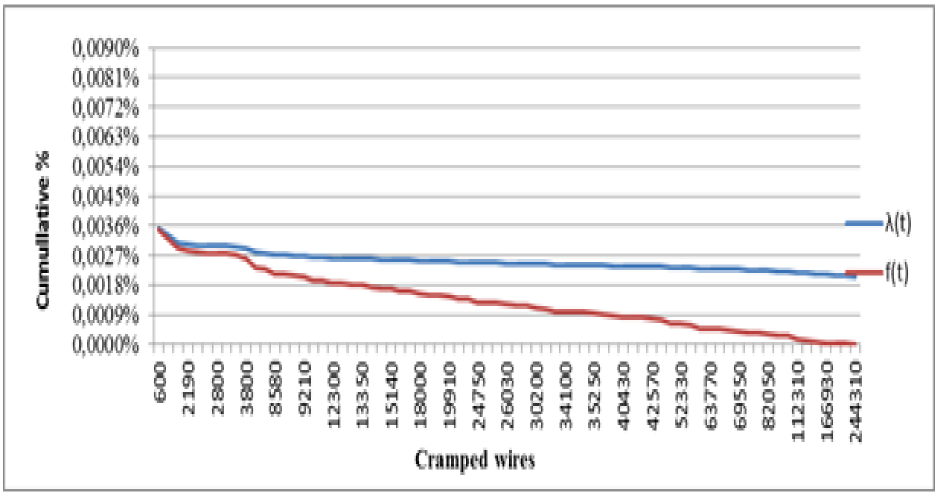
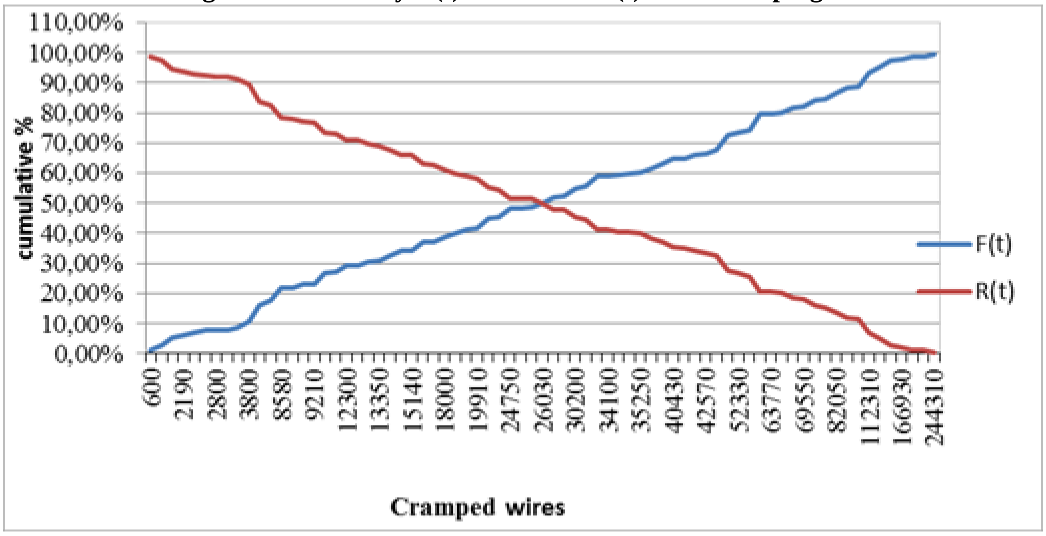


Figure 7: Failure rate of the cramping tool.

Figure 7: Reliability R(t) and failure F(t) of the crimping tool



The diagram bellow shows the reliability R(t) and the failure F(t) of the crimping tool.
The failure rate is almost constant, while equipment is in the maturity phase, during this period failures are purely accidental, therefore it should be considered solutions to solve this problem in the next section.

3.4 Innovate

The analysis results described in the previous section shows the necessity to update the old preventive maintenance plan to reduce failure of critical elements.

We tried to find the optimal cycle for replacing the crimping tool parts and performing preventive maintenance after a series of repairs which make it possible to guarantee minimum costs, a natural strategy is to replace the system with all θ, where θ guarantees minimum possible costs. The total costs of maintenance are

- cost of preventive maintenance
- cost of corrective maintenance

preventive maintenance cost:
The total cost of preventive maintenance is the sum of spare parts cost and labor cost, so we found that:
The mean cost of spare part Cp and labor cost Cm are:
Cp = 105 € and Cm = 1 €.
So the unity cost of preventive maintenance MPSu = Cp + Cm = 106 €.
During the manufacturing interval TO wires are crimped and the total cost of preventive maintenance having θ periodicity is given:

$$MPS = \frac{MPSu \times TO \times R(t)}{\theta} .$$

Corrective maintenance cost:
The total cost of corrective maintenance is the sum of direct and indirect costs while:
Direct cost = labor cost + spare part cost
Indirect cost = unavailability cost
So we have:
Cm/h = 2 € and MTTR = 13 min
Labor cost: Cm = 0.43
Spare part cost: Cp = 105 €
Direct cost: Cd = 105.43 €
Unavailability cost: Cunv = 6.33 €
Indirect cost: Cind = 6.33
So the mean cost of corrective maintenance intervention is
MCu = Cd + Cind = 111.76 €
The mean cost of long term reparation per unit of use is given:

$$MC = \frac{MCu \times TO \times (1 - R(t))}{MTBF}$$

Systematic total intervention

The combination of corrective maintenance costs and preventive maintenance costs help us to obtain the total cost per cycle based on optimal periodicity of preventive maintenance execution.
The model equation is given by Ct= MPS +MC

So Ct = $\frac{MPSu \times TO \times R(t)}{\theta} + \frac{MCu \times TO \times (1-R(t))}{MTBF}$

Results

The table below give us the optimal of preventive maintenance execution of the crimping tool with MTBF = 40385.

θ	***R (θ)***	***MCres***	***MPS***	***Cout total***
4000	88,9%	58,56 €	4 474,22 €	**4 532,78 €**
8000	79,5%	107,98 €	2 000,50 €	**2 108,48 €**
12000	71,4%	150,33 €	1 198,48 €	**1 348,81 €**
16000	64,4%	187,36 €	810,20 €	**997,56 €**
20000	58,1%	220,08 €	585,50 €	**805,58 €**
24000	52,6%	249,16 €	441,50 €	**690,66 €**
28000	47,7%	275,13 €	342,91 €	**618,04 €**
32000	43,2%	298,39 €	272,20 €	**570,59 €**
36000	39,3%	319,29 €	219,72 €	**539,01 €**
40000	35,7%	338,10 €	179,74 €	**517,83 €**
44000	32,5%	355,06 €	148,63 €	**503,69 €**
48000	29,6%	370,37 €	124,02 €	**494,40 €**
52000	26,9%	384,22 €	104,28 €	**488,51 €**
56000	24,5%	396,76 €	88,25 €	**485,02 €**
60000	22,4%	408,13 €	75,12 €	**483,24 €**
64000	20,4%	418,44 €	64,25 €	**482,69 €**
68000	18,6%	427,80 €	55,20 €	**483,00 €**
72000	17,0%	436,30 €	47,61 €	**483,91 €**
76000	15,6%	444,03 €	41,21 €	**485,24 €**
80000	14,2%	451,06 €	35,78 €	**486,84 €**
84000	13,0%	457,47 €	31,16 €	**488,62 €**
88000	11,9%	463,30 €	27,20 €	**490,50 €**
92000	10,9%	468,62 €	23,81 €	**492,42 €**
96000	10,0%	473,46 €	20,88 €	**494,34 €**
100000	9,1%	477,88 €	18,35 €	**496,23 €**

Table 7: preventive and corrective maintenance in function of θ

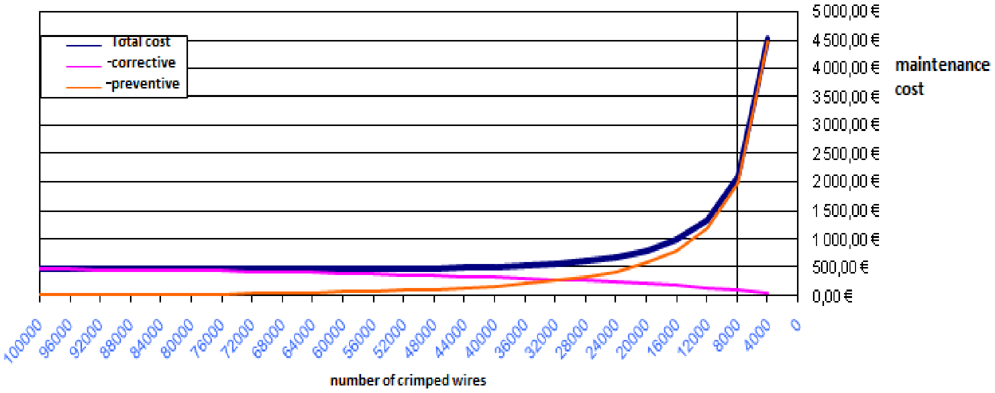


Figure 8: maintenance cost in function of θ

From the diagram, we conclude that the optimum periodicity θ to execute preventive maintenance is θ = 64000 wires crimped.

IV. Conclusion:

The objective of this project is to optimize a maintenance strategy based on Repair for crimping tools that are randomly degraded and having an Approximately constant failure rate.

What is sought is the optimal time to replace the equipment as a result of a series of repairs minimal, whenever the number of crimped wires reaches an optimal number.

As a first step, we studied the critical equipment, starting with the implementation of the FMEA components Critical to generate solutions to minimize their criticality in the future. Then, We have made a reliable analysis by the law of WEIBULL with three parameters, in Determining the MTBF of the problematic tools, this allowed us to calculate the New periodicity associated with an optimal total cost, for these tools.

Based on the results of the AMDEC and WEIBULL's analysis, we have To update the preventive maintenance plan and create maintenance ranges Associated. To conclude, the methodology applied in this paper made it possible to Feasible solutions in order to achieve the expected objectives at the level of DOWN TIME of the cutting area. For the critical equipment studied, This reduction is estimated at 20.40% over a period of 2 months.

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