

Operational Safety-Based Maintenance Study for the DELTA X Welding Machine at National Electronic Industries Company, Sidi Bel Abbès-ALGERIA

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Abstract: This work presents a study on the reliability, availability, maintenance and safety of the VITRONICS SOLTEC DELTA X welding machine. These include examining fault patterns, evaluating the effectiveness of maintenance means, and suggesting improvements. An FMEA (Failure Modes and Effects Analysis) analysis is used in this study to identify the most important failure patterns, a Pareto diagram to determine the main causes of failure, and a statistical analysis of the major causes. According to the results, electrical and heating elements are the most vulnerable to failure. The implementation of regular preventive maintenance programs and the use of advanced monitoring technologies for predictive maintenance are recommendations. The implementation of these recommendations aims to enhance the performance and operational safety of the DELTA X machine.

Keywords: Electronic Industries, Failure, Reliability, Maintainability, Availability, Pareto, Weibull, FMEA.

1. INTRODUCTION

In a constantly evolving industrial environment, equipment maintenance is crucial to ensure the continuity and efficiency of operations. The increasing complexity of production systems, increased competitiveness and stricter regulatory requirements require companies to adopt optimized and robust maintenance strategies. Maintenance is no longer limited to the simple repair of breakdowns, but integrates a proactive approach aimed at preventing failures, maximizing equipment availability and guaranteeing the safety of operations. Maintenance based on operational reliability indicators, also known as Reliability-Centered Maintenance (RCM), is a strategic and proactive approach that focuses on the use of specific performance indicators to continuously monitor and assess the condition of equipment and technical systems. This method allows for the anticipation of potential failures, optimization of maintenance interventions, and ensures increased availability and reliability of installations. In the electronics industry, where soldering machines are critical for the production of printed circuit boards and other components, implementing an RCM approach can significantly enhance production quality, reduce downtime, and extend equipment lifespan.

The foundational concepts of RCM are well-documented in various books and studies. Moubrey (1997), in his book *Reliability-Centered Maintenance*, highlights the importance of reliability and proactive maintenance, laying the groundwork for the use of performance indicators to enhance maintenance processes. Dhillon (2006), in *Maintainability, Maintenance, and Reliability for Engineers*, explores the technical aspects of maintenance and reliability, emphasizing the importance of indicators for effective management of technical systems. Recent studies have further developed these concepts by focusing on the practical application of RCM in the context of electronic soldering machines. Xiang et al. (2020), in their article *Predictive Maintenance for Soldering Machines Using IoT and Machine Learning* published in *IEEE*

Transactions on Industrial Informatics, present an innovative approach using the Internet of Things (IoT) and machine learning to monitor and analyze soldering machine data. This approach enables the anticipation of failures and optimization of maintenance schedules, thus improving the reliability and efficiency of soldering processes. Nguyen et al. (2021), in their study *Reliability Analysis and Maintenance Strategy for Electronic Soldering Equipment* published in *Journal of Manufacturing Processes*, discuss maintenance strategies based on performance indicators specific to electronic soldering equipment. They highlight the importance of data collection and analysis to improve the reliability and availability of soldering machines, which is crucial for maintaining high-quality production standards in the electronics industry. International standards also play a crucial role in establishing guidelines for the collection and exchange of reliability and maintenance data. ISO 14224:2016 provides guidelines for these practices, essential for implementing RCM systems. Additionally, ISO 55000:2014 sets out the principles and terminology for asset management, emphasizing the role of performance indicators in improving maintenance processes. Kumar (2021), in *Advanced Maintenance Strategies in Industrial Operations* published in *Journal of Industrial Engineering and Management*, highlights the latest advances in maintenance strategies, including case studies and practical applications of reliability indicators in various industrial sectors, including electronics.

Industrial equipment maintenance is a key discipline that directly influences productivity, product quality and worker safety. In this context, the use of operational safety indicators becomes essential to evaluate and improve the effectiveness of maintenance strategies. Metrics such as MTBF (Mean Time Between Failures), MTTR (Mean Time to Repair) and availability provide valuable information to diagnose equipment performance and identify areas requiring improvement. The use of these indicators is part of a process of continuous improvement and optimized asset management.

They not only make it possible to monitor equipment performance, but also to predict potential failures and develop preventive and predictive maintenance plans. This way, businesses can anticipate problems, reduce unplanned downtime and optimize maintenance costs. This dissertation explores in depth the concepts of industrial maintenance and operational safety indicators, applying them to a real case study within the ENIE company. This case study will highlight the practical challenges and solutions implemented to improve equipment maintenance.

2. PRESENTATION OF THE EQUIPMENT STUDIED

The Vitronics Soltec Delta X welding machine has evolved from a long heritage of welding machines, with thousands of units in production around the world. Packed with technology-driven features developed over generations. The DELTA X is a reliable, robust and cost-effective wave-welding machine available to the industry. Exceptional throughput, Up to three products can be processed simultaneously for maximum throughput.



Figure 2. DELTA- machine

To avoid serious corrosion in the machine, only the use of non-corrosive fluxes is permitted. These are fluxes that do not need to be removed from the PCB after soldering. The machine uses myWave software.



Figure 1. Electronic Integration Unit

3. FAILURE HISTORY

Data collection involves gathering the necessary data for calculations. Failure data is collected from historical files maintained by the operations and maintenance department of ENIE. The focus is on historical files updated from June 2023 to September 2023 and from March 2024 to May 2024. The operating and downtime caused by equipment failures (DELTA X) in minutes are presented as follows:

Table 1. Dossier historique de DELTA-X

N	Sub-elements of the machine DELTA-X	Time Between Failures (TBF) (min)	Number of Failures	Downtime due to Failures (min)
1	Conveyor- Parallelism system	120	4	360
2	Welding bath	180	3	300
3	Flux unit	300	2	180
4	Preheating	360	2	120
5	Heavy-duty titanium fingers	420	2	60
6	Crash detection	430	1	50
7	Wire feed support	440	1	40
8	PCB tracking systems	450	1	30
9	Mist spray fluxer	455	1	25
10	NitroWave	465	1	15
11	SmartWave	470	1	10

4. METHODE D'ANALYSE PREVISIONNELLE « PARETO 80/20 »

Tout d'abord, nous recueillerons les informations concernant les périodes de réparation pour chaque équipement ou intervention pendant une période spécifique. Ensuite, nous classerons ces TTR par ordre décroissant du plus long au plus

court. Ainsi, nous effectuerons le calcul des TTRs cumulés, c'est-à-dire que nous ajouterons sa durée à celle de tous les TTR supérieurs ou égaux. Les fréquences cumulées seront divisées par le total des TTR afin d'obtenir les pourcentages cumulés.

Table 2. L'analyse Pareto

N	Sub-elements of the machine DELTA-X	Number of failures	Cumulative number of failures	TTR	TTR Cumulative	TTR Cumulative %
1	Conveyor- Parallelism system	4	4	360	360	30,2%
2	Welding bath	3	7	300	660	55,4%
3	Flux unit	2	9	180	840	70,58%
4	Preheating	2	11	120	960	80,6%
5	Heavy-duty titanium fingers	2	13	60	1020	85,71%
6	Crash detection	1	14	50	1070	89,9%
7	Wire feed support	1	15	40	1110	93,27%
8	PCB tracking	1	16	30	1140	95,79%
9	Mist spray fluxer	1	17	25	1165	97,89%
10	NitroWave	1	18	15	1180	99,15%
11	SmartWave	1	19	10	1190	100%

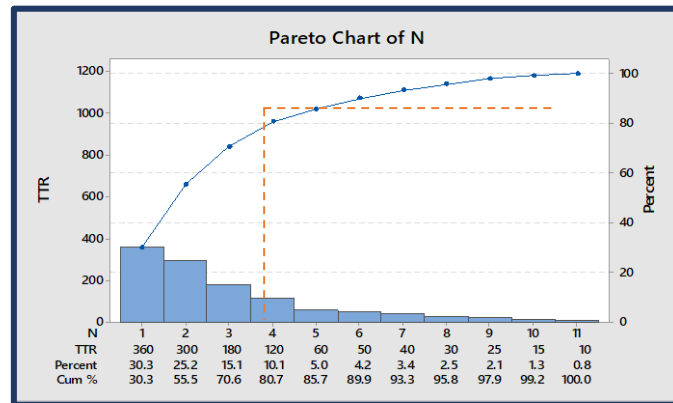


Figure 3. Pareto 80-20 Curve

The 'Conveyor System - Parallelism' has the highest total downtime (TTR), with a duration of 360 minutes, representing approximately 30.2% of the total TTR. The 'Soldering Bath' is the second most critical element, with a downtime of 300 minutes, accounting for about 25.2% of the total. Together, these two factors account for approximately 55.4% of the total downtime.

Approximately 70.6% of the total downtime is attributed to the top three elements (including 'Flow Unit' with 180 minutes). The curve shows that nearly 20% of the items (the first 3-4) are responsible for about 80% of the total downtime, highlighting the Pareto principle. Improving these critical elements such as the conveyor system, soldering bath, and flow unit could significantly reduce overall downtime. Pareto analysis emphasizes that key subsystems are responsible for

most interruptions. Focusing on these specific areas would have a significant impact on the overall availability of the DELTA X machine.

5. WEIBULL PARAMETERS CALCULATION

The statistical tool Minitab is used to perform the necessary analyses. The following $TBFs$ are sorted in ascending order, while $F(i)$ values are calculated using the median ranks method.

$$F(i) = \frac{\sum n_i - 0,3}{N + 0,4} \quad (1)$$

In our case $N=11 \leq 20$, then we plot the Weibull curve:

Table 3. Actual distribution function

N°	TBF (min)	N	$\sum n_i$	F(i)	F(i) %
1	470	1	1	0,0486	4,86
2	465	1	2	0,1180	11,80
3	455	1	3	0,1875	18,75
4	450	1	4	0,2569	25,69
5	440	1	5	0,3263	32,63
6	430	1	6	0,3958	39,58
7	420	1	7	0,4652	46,52
8	360	1	8	0,5347	53,47
9	300	1	9	0,6041	60,41
10	180	1	10	0,6736	67,36
11	120	1	11	0,7430	74,30

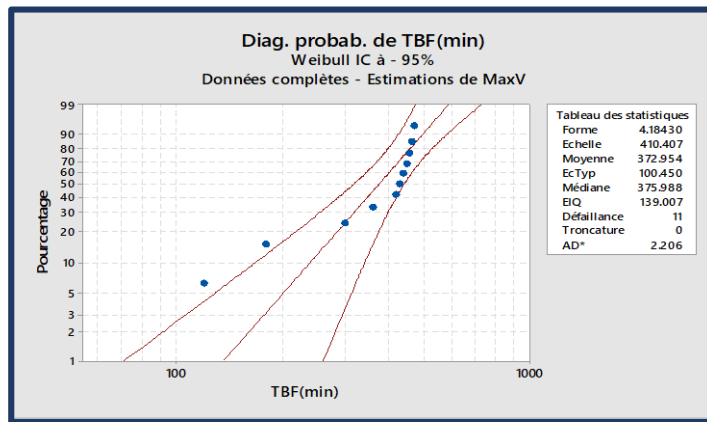


Figure 4. Weibull paper, Minitab software.

Parameter Estimation: β , η et γ using Minitab:
 $\beta = 4,18430; \eta = 410,407; \gamma = 0$,

$$F(t) = 1 - R(t) = 1 - e^{-\left(\frac{t-\gamma}{\eta}\right)^\beta} \quad (3)$$

5.1 Exploitation of WEIBULL Parameters

Le MTBF : The table of MTBF (Elsayed, A. A., 2012) gives $A=0.9077$

$$MTBF=A\eta + \gamma=0,9077*410,407+0=372,5264339 \text{ min}$$

The probability density as a function of MTBF:

$$f(t = MTBF) = \frac{\beta}{\eta} \left(\frac{t-\gamma}{\eta}\right)^{\beta-1} e^{-\left(\frac{t-\gamma}{\eta}\right)^\beta} \quad (2)$$

$$f(t) = \frac{4,18430}{410,407} \left(\frac{372,5264339}{410,407}\right)^{4,18430-1} e^{-\left(\frac{372,5264339}{410,407}\right)^{4,18430}} = 0,00384$$

The distribution function as a function of MTBF:

$$F(t=MTBF) = 0,48 = 48\%$$

The reliability as a function of MTBF: $R(t=MTBF) = 1 - F(t=MTBF) = 1 - 0,48 = 0,52 = 52\%$

It is noted that 52% reliability is relatively average.

The failure rate as a function of MTBF:

$$\lambda(t) = \frac{\beta}{\eta} \left(\frac{t-\gamma}{\eta}\right)^{\beta-1} \quad (4)$$

$$\lambda(t=MTBF) = 0,0074 \text{ failures/minute}$$

5.2 Study of the Weibull model:

The probability density function : $f(t) = \lambda(t).R(t)$

Table 4. Calculation of the Probability Density Function

TBF (min)	120	180	300	360	420	430	440	450	455	465	470
$f(t) \times 10^{-3}$	2,2	7,1	28,1	37,6	36,4	35	33,3	31,4	30,3	28,1	26,9

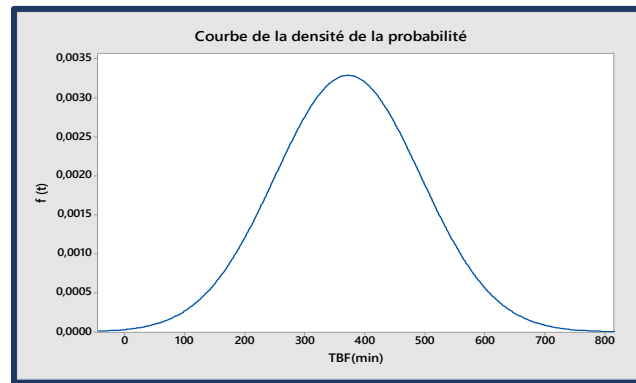


Figure 5. Probability Density.

The probability density provides a visual representation of the distribution of times to failure for a specific piece of equipment or system. It is observed that the function $f(t)$ (probability

density) increases over time until the value ($t=470 \text{ min}$), then decreases after this value.

b) *Cumulative Distribution Function F(t)*

Table 5. Distribution Table.

TBF	470	465	455	450	440	430	420	360	300	180	120
F(t)	0,82	0,81	0,78	0,77	0,73	0,7	0,66	0,43	0,23	0,03	0,0058

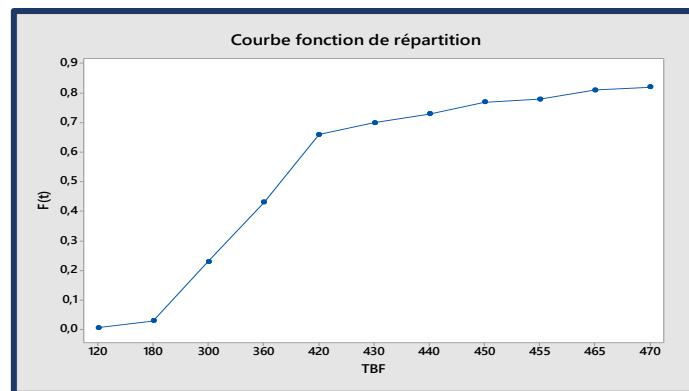


Figure 6. Cumulative Distribution Function

The curve illustrates the distribution rate $F(t)$ as a function of TBF time in minutes. The distribution function represents the risk that a failure will occur before a certain time t .

- The period (120 to 300 minutes): From 0 to approximately 0.2, the distribution function increases slightly. In this period, there is little chance of initial failure, which suggests that the equipment is still in good condition and functioning properly.
- Phase (300 to 420 minutes): The increase in the distribution function is significant, reaching approximately 0.7. This is a crucial time when the risks of failure increase rapidly. This may be caused by increased wear of equipment elements.
- Phase (420 - 470 minutes): The evolution of the curve stabilizes, with a distribution function close to 0.8,

The probability of failure keeps increasing, but at a lower rate. This suggests that most failures have already occurred, and other components are operating more stably.

5.2.3 Reliability $R(t)$

After calculating the reliability of the compressor at $t=MTBF$, we see that the value is not satisfactory. This means that the equipment is not reliable at $t=MTBF$ when the distribution function is $R(t) = 1 - F(t)$.

$$R(t) = e^{-\left(\frac{t-\gamma}{\eta}\right)\beta} \quad (6)$$

$R(t=MTBF) = 0,52$

Table 6. Reliability table

TBF	120	180	300	360	420	430	440	450	455	465	470
R(t)	0,99	0,96	0,76	0,56	0,33	0,29	0,26	0,22	0,21	0,18	0,17

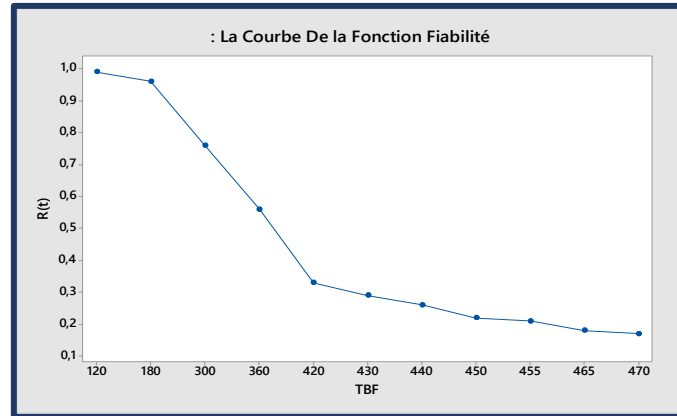


Figure 7. Reliability curve.

The reliability $R(t)$ of the equipment is represented by the curve as a function of the time TBF in minutes. Reliability refers to the probability of operating without failure over a specific period. Increasing TBF leads to a decrease in reliability, suggesting that the probability of operating without failure decreases as the equipment remains in service longer.

- Phase (120 to 300 minutes): A rapid increase in reliability from 1.0 to about 0.5.

Reliability degrades quickly during this phase, suggesting that failures become more common.

- Phase (approximately 300 to 420 minutes): Reliability continues to decline, reaching a value of about 0.3.

The probability of failure continues to increase, but at a slightly slower rate than in the initial phase.

- Phase (420 to 470 minutes): Reliability decreases more steadily, reaching about 0.1.

The decline in reliability stabilizes, indicating a period where the remaining components are at the end of their life and failures occur at a more predictable rate.

5.2.4 The failure rate $\lambda(t)$

Table 7. Failure rate table

$TBF (min)$	120	180	300	360	420	430	440	450	455	465	470
$\lambda (t)$	0,0002	0,0007	0,003	0,006	0,010	0,011	0,012	0,013	0,014	0,015	0,016

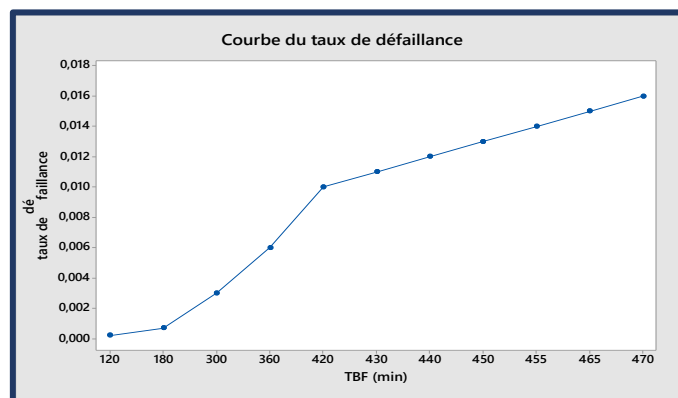


Figure 8. Failure rate curve.

The curve allows the evaluation of the failure rate of DELTA X equipment based on the TBF , expressed in minutes. It highlights the variation in the failure rate over time. Overall, the TBF leads to an increase in the failure rate, suggesting that DELTA X equipment is more likely to fail as it operates for longer periods.

- Stage (120 to 300 minutes): The failure rate is very low and has slightly increased. This period can be described as the break-in phase where failures are infrequent.

- Phase (approximately 300 to 420 minutes): A significant increase in the failure rate. This is the critical moment where the equipment begins to show signs of rapid wear. This stage is marked by an increase in failures, suggesting a greater need for monitoring and maintenance.

- Phase (420 to 470 minutes): The failure rate continues to increase but more gradually. This stage indicates a certain stability in the increase of failures.

5.3 Maintainability Calculation

$MTTR = 62,63$

According to the failure history of DELTA X:

$M(t) = 1 - e^{-\mu(t)}$ (7)

$MTTR = \sum TTR / N$; TTR : Time To Repair; $MTTR$ (Mean Time To Repair); N : number of breakdowns

$\mu = 1/MTTR = 1/62,63 = 0,0159$ intervention / minute

Table 8. Maintainability Table

TTR	10	15	25	30	40	50	60	120	180	300	360
$M(t)$	0,147	0,212	0,328	0,379	0,470	0,548	0,614	0,851	0,942	0,991	0,996

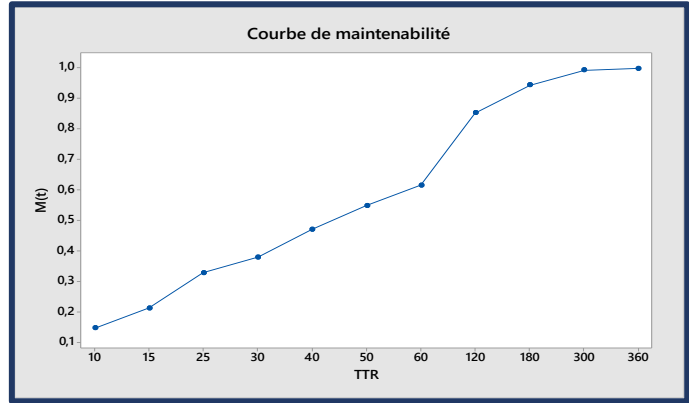


Figure 9. Maintainability Curve.

The curve illustrates the relationship between maintainability ($M(t)$) and Time to Repair (TTR) in minutes. Maintainability is an indicator of the ease and speed with which equipment can be repaired and put into service after a breakdown. Maintainability increases with TTR , suggesting that repairs become more frequent and more efficient as the time spent on repairs increases.

- (10 to 60 minutes): The degree of maintainability gradually increases from 0.1 to almost 0.5. The phase presents a continuous improvement in the repair capacity of the equipment. The efficiency of repairs increases.
- (60 to 180 minutes): Maintainability increases faster, reaching around 0.9. This phase demonstrates a notable improvement in sustainability.

• (180 - 360 minutes): The saturation values of the curve are 0.9 to 1.0. Maintainability is approaching its peak, which suggests that most repairs can be carried out in this period. There is no significant improvement in maintainability by increasing the TTR .

$MTBF = \frac{1}{\lambda} \Rightarrow \lambda = \frac{1}{MTBF} = \frac{1}{372,5264339} = 0,00268$;

$MTTR = \frac{1}{\mu} \Rightarrow \mu = \frac{1}{MTTR} = \frac{1}{62,63} = 0,0159$

$D(t) = \frac{0,0159}{0,00268+0,0159} + \frac{0,00268}{0,00268+0,0159} e^{-(0,00268+0,0159)t}$

5.4 Availability calculation

$D(t) = \frac{\mu}{\mu+\lambda} + \frac{\lambda}{\lambda+\mu} e^{-(\lambda+\mu)t}$ (8)

Table 9. Availability table

$T(h)$	10	20	30	40	50	60	70	80	90	100	110
$D(t)$	6,05	6,03	6,01	6	5,99	5,98	5,97	5,96	5,95	5,94	5,93

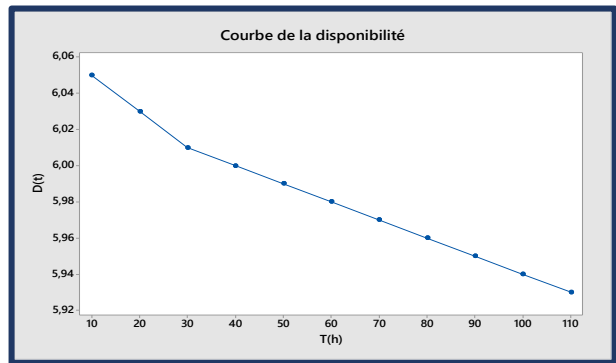


Figure 20. Courbe de la disponibilité.

The curve illustrates the evolution of availability $D(t)$ as a function of time $T(h)$. Equipment availability decreases over time. This suggests that equipment is becoming less accessible over time.

• (10 to 30 hours): The number of availabilities quickly increases from 6.06 to almost 6.00. During this stage, we

observe a rapid decrease in availability, probably due to initial failures or an increase in component load.

• (30 to 110 hours): More and more regularly, availability decreases, going from 6.00 to 5.92.

The fact that availability gradually decreases indicates constant wear and tear of equipment elements, which requires regular maintenance interventions.

5 FMEA

Table 10. FMEA (Failure Modes and Effects Analysis)

Analysis of failure modes, their effects and their criticalities										
Subsystem: DELTA X					Date : May 2024					
The element	Function	Failure Modes	Cause	Effect	Detection	Criticality				Action
						O	S	D	C	
Conveyor system - parallelism	Guide and carry cards	Misalignment, belt misalignment	Wear, improper tension, crash	Bad board interface/wave of welding, welding defects	Visual	6	7	5	210	Regular maintenance, adjustment of belt tension
Solder bath	Providing a pool of molten solder	Contamination, oxidation of the bath	Inadequate bath maintenance, debris	Weld bridges, insufficient wetting, defective joints	Visual	5	8	4	160	Frequent inspection of the bath, regular filtration and cleaning
Flow unit	Apply flux evenly	Clogging, irregular flow deposit	Flow quality problems, clogged nozzles	Excessive/insufficient flux, defective seals	Visual	4	6	6	144	Cleaning and checking nozzles, checking flow quality
Preheating	Heat the cards evenly	Uneven heating, overheating	Failure of heating elements, temperature regulation problems	Thermal stresses on components, welding defects	Visual	5	7	5	175	Inspection of heating elements, regular calibration of the regulation system
Titanium conveyor fingers	Carry the cards	Damaged, misaligned fingers	Crash, wear, debris	Board transport problems, soldering defects	Visual	4	6	5	120	Replacement of damaged fingers, cleaning and preventative maintenance
Crash detection	Detect collisions	Detection failure	Failing sensors, software issues	Potential damage to the machine, safety risks	Alarm	3	9	3	81	Regular sensor testing, software updating, preventive maintenance
Card rail support	Support card	Misalignment, damage	Wear, crash	Inadequate board support, solder defects	Visual	4	6	6	144	Regular inspection and adjustment of rails, replacement of worn rails
Card Tracking Systems	Track map position	Tracking Failure	Software issues, faulty sensors	Bad wave interface, soldering defects	Visual	4	7	5	140	Verification and calibration of sensors, updating and testing of software
Fluxator spray	Spray flow	Clogging, irregular deposit	Flow quality problems, clogged nozzles	Excessive/insufficient flux, defective seals	Visual	4	6	6	144	Cleaning and checking nozzles, checking flow quality
NitroWave, SmartWave	Produce optimal wave dynamics	Component failure, calibration problems	Wear, improper adjustments	Welding defects, incomplete filling	Visual	5	8	4	160	Regular maintenance, calibration and adjustment of machine parameters

Frequency, severity, detection, and criticality values in a FMEA table are often determined by qualitative and quantitative analysis based on experience, historical data, and expert knowledge. These parameters are evaluated as follows, according to Carlson, C. S. (2012) and Hua, A. H. (2009):

Occurrence (O): Probability of occurrence of the failure mode: 1 to 2: Very rare; 3 to 4: Rare; 5 to 6: Occasional; 7 to 8: Common; 9 to 10: Very common.

Severity (S): Impact of the failure mode on the system, safety, or quality, 1 to 2: Minor impact; 3 to 4: Moderate impact; 5 to

6: Significant impact; 7 to 8: Severe impact; 9 to 10: Catastrophic impact.

Detection (D): Ability to detect the failure mode before it causes damage, 1 to 2: Very easy detection; 3 to 4: Easy detection; 5 to 6: Moderate detection; 7 to 8: Difficult detection; 9 to 10: Very difficult detection.

Criticality (C): Product of the three previous values: $C = S \times O \times D$

7. CONCLUSIONS

In the present work we can conclude that It is essential to conduct an in-depth study in this chapter on the reliability and durability of the DELTA X welding machine from VITRONICS SOLTEC, Through the use of renowned analysis methods like Pareto, Weibull and FMEA, essential variables such as failure rate $\lambda(t)$, *MTBF*, *MTR* and availability were carefully calculated. Thanks to these results, it is possible to identify essential subsystems that require special attention with regard to preventive maintenance and replacement of parts. Additionally, a good understanding of different types of failures and their consequences allows proactive corrective measures to be taken to reduce downtime and improve overall machine performance. It is essential to regularly perform detailed reliability and maintainability analyzes for complex industrial systems, as this study highlights. Exploiting this knowledge, companies have the opportunity to reduce operating expenses, improve product quality and optimize overall productivity.

ENIE's case study revealed several practical challenges, including managing downtime and repair process efficiency, by analyzing company-specific data and comparing performance to company standards. In industry, we were able to identify concrete solutions and formulate recommendations to improve maintenance. These recommendations, based on a rigorous analysis of performance indicators, aim to maximize the availability of equipment and guarantee the safety of operations. Thus, this work highlights the crucial importance of operational safety indicators in industrial maintenance. It provides a roadmap for maintenance managers, allowing them to navigate a complex and constantly evolving industrial environment. By adopting a data-driven approach and committing to continuous improvement, businesses can not only meet current requirements, but also prepare for future challenges, ensuring sustainable and competitive performance in the long term.

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