SMART MAINTENANCE STRATEGIES FOR EQUIPMENT OPTIMIZATION: A RELIABILITY-CENTERED APPROACH TO ARCHERFISH

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ABSTRACT

Efficiency is a crucial component in almost every industry. In the modern era of fast-paced manufacturing and innovation, the ability to produce a product with the least amount of necessary resources provides a significant competitive edge.

In this paper, the authors demonstrate the application of Reliability Centered Maintenance (RCM) in identifying the appropriate maintenance tasks for one of the key parts of the DACA (Die Attach Clip Attach) machine, specifically the Archerfish. It is responsible for generating different air pressure levels in its dispense system. Guided by RCM principles, a holistic and efficient approach was established to enhance the repair procedure of the Archerfish module. The installation of air filters in the Archerfish modules to mitigate dirt accumulation proved to be a critical step in preventing functional failures.

Using RCM methodology, an effective maintenance and repair procedure was developed and implemented, establishing a cost-efficient solution that extends the lifespan of the machine's key components. This approach achieves annual hard cost savings of $150,000.

1. 0 INTRODUCTION

The process of producing semiconductors is intricate and extremely accurate, requiring several stages in order to create integrated circuits (ICs) or microchips. Every step of the process, from the first silicon wafer preparation to the last packaging and testing, is essential to creating the high-performance microchips that drive modern electronics.

Part of the assembly process at Nexperia is the DACA process, which is essential in device packaging, particularly for power devices and high-performance ICs. These technologies are crucial for ensuring proper thermal management, mechanical stability, and electrical connectivity within a semiconductor package.

Die attach secures the die to its substrate, establishing critical thermal and electrical connections, while clip attach strengthens these connections, especially for power devices that demand efficient heat dissipation and low electrical resistance. Together, these processes ensure the reliable performance of semiconductor devices in various demanding applications.

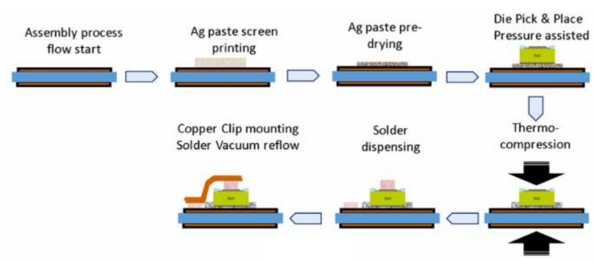


Fig. 1: Die Attach Clip Attach Process Flow

A critical aspect of this process is the dispensing system, which ensures that components are securely bonded and that the final products adhere to strict quality standards. Within this system, the Archerfish plays a key role by generating precise air pressure levels at specific time intervals, enabling the dispensing tool to accurately apply adhesive materials.

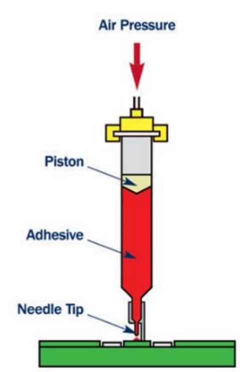


Fig. 2: Dispensing using Time-Pressure Valve

Proper dispensing minimizes the risk of common defects such as inadequate adhesion, voids, overflow, or excessive adhesion, which could compromise the thermal and electrical performance of the assembled device or lead to its failure.

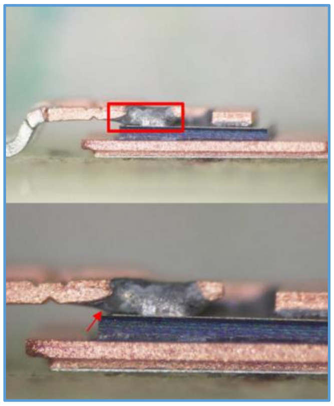


Fig. 3: Excessive Gate solder due to Dispensing Failure

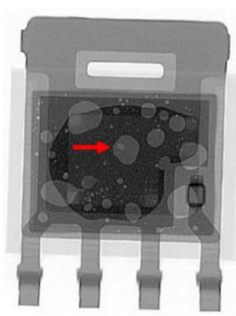


Fig. 4: Solder Voids

At the beginning of 2024, a substantial number of Archerfish units were escalated for repair. Data analysis revealed a rising failure rate, increasing from less than one defective unit per week to an average of 2.31 failures per week in the first quarter of 2024. This increase is attributed to the lack of maintenance, or the machine being operated under a run-to-fail condition.

Fig. 5: Archerfish Failure Rate

Given that the DACA line is a constrained area, the issue was quickly escalated for immediate resolution. The initial challenge identified was the high cost associated with the existing repair procedure, which typically involves replacing the defective unit. Although refurbishment offers an alternative, it still requires a substantial financial investment. The failure also led to additional downtime due to extended isolation, offline repairs, and recalibration.

With the severity of the situation now clear, an efficient and sustainable solution has become necessary. The primary goal of this study is to enhance the maintenance program and repair system. RCM was selected as the methodology, as it aligns with the objective of providing a sustainable and cost-effective solution.

2. 0 REVIEW OF RELATED WORK

Developed in the 1970s within the aviation industry, RCM was designed to ensure flight safety while minimizing maintenance expenses (Moubray, 1997). Since then, RCM has been widely adopted across various sectors such as manufacturing, power generation, and healthcare, due to its ability to improve equipment reliability by focusing on specific failure modes and their consequences. Its effectiveness stems from balancing maintenance costs against the risks of equipment failure, ultimately enhancing operational efficiency.

RCM has been effectively applied across a variety of industries. In the oil and gas sector, for example, RCM has extended the lifespan of drilling equipment by analyzing the effects of harsh operational conditions and developing maintenance strategies tailored to specific wear-and-tear patterns (Harris & McKay, 2008). Likewise, RCM has been instrumental in the healthcare industry, particularly in the maintenance of medical devices where equipment failure can have severe, life-threatening consequences (Rausand, 2013). Studies consistently demonstrate that RCM enhances safety and performance in multiple sectors by addressing potential equipment failures before they lead to significant operational disruptions.

In Nexperia, RCM has been implemented for several years with numerous studies demonstrating its methodology's significant impact on performance improvement, process efficiency, and cost savings.

From 2021 to 2024, a total of 47 projects were completed, generating an accumulated cost savings of $1.8 million.

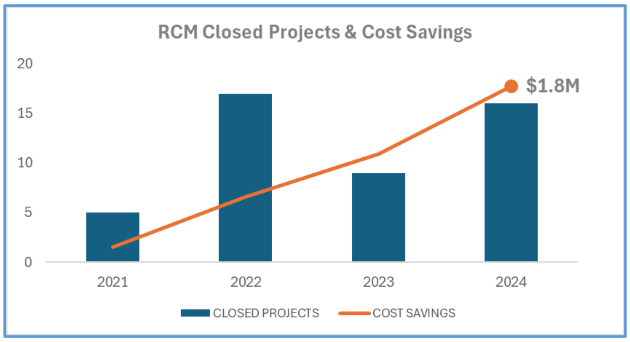


Fig. 6: Nexperia RCM Closed Projects & Cost Savings

Unlike the conventional time-based maintenance approach, RCM introduces a novel method for identifying necessary tasks and eliminating traditional preventive maintenance part replacements, which are often found unnecessary and can lead to resource wastage.

Below are some notable RCM Projects since its implementation in Nexperia:

2.1 Wirebond Hesse Grub Screw Cost Reduction (Frontline)

Consumption reduction by 33% through defining Grub screw life.

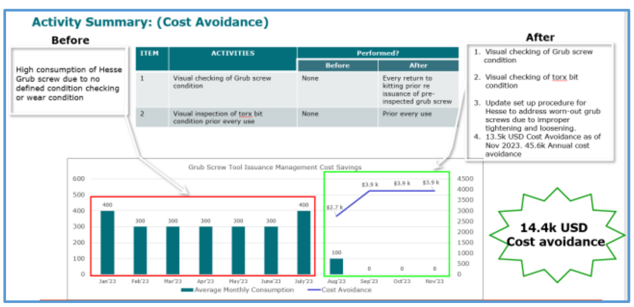


Fig. 7: Grub Screw Consumption RCM Project

Significantly reduces the Grub Screw consumption that translates to $45.6k projected annual cost avoidance and $6.1k direct cost savings.

2.2 MDA3-010 Capacity Restoration (Midend)

Initiative to recover MDA3-010 capacity from 281kpd to 312kpd by determining the top downtime count and duration contributor.

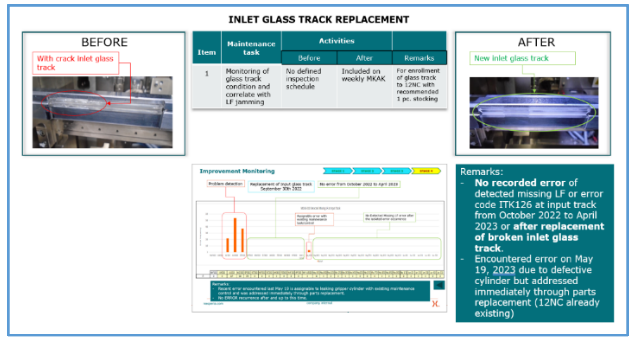


Fig. 8: Inlet Glass Track RCM

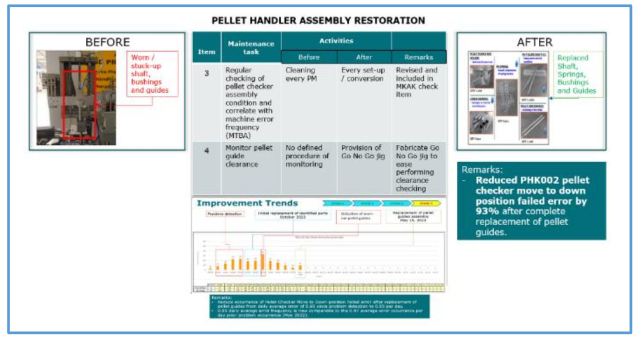


Fig. 9: Pellet Handler Assembly RCM

The target capacity was not only recovered but also improved by 0.64% following the implementation of the identified maintenance tasks on the targeted modules.

2.3 SOT1210 Contact Finger Consumption Reduction (Backend)

An initiative to reduce 20% contact finger consumption for SOT1210 package.

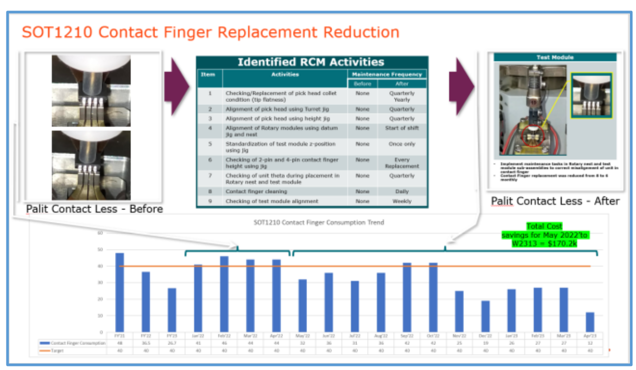


Fig. 10: SOT1210 PCL RCM Project

Implement maintenance tasks in Rotary and Test Site modules corrected the misalignment and theta alignment issues in test modules. This resulted in reduced contact finger replacement from an average of 8.3 (January to April) to 4.5 in May and June 2022 and generated $47.6k cost savings.

Overall, RCM improves operational efficiency, safety, and cost-effectiveness, making it an indispensable tool in modern maintenance management. Continued adoption of the maintenance system demonstrates its effectiveness and long-term sustainability for the company's future.

3.0 METHODOLOGY

Reliability Centered Maintenance is intended to maximize maintenance efforts by concentrating on significant malfunctions that affect the performance, safety, and operation of the system. It assists businesses in creating focused, affordable maintenance plans that reduce risks and increase dependability.

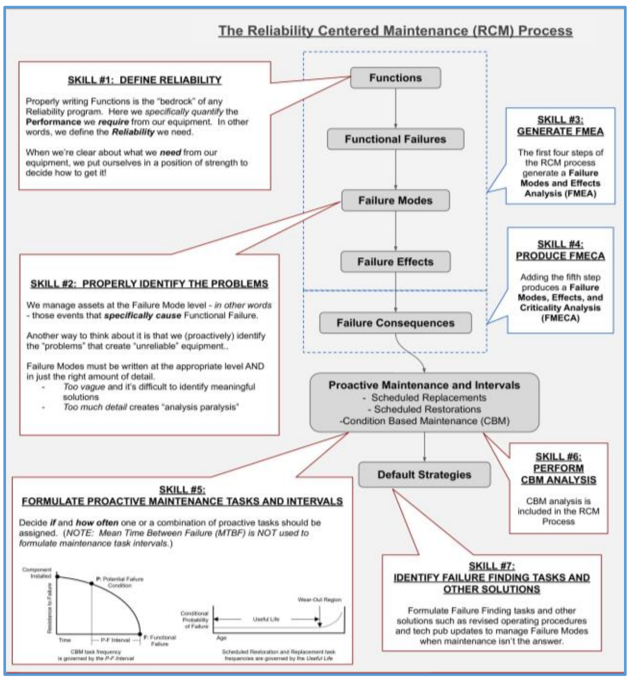


Fig. 11: RCM Process

RCM also has several advantages over conventional maintenance techniques. Its primary benefit is that it emphasizes system functionality and criticality, resulting in more effective and efficient maintenance procedures. Instead of using a preventative maintenance schedule that is universally applicable, as in the case of traditional techniques, RCM customizes maintenance chores according to the unique failure modes, consequences, and criticality of each component in the system.

Providing Archerfish with an efficient maintenance program at the lowest possible cost of upkeep and repairs is crucial. These two conditions are met by RCM, and the main reason why the maintenance system was adopted.

The following structured procedures were put into practice in accordance with the RCM methodology:

3.1 Identify System Functions

The first step is to define the system's intended uses, performance requirements, and operational environment.

3.1.1 Archerfish Process Flow and Functionality

Archerfish is a tool in DACA machines capable of generating different levels of air pressure needed for dispense.

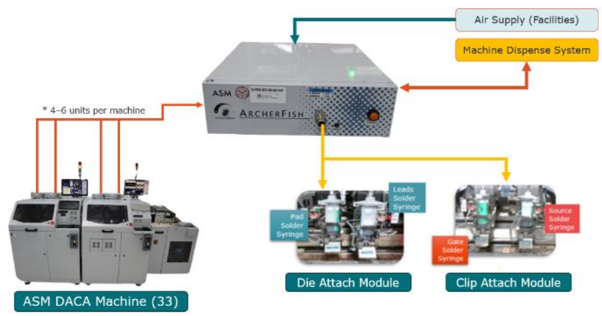
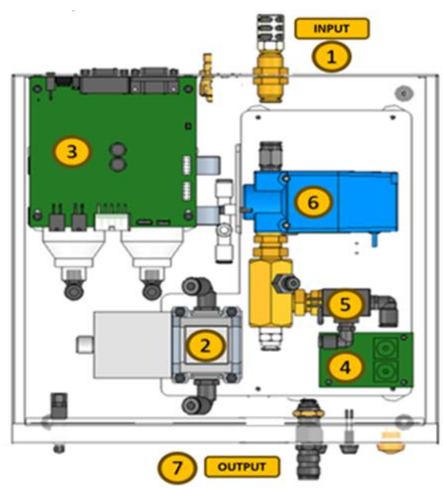


Fig. 12: Archerfish Process Flow

Below are the list of parts and functionality:



Part Number	Description	Function (short description of the functionalities of each part)
1	Compressed Air (CA) Input	Receives the compressed air input from the facility source
2	Regulator	Regulates the compressed air from the facility source input
3	Pressure Board	Communicates with the main machine and other board in the unit to send analog signal to other parts of the Archerfish to generate specific air pressure required
4	ALG Board	Receives electrical signal from Pressure Board to control air output in the solenoid valve
5	Flow Valve	Control the flow rate of the air output
6	Manifold Valve	Divert excess air to the exhaust to maintain consistent pressure level
7	Output	Supply the compressed air to the dispensing module

Fig. 13: Archerfish Parts and Functions

3.1.2 Operating Context

Defining Operating Context provides a comprehensive perspective of the existing conditions in which a system or physical asset is anticipated to function.

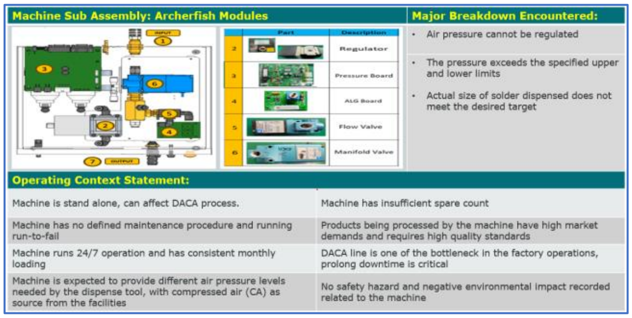


Fig. 14: Operating Context Statement

Understanding the operating context allows for the development of maintenance strategies that are tailored to the specific demands, risks, and constraints of the system.

3.2 Identify Failure Mode

Identifying failure modes in RCM involves a thorough understanding of the system, a breakdown of its components, and an analysis of potential causes of failure. A comprehensive understanding of critical components and their functions is essential for identifying potential functional failures and determining their failure modes.

3.2.1 Identifying Functional Failure

During the initial data gathering, a Pareto analysis was conducted to identify the most frequently failing components of Archerfish. The data indicates that the Manifold Valve is the component with the highest failure occurrence (See Fig.15).

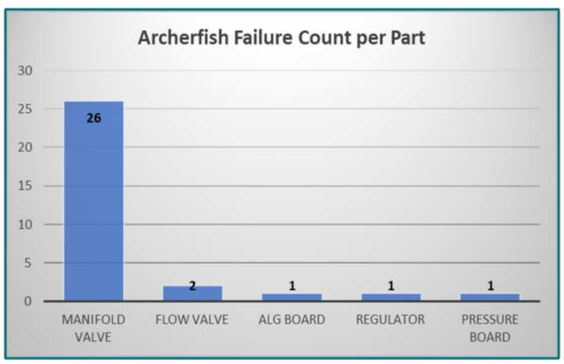


Fig. 15: Archerfish Failure Rate

The critical components of the Manifold Valve were thoroughly evaluated, and failure modes were systematically identified by analyzing historical data, consulting experts, and considering various operational conditions.

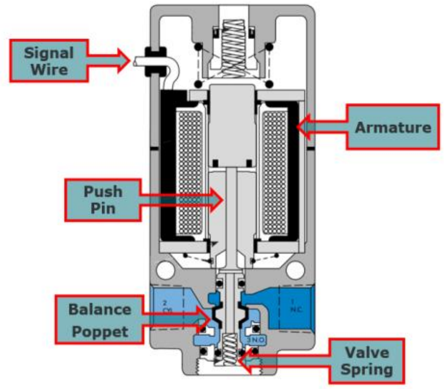


Fig. 16: Manifold Valve Parts

Figure 17 revealed that Archerfish units that encounter functional failure shows contamination of parts due to accumulated dirt, debris, or other foreign particles.

Fig. 17: Defective Manifold Valve

The accumulation of dirt is due to the type of air source used by the DACA machine, which relies on Compressed Air (CA) from the facility. Compressed air that is not properly dried can negatively impact solenoid valves by introducing moisture and contaminants. Moisture in the air brings water vapor into the valve, which, over time, can corrode internal metallic components like springs and plungers. This corrosion can lead to valve sticking, leaking, and impaired sealing surfaces, ultimately resulting in obstructed movement or valve failure.

Figure 18 illustrates how accumulated dirt on the balance poppet obstructs its movement, leading to intermittent air exhaustion affecting output air pressure levels.

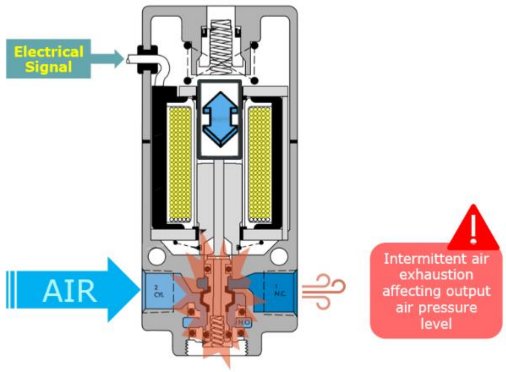


Fig. 18: Manifold Valve Functional Failure

3.2.2 RCM Information Worksheet

RCM Information Worksheet is a specialized tool in the RCM process that offers a structured method for documenting, analyzing, and prioritizing maintenance-related information.

After collecting all necessary information, the team completed the RCM Information Worksheet to gain a comprehensive view of the failure modes. (See Fig.19)

	Component | Function		Functional Failure		Failure Mode	Failure Effect Side Effect if not replaced
1	Divert excess air to the exhaust to maintain consistent pressure level ❑ Air Pressure Levels: 20kpa / 50kpa / 100kpa / 200kpa ❑ Tolerance: +/- 10kpa	A	Failure to divert excess air to the exhaust to maintain consistent pressure level (intermittent) ❑ Intermittently exceeding +/- 10kpa tolerance, but still can be adjusted	1	Failure to divert excess air due to **worn-out balanced poppet**	**EFFECT:** Archerfish will continue function but with slight inaccuracy in defined air pressure range **CONSEQUENCES:** Actual size of solder dispensed does not meet the desired target **EHS:** None **Productivity:** Machine downtime **Machine DT:** 50mins (replacement/recalibration of Archerfish unit) **Quality:** Dispensing inaccuracy **Cost:** (per item specific)
				2	Failure to divert excess air due to **dirt accumulation on balanced poppet**	
				3	Failure to divert excess air due to **worn-out valve spring**	
				4	Failure to divert excess air due to **dirt accumulation on valve spring**	
				5	Failure to divert excess air due to **worn-out solenoid push pin**	
				6	Failure to divert excess air due to **worn-out armature**	

Fig. 19: RCM Information Worksheet

By consolidating all relevant information in a single resource, the worksheet ensures that maintenance decisions are informed and tailored to the specific requirements of the system.

3.2.3 RCM Decision Diagram Tree & Maintenance Plan

RCM Decision Diagram Tree was utilized to identify the most suitable maintenance approach—whether preventive, predictive, corrective, or run-to-fail—by systematically assessing the failure modes of the system in terms of their impact on safety, operations, and costs.

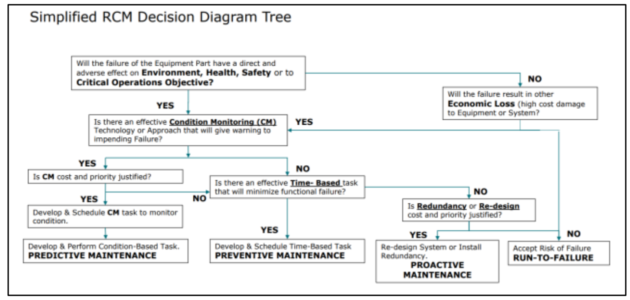


Fig. 20: Simplified RCM Decision Diagram Tree

After identifying the failure modes of the critical components and utilizing the Decision Diagram Tree, it was determined that the failure consequence is Hidden, necessitating Predictive Maintenance. Regular inspections of identified critical parts and the installation of an air filter are defined as the required maintenance tasks. Transitioning from the previous run-to-fail approach due to the lack of a maintenance program, proper maintenance for Archerfish will now be conducted semi-annually by the Electrical Board Repair Team (EBRT).

Failure Mode	Failure Consequence	RCM Decision Diagram Maintenance Program	Proposed Maintenance Task	Maintenance Classification							Interval	Responsible
				PdM	PM-R	PM-D	FFT	OTC	CoT	RTF		
Failure to divert excess air due to worn-out balanced poppet	Hidden	Predictive Maintenance	Regular checking of air pressure ranges, checking, cleaning, and replacement of parts as needed.	Yes	-	-	-	-	-	-	Semi-annual	EBRT
Failure to divert excess air due to dirt accumulation on balanced poppet	Hidden	Predictive Maintenance	Installation/replacement of air filter to input compressed air source to minimize debris/dust accumulation inside the Archerfish modules.	Yes	-	-	-	-	-	-	Semi-annual	EBRT
Failure to divert excess air due to worn-out valve spring	Hidden	Predictive Maintenance	Regular checking of air pressure ranges, checking, cleaning, and replacement of parts as needed.	Yes	-	-	-	-	-	-	Semi-annual	EBRT
Failure to divert excess air due to dirt accumulation on valve spring	Hidden	Predictive Maintenance	Installation/replacement of air filter to input compressed air source to minimize debris/dust accumulation inside the Archerfish modules.	Yes	-	-	-	-	-	-	Semi-annual	EBRT

Fig. 21: RCM Task Decision Worksheet

3.2.4 Monitoring and Controls

To support monitoring and control efforts, a Repair Monitoring Tool (SharePoint) was developed. Additionally, work instructions for the new maintenance procedure were issued, along with a checklist to ensure consistent and ongoing implementation of proper maintenance practices.

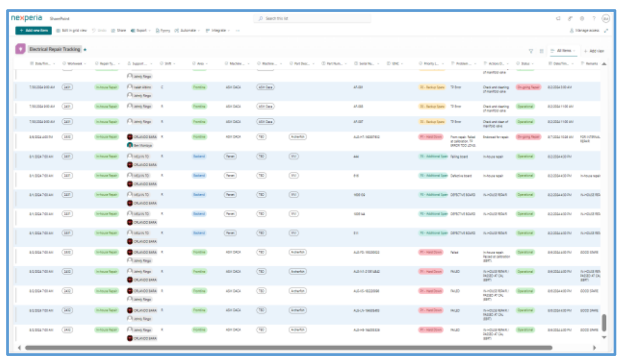


Fig. 22: Repair Monitoring Tool

Mean Time Before Failure (MTBF) monitoring was also performed to ensure the quality of work of the repair team.

Continuous monitoring of the maintenance plan's effectiveness and making necessary adjustments are crucial for optimizing the performance of the Archerfish.

4.0 RESULTS AND DISCUSSION

This section presents the results and analysis of the methodology described in the previous sections. It starts with the implementation of Repair Improvements, followed by the development of a new Maintenance Procedure, and concludes with the Cost Savings achieved through these initiatives.

4.1 Repair Improvements

For over a decade, Archerfish units at Nexperia followed a run-to-fail strategy, where defective units were replaced with new ones, each costing $3,827.25. In 2023, a refurbishment program was launched, allowing the purchase of $1,528 replacement kit that restored most major components, reducing the reliance on buying new units. This repair method continued until the implementation of the RCM initiative in 2024.

Today, Archerfish repairs prioritize addressing specific component failures. The initial step in the process involves restoring functionality through cleaning, with part replacements being made only when necessary. The team has also developed the capability to repair component-level failures in critical Archerfish modules by systematically troubleshooting and identifying frequently failing parts, which has been essential to the repair process. Furthermore, a straightforward yet effective tool, the Archerfish Checker (see Fig.24), has been created to test the functionality of repaired components (Air Regulator, Manifold Valve, and Flow Valve), ensuring their full operability before reinstallation.

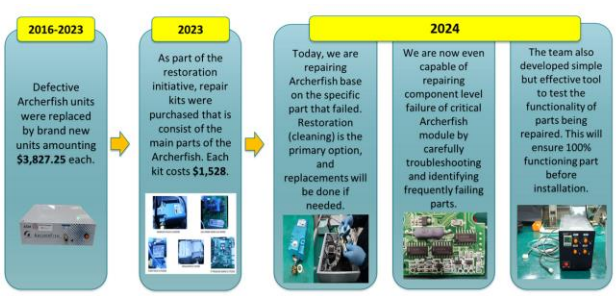


Fig. 23: Archerfish Repair History

Fig. 24: Archerfish Checker

Figure 25 illustrates the cost impact of the repair improvement. Following the implementation of a new repair procedure, the cost of repairing a single Archerfish unit was substantially reduced. This trend is particularly evident starting year 2024; despite an increase in the number of accumulated units repaired, the total repair cost is significantly lower. This outcome highlights the effectiveness of the new repair process.

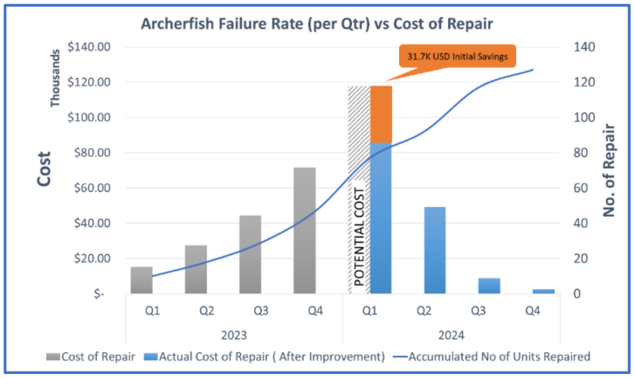


Fig. 25: Archerfish Failure Rate vs Cost of Repair

Another key element of the new repair system is evaluating its effectiveness by monitoring MTBF for each repaired unit. Figure 26 illustrates the MTBF trend of the repaired units that started workweek 2 of 2024.

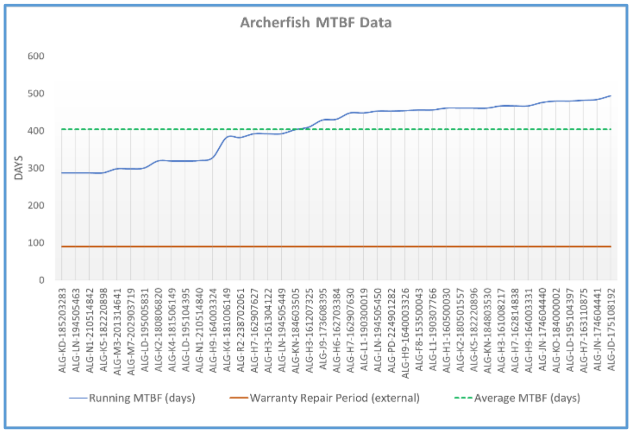


Fig. 26: MTBF Graph

As of workweek 20 of 2025, the first repaired unit has achieved over 494 days of continuous operation without failure. This performance is consistent across most repaired units, which exhibit an average Mean Time Between Failures (MTBF) exceeding 404 days, surpassing the standard 90-day warranty offered by external vendors. These results underscore the improved reliability and effectiveness of the new in-house repair process.

4.2 Maintenance Improvements

The significant increase in the failure rate of Archerfish units can be directly linked to the absence of an effective maintenance program. This issue was addressed by developing appropriate maintenance tasks for critical components, establishing criteria for proper assessment, and implementing control measures through documented procedures and checklists.

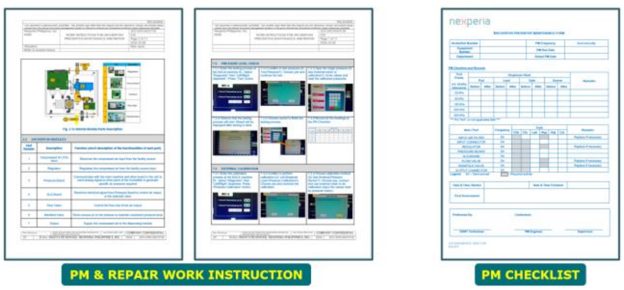


Fig. 27: Documented Controls

As part of the maintenance enhancements, air filters will be installed on each Archerfish unit to mitigate dirt accumulation in critical components, which can lead to functional failures.

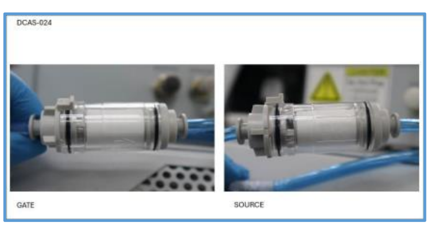


Fig. 28: Air filter installation

Additionally, the installed air filters will be monitored regularly post-installation.

4.3 Internal Repair Cost Savings

Implementing an effective maintenance program and enhancing the repair procedures directly results in cost savings. Extending the lifespan of each Archerfish unit translates to significant financial savings for the company, as the need to purchase new units or parts is reduced (Direct Cost Savings). Additionally, developing internal repair capabilities has allowed the company to avoid substantial repair expenses (Cost Avoidance).

The formula used to calculate total cost savings is shown below in Figure 29.

Cost Savings:

$$\text{Cost Savings} = \left(\frac{\text{Cost of New Parts} - \text{Cost of Refurbishing}}{\text{Cost of New Parts}}\right) \times 100$$

This measures the percentage of savings from refurbishing.

Fig. 29: Cost Savings Formula

Figure 30 illustrates the repair history, and the corresponding cost avoidance achieved throughout the project.

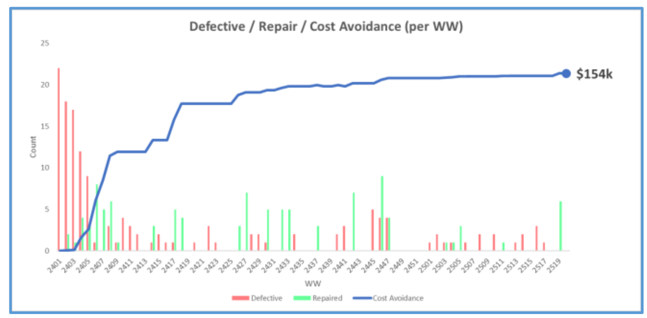


Fig. 30: Defective vs Repaired and Accumulated Cost Avoidance per Workweek

As of workweek 20 of 2025, the initiative has achieved $154,000 in cost avoidance through internal repair activities. Additionally, it has generated $67,000 in direct cost savings by reducing the consumption of spare parts in 2024—savings that are expected to continue in the subsequent years.

5.0 CONCLUSION

Maintenance is essential for ensuring reliable performance, extended lifespan, and prevention of unexpected failures in machines. Routine maintenance reduces downtime, lowers repair costs, and improves safety by proactively addressing potential issues before they escalate. This proper upkeep not only enhances efficiency and productivity but also contributes to overall operational success.

As technology and machinery evolve, maintenance systems must adapt. RCM stands out as a superior maintenance approach, focusing on optimizing strategies based on specific system functions and failure modes. It prioritizes maintenance activities by evaluating their impact on safety, reliability, and cost-effectiveness, ensuring efficient resource allocation. Unlike traditional, one-size-fits-all maintenance programs, RCM customizes maintenance tasks to target critical components, reducing unnecessary work, minimizing downtime, and boosting overall system performance.

The completion of the Archerfish project marks the beginning of a continuous, evolving process. As RCM adapts to the system's feedback and controls, it will drive necessary improvements to ensure sustained positive outcomes and long-term operational success.

6.0 RECOMMENDATIONS

Reliability Centered Maintenance is a dynamic and evolving maintenance approach designed to adapt to the demands of advancing technologies, shifting operational conditions, and changing system requirements. By fine-tuning maintenance strategies based on real-world data and outcomes, RCM ensures that maintenance practices remain both effective and relevant.

Recent advancements in predictive maintenance technologies, such as machine learning and IoT (Internet of Things) sensors, further enhance the potential of RCM. Predictive analytics provide real-time data on equipment health, enabling organizations to make more informed maintenance decisions based on current operational conditions rather than relying solely on historical data. Integrating predictive technologies such as SPC (Statistical Process Control) and even AI (Artificial Intelligence) into RCM frameworks improves the accuracy of failure mode predictions and opens up new opportunities for optimizing maintenance strategies.

As part of the project's ongoing improvement, evaluating the compressed air supply is the next step. Given that most Archerfish repairs are due to dirt and moisture damage from the current compressed air, it is worth considering the feasibility of switching to Compressed Dry Air (CDA). CDA could either be supplied by the facilities or generated by installing filter dryers on the equipment. Presently, facilities provide CDA at -22 to -40°C Td (dew point), while existing production filter dryers achieve around -30°C. A cost analysis will help determine the most economical approach.

In a competitive environment like Nexperia, where efficiency is a core principle, RCM introduces the necessary flexibility to adapt to evolving technological challenges. Its ability to maintain product quality in a cost-effective manner provides a clear advantage over the competition. From managing critical machinery to optimizing complex manufacturing processes, RCM can be adopted to streamline operations and reduce resource utilization.

7.0 ACKNOWLEDGMENT

In order to finish the project, collaboration with several teams were made, whom the authors would like to thank and appreciate. These consist of Operations Management, Equipment and PM Technicians, and Engineers.

The authors also like to extend their special gratitude to Joebert Saballas, Edwin Ang, George Ila, Josel De Leon, Nellie Castillo, Allan Sosa, Harold Gutlay, Debbie Alcala, and Gareth Hughes for their guidance and support.

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