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Solving Manufacturing Problems with 8D Methodology: A Case Study of Leakage Current in a Production Company

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Abstract
Customer satisfaction is critical for the success of any organization. This case study presents a design company and manufacturing supplier that has received customer complaints about defective temperature sensors and power supply units in maritime vessels. The research aims to identify the root cause of the issue and implement a solution to prevent its recurrence using the Lean Eight Disciplines methodology. This includes: (1) a 5 Whys analysis by a cross-functional team, (2) confirmation of the problem description, (3) containment actions, (4) root cause analysis of the occurrence, (5) permanent corrective actions, (6) implementation of the permanent corrective action, (7) actions to prevent recurrence, and (8) closure with an 8D report and congratulations to the cross-functional team from the design, engineering, and supplier production sites.

This study presents the development and implementation of the Eight Disciplines (8D) investigation tool for addressing issues in the factories and improving the product life cycle in the manufacturing industry. The 8D tool is designed for the cross-functional teams to work together to identify the root cause of problems using the "five whys" method and implement corrective and preventive actions to prevent similar issues from occurring in the future. The novelty of this case study is the development of an 8D analytics template for product managers and practitioners in manufacturing and production companies to use for improving the quality of products throughout their life cycle. The case study also highlights the challenges and opportunities of using the 8D tool for problem-solving, including the high warranty cost and production failures, the unreliability of products and resources, and different scopes of issues. In one example, the 8D analytics template was used to identify a long-term fix for a circuit prone to leakage current by using a different flux chemistry that can be cleaned with a water-based solvent, rather than the traditional "no-clean" solder flux that requires specific solvents for effective cleaning.

Keywords: Analytic, Lean Eight Disciplines Methodology, 8D, Five Whys Analysis, Root Cause Analysis, Corrective Action, Lessons Learned, Problem Solving Method.

Highlights
This research paper presents a case study on the use of the Eight Disciplines (8D) methodology for identifying the root cause of temperature sensor failures in a manufacturing process. The findings of the study suggest that the 8D framework can be applied to root cause investigations and problem-solving in various industries by adapting the critical variables to their specific contexts. The study demonstrates the potential for the 8D methodology to be used as a template for addressing production floor issues in other organizations.

Introduction
Effective problem-solving analytics is essential for the manufacturing industry to reduce defects and waste in the production process. According to literature, common causes of defects and waste in the manufacturing process include overproduction of units, excess inventory, lack of lean manufacturing frameworks, sub-assembly and shipping delays, transportation and storage in central warehouses, and product defects [1, 2]. These issues can negatively impact the cost and quality of products for customers. Production defects can arise from failures in the manufacturing process or from the use of subpar raw materials from suppliers. Defects are a significant contributor to high warranty costs and damage to final products or components, which has been exacerbated by supply chain disruptions caused by the Covid-19 pandemic, particularly in the manufacturing sector in the Far East.

Customer satisfaction and product quality are critical requirements for organizations to meet the ISO 9001:2015 standard and maintain their global competitiveness [3-5]. It is the responsibility of product management, design, engineering, supply chain, service, and manufacturing teams to fulfil technical product requirements and customer specifications, and to ensure changes to the product design and production processes. Product design issues can lead to customer dissatisfaction and end-user issues, which can result in decreased sales and the need for product recalls due to health and safety concerns. To address these issues, manufacturers must improve the effectiveness and efficiency of their solutions and production processes through quality assurance efforts using the Lean Six Sigma framework based on the DMAIC (Define, Measure, Analyze, Improve, and Control) process and the PDCA cycle of the ISO 9001:2015 and the Lean 8D method [6-10]. The 8D methodology, also known as the Ford TOPS 8D, was first developed and implemented by Ford Motor in the 1980s Click or tap here to enter text.and has been widely adopted in the automotive industry for problem-solving [11-13]. It is still used by many companies.

Company S has identified that the fault appears to be specific to devices manufactured at the Chinese location, while devices manufactured at the Thailand location have not exhibited the same faults. To understand the root cause of the issue, Company S has initiated an Eight Disciplines (8D) investigation of the faulty devices from the Chinese manufacturing site and comparison devices from the Thailand site. The 8D methodology is a lean tool used to identify the root causes of problems and implement permanent solutions, as required by the International Automotive Task Force IATF 16949: 2016 automotive quality management system standard and widely adopted in the automotive industry and other manufacturing sectors and industries worldwide [14, 15]. The company is using Root Cause Analysis (RCA) investigation analytics to determine the root cause of the failures based on the samples provided, as listed in Table 1: Product Serial Numbers

Table 1: Product Serial Numbers

Manufacturing Suppliers Sites	Thailand	China
Units Serial Number (s)	4778694999 4778695004	4906913946, 4796134553, 4906935146, 4906915377, 4906915425, 4906914968

This research paper presents a case study of the techniques used by manufacturing suppliers in Thailand and China to address problems in the production of fridge-freezer temperature controllers and sensor units. The device is shown in Figure 1: FCR Sensor Overview, and the location of the MLCC (PCB Component C11) that is the focus of the investigation is indicated by the arrow in Figure 2: Location of the affected capacitor.

Figure 1: FCR Sensor Overview

Figure 2: Location of affected capacitor

Each device undergoes various tests to ensure quality using computer-aided programs for inspection checks. This production process is designed to produce high-quality products. However, recently, sellers and end users have received reports of defects from customers regarding 2000 returned temperature sensor units. The MLCC component is a 406-package size rated at 1µF and 25V. The insulation resistance of the potting material in devices manufactured in China and Thailand was measured using a Megger insulation test meter.

There have been numerous case studies in the manufacturing sector using methods such as Value-Stream mapping Lean Sigma, and the PDCA (Plan-Do-Check-Act) cycle of the ISO 9001:2015 framework [3, 16- 21]. This research employs a single case study approach, as it allows for a thorough examination of the impact of the Lean 8D methodology on reducing defects in the manufacturing process of PCB boards in a single case. The insulation resistance across a distance of approximately 2mm on the surface of the potting material was measured at 1000V and found to be >200 GΩ Ohm for both sets from the manufacturing sites.

The potting material was removed from a selection of devices to reveal the capacitor. The potting material adjacent to the base of the capacitor had a different appearance compared to the bulk material, as shown in Figure 3: Potting material adjacent to MLCC – China Unit, and Figure 4: Potting material adjacent to MLCC – Thailand Unit.

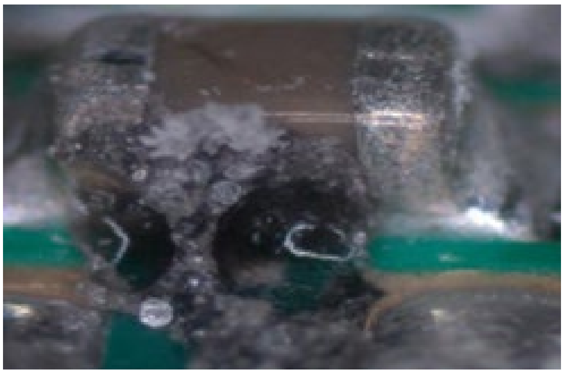

Figure 3: Potting to MLCC - China Unit

Figure 4: Potting to MLCC - Thailand Unit

The potting material had a black, glassy appearance, which was more pronounced in samples from the China manufacturing site compared to those from the Thailand manufacturing site. The red arrow in the images indicates the potting material that has been in contact with the capacitor. This case study demonstrates the usefulness of a single case study and the application of an easy SEM technique for detecting solder flux contamination and improving production process failures.

The potting material had a black glassy appearance. The difference was more pronounced in the samples from the China manufacturing site, as compared with samples from the Thailand manufacturing site, where the red arrow indicates the potting material that has been in contact with the capacitor. This paper contributes towards a single case study, and an easy SEM technique can be used to improve a production process failure and detective solder flux contamination.

This paper is divided into the following sections: Section 2 is a literature review of the 8D method; Section 3 presents the Fourier Transform Infrared (FTIR) analysis of the potting material; Section 4 discusses the findings of the Lean 8D analysis of the potting materials; Section 5 presents the findings of the Scanning Electron Microscopy (SEM) analysis and production floor soldering process analysis; and finally, Section 6 provides a conclusion for manufacturing companies and offers an 8D solution for industrial implementation, as shown in Figure 5: Lean 8D Framework [1, 22].

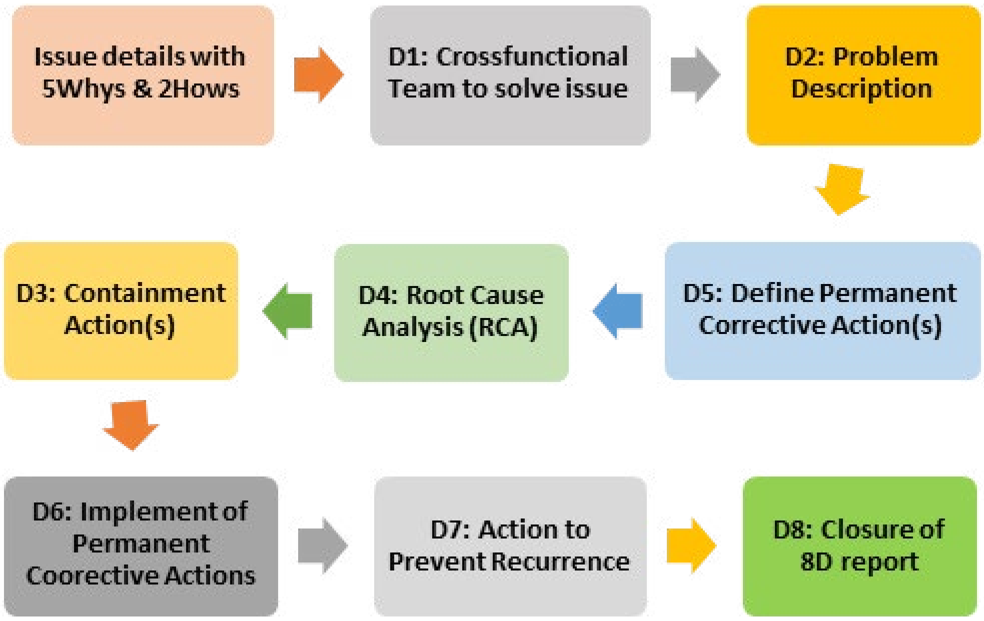

Figure 5: Lean 8Ds Framework

Literature Review of 8Ds Method Analytics

The Eight Disciplines (8D) method is a cross-functional platform for problem-solving that aims to identify the root cause of a problem and implement corrective action to solve it (Chen & Cheng, 2010). The 8D method, also known as G8D, Global 8D, or TOPS 8D, was developed at Ford Motor Company in 1987 and outlined in a manual titled "Team Oriented Problem Solving" (TOPS) [12]. Since its inception, it has been widely used in the automotive, aerospace, consumer electronics, and maritime sectors to address product and production problems. To improve quality applied the 8D method to analyse a quality issue in the global supply chain of Scania and was able to identify the root cause of the problem and implement a solution [23, 24]. The 8D method is a commonly used tool to solve non-conformances and prevent recurrence in manufacturing, service, and production factories worldwide.

The implementation of lean principles by Pacheco-Pacheco resulted in the optimization of delivery times for altered clothing in a tailor shop using the 8D method [25, 26]. This resulted in a 21% reduction in production time and a 33.33% reduction in delivery time, improving customer satisfaction. For integrated solutions used the 8D method to reduce the downtime of preventive maintenance during machine changeovers in production processes by making batch changes that eliminated bottlenecks on the production floor [27, 28]. Six sigma Click or tap here to enter text. implement a quality system, including the 8D method, to reduce scrap costs in an industrial company by identifying the root causes of scrap and implementing corrective actions to address the cost drivers [28]. The 8D method has also been used to reduce customer complaints and address quality issues through the use of the 5W and 2H approaches to understand the causes and effects of failure modes, as demonstrated by Click or tap here to enter text. in their analysis of power painting errors in the automotive industry [1]. For growth Click or tap here to enter text. used the 8D method and value stream mapping to improve production quality and reduce cycle time by identifying the root cause of productivity issues in the form of flux contamination [29]. For customer issues used the 8D approach to address customer complaints related to sheet metal hardness, resulting in a decrease in hardness from 28% to 0.5% and a savings of $22 million for the company [30]. Other manufacturing companies have also adopted various problem-solving techniques, as shown in Table 2: Problem-solving tools.

Table 2: Problem-solving tools

Concept	Origin	Aim	Focus	Method
Six Sigma	Motorola (1987)	Improve process capability	Reduce variations in process inputs	Lesson learn use to implement change
Total Quality Management (TQM)	Japan Panasonic (1990s)	Improve quality and processes control	Customer Complaints Management	Resources matrix of consumption, vogue results.
8D	Ford Car (1980s)	Solve complex problems	Reduce failures and implement solutions	8D methodology Implemented

The following case studies are used to validate these problem-solving techniques;

- Six Sigma - [22, 31, 32]
- TQM - [33, 34, 35]
- 8D - [1, 10, 13, 22, 36]

The automotive industry has a globally interconnected supply chain with a high level of production across networks, which requires the exchange of quality information throughout the product life cycle, including the service phase Click or tap here to enter text.to meet customer needs [17, 19, 20, 37]. It is essential to use effective problem-solving tools for managing customer complaints and handling internal nonconformities. The 8D platform provides a problem-solving framework, combining ISO 9001 tools and methods from various PDCA (Plan-Do-Check-Act) cycle-based problem-solving methodologies to solve issue, as shown in Figure 6: 8D problem-solving PDCA cycle [14, 24].

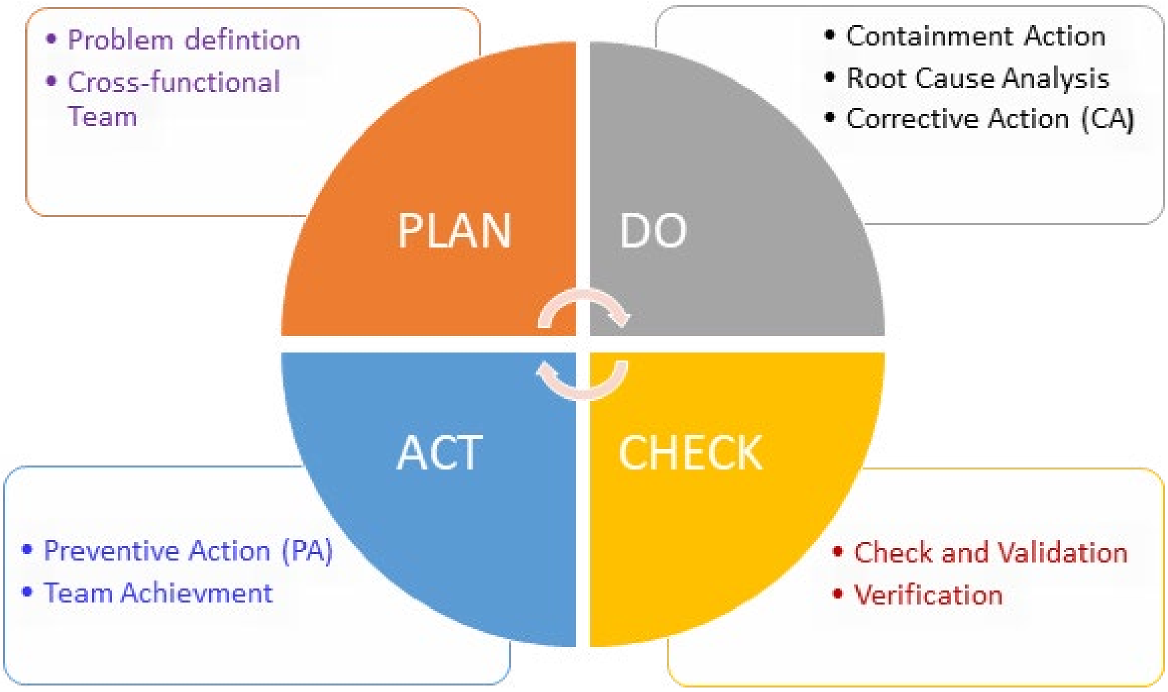

Figure 6: 8D problem-solving PDCA cycle (own processing)

The successful implementation of the 8D method across various sectors has led to its commercialization and the ability to request 8D reports from suppliers in cases of random errors, where it is necessary to identify the root cause of failures and random effects in the process that cannot be eliminated. The 8D methodology has proven to be an effective and easy-to-implement tool for problem-solving in the manufacturing and service sectors and is officially recognized as the key source of RCA investigation in documentation at Ford Motor Company, where it is still in use today. Many other manufacturing companies have also adopted this technique in their toolkit for investigating issues [3, 32, 38]. Some case studies of the 8D methodology implementation are presented in Table 3: 8D methodology implementation case studies.

Table 3: 8D methodology implementation case studies

Authors	Companies	Problem-solving with 8D methodology
(Behrens et al., 2007) [39]	Ford and sub- Suppliers	The 8D methodology first started at the Powertrain part of the Ford automotive group. A cross-functional Team Oriented Problem Solving (TOPS) has implemented which has solved the issue in the Powertrain factory and sub suppliers supply chain as well, due to the success of it, this problem solving framework is implemented in all Ford business groups.
(Kumar & Adaveesh, 2017) [15]	Valve Spring Manufacturing	The 8D problem-solving technique is used to find root cause of the 17% rejection rate of the Valve Spring in manufacturing, which is reduce to 4.91% by making the pitch distance equal at the begin-end side of the Value.
(Realyvásquez-Vargas et al., 2020) [40]	Electric Cable Manufacturing company	Customer complaints about defectives of custom cable assemblies which integrated in an engine. The 8D method is used to develop a software tool for the production floor to conduct functional test on the assembly lines, which has decrease the number of defective products by 75%.

The purpose of this paper is to present a manufacturing case study that investigates the root cause of temperature sensor failures using the lean eight disciplines (8D) methodology. This study aims to provide a practical application of the 8D framework to a real production floor process issue, with the goal of demonstrating the utility of the 8D method for root cause investigation and problem-solving in various industries. By implementing critical variables in their context, other companies may be able to adapt the 8D framework and template to their own problem-solving efforts.

Quality design, development, production processes, and manufacturing are essential for the success of any organization, and a robust problem-solving framework is necessary for the life cycle assessment of products. This study develops the 8D investigation tool, which enables cross-functional teams, both internal and external, to work together to solve issues and improve the product life cycle in the field. The 8D method includes the use of the "five whys" technique to identify the root causes of problems in critical processes, and, if necessary, the integration of the 8D and Six Sigma approaches to provide solutions. The 8D method enables the implementation of corrective and preventive actions, as well as the creation of customer reports with timelines for the execution of fixes and measures to prevent similar issues from occurring in the future. The novelty of this case study lies in the development and provision of the 8D analytics template for product managers and practitioners in manufacturing and production companies to use for the improvement of product quality throughout the product life cycle.

Potting Material Fourier Transform Infra-Red Analytic

The Eight Disciplines (8D) methodology is a well-established problem-solving framework that has been widely adopted in various manufacturing sectors to improve product quality and customer satisfaction. By using a cross-functional team approach and implementing a series of systematic steps, including root cause analysis and corrective action, the 8D methodology enables organizations to identify and resolve issues effectively, prevent their recurrence, and improve the overall life cycle of their products. In this study, the 8D methodology was used to investigate the root cause of defects in temperature sensor units manufactured at two different sites in China and Thailand. By implementing various analytics techniques, including Fourier Transform Infrared (FTIR) and Scanning Electron Microscopy (SEM), the team was able to identify the root cause of the defects as contamination of the potting material with flux residue. The 8D methodology was then used to implement permanent corrective actions to prevent the recurrence of the issue and improve the quality of the units. The success of this case study demonstrates the effectiveness of the 8D methodology in addressing and resolving quality issues in the manufacturing process.

The implementation of 8D methodologies, such as the Lean 8D approach, is essential for identifying and resolving problems in the manufacturing industry. These methodologies, which were first developed by Ford Motor Company in the 1980s and have since been widely adopted in various sectors, involve a systematic process for determining the root cause of a problem and implementing permanent corrective actions to prevent recurrence. According to the International Automotive Task Force IATF 16949:2016, the 8D methodology is a valuable tool for ensuring the quality of products and processes in the automotive industry. It has also been effectively applied in other sectors, such as aerospace and consumer electronics, to solve production issues and improve customer satisfaction. By using the 8D approach, manufacturers can effectively address defects, warranty costs, and customer complaints, leading to increased efficiency and profitability.

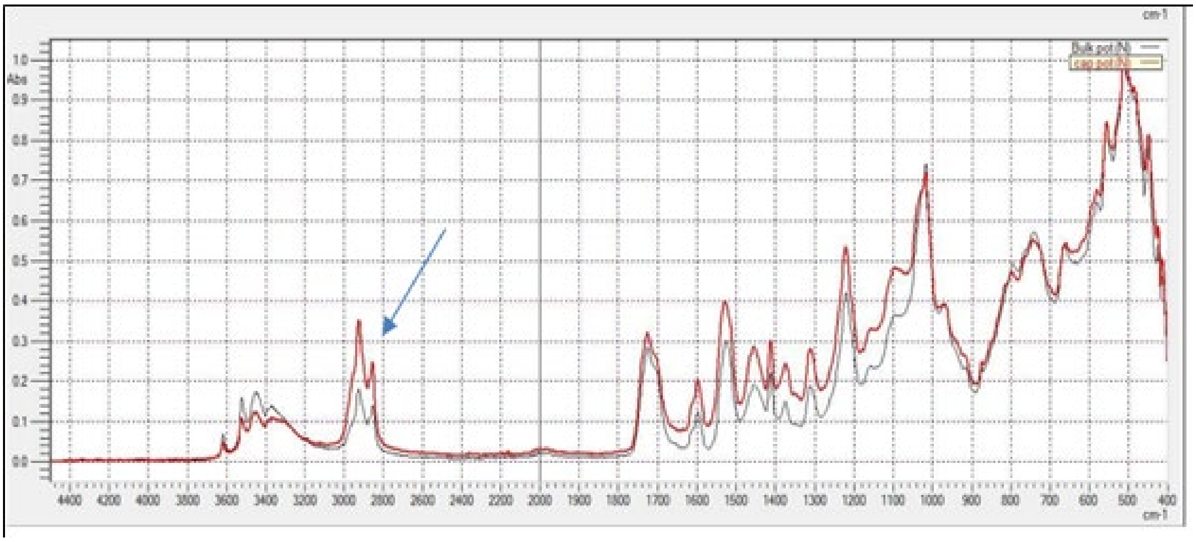

Figure 7: FTIR analytic of potting material

Effective problem-solving is essential for the manufacturing industry to address defects and waste, as well as any product or process failures that do not provide value for customers [18]. Literature review suggests that product defects and waste categories, such as overproduction, dead inventory, lack of lean manufacturing frameworks, sub-assembly motion in sub-suppliers, waiting for shipments, transportation to central warehouses, and product defects, negatively impact products and increase costs for customers [2, 41]. Defects can occur during the manufacturing process or be caused by raw materials supplied by suppliers. Product defects are a common cause of high warranty costs or damage to final products or components supplied to suppliers, which has been exacerbated by post-COVID-19 supply chain issues from the Far East for all manufacturing sectors.

To ensure customer satisfaction and product quality, it is important for organizations to meet the technical product requirements and customer specification needs outlined in the ISO 9001:2015 standard [24]. It is the responsibility of product management, design, engineering, supply chain, service, and manufacturing teams to make sure that changes to product design and production processes are made accordingly. All product design issues can lead to dissatisfaction among customers and end-users, resulting in decreased sales and the need for product recalls due to health and safety issues. Therefore, it is essential for manufacturers to improve the effectiveness of solutions and efficiency in production processes for quality assurance using the lean six sigma framework and the DMAIC (Define, Measure, Analyze, Improve, and Control) process and the PDCA (Plan, Do, Check, Act) cycle of the ISO 9001:2015 and the Lean 8D method implement 8D methodology [1, 6, 8, 10, 40, 44].

After examining the MLCC, it was found to be in good external condition. The solder fillet was properly formed and the amount of solder used was appropriate, as excess solder can cause mechanical stress on the component and increase the risk of cracking. There were no visible cracks on the component. The PCB tracks connected to the capacitor were cut to isolate it from the rest of the circuit and its capacitance and resistance were measured. The capacitance was approximately 970nF, and the resistance was measured using a Sefalec Megohm resistance meter at voltages between 1Vdc and 10Vdc. There was no evidence of electro-migration on the surface of the MLCC, which can cause high current leakage and potentially result in a short circuit. The resistance was relatively constant at around 1x103MΩ and did not decrease with increasing test voltage. One of the MLCCs was also removed from the PCB by cutting the solder connection for further inspection of the underlying PCB surface, which showed no evidence of electro-migration.

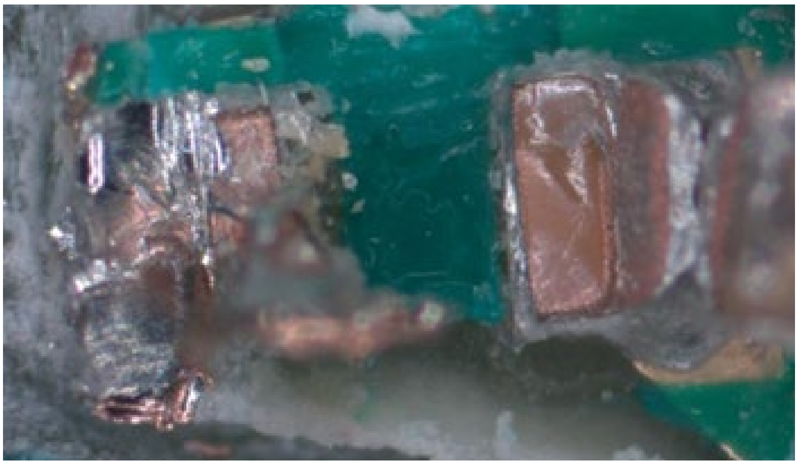

Figure 8: MLCC underside PCB surface inspection

Use Five Whys Analysis, an Integrated 8Ds Analytic

The Lean 8D template for investigating and resolving manufacturing issues includes the use of the Five Whys method to identify root causes and the implementation of corrective actions, followed by a verification of solution effectiveness through the use of lesson learned checks in accordance with ISO 9001:2015 standards. The current quality issue being addressed is the failure of the temperature sensor controller, which has caused problems with the bottle coolers for customers. The Five Whys and Two How steps are outlined in Table 4, and the Ishikawa diagram is used to identify the root cause of the issue as described by [42].

Table 4: 5 Whys and 2How

This temperature controller freezing issue has occurred in many countries.	
Who	Head of Quality of the manufacturer with both suppliers' sites
What	The freezing issue needs to be solved.
When	Production batch of 2019 units
Where	Lean 8D investigation report
Why	C11 failure due to access Flux contamination of potting material
How	Production floor failure causing issues in the field
How many	10 PCs returned back to the UK out of many field failure cases

D1 – Problem Description

During the 8D investigation into several failed units that were returned to the manufacturer, it was determined that the issue was related to the use of a 0402 MLCC (C11) as a filter capacitor on the probe input circuit. These capacitors were found to be leaky or have low resistance, leading to a DC shift in the probe measurement and resulting in a shift in the temperature reading. However, after removing the potting material around C11, the current leakage was reduced and the sensor performance improved.

D2 –. Problem Defective Units

As part of the 8D investigation into manufacturing issues, two defective units and one good unit from the same production batch were returned to the manufacturing site in China for further testing, analysis, and corrective action. The serial numbers of the returned units were SN1 and SN2, and a good sample unit was also included in the investigation. These units were shipped to the factory for further examination and analysis.

D3 – Containment Action

As part of the 8D investigation process, the supplier was given two days to take containment actions after receiving the complaint. In this case, the manufacturer's site in China confirmed that there were no semi-finished goods on the production floor or lines and no finished goods in the warehouses. These actions were taken to prevent the issue from affecting any additional products.

D4 – Root Cause Analysis (RCA)

As part of the 8D investigation process, suppliers and sub-assembly manufacturers are required to investigate defective units upon receiving complaints from customers and to complete failure investigation analytics. In this case, the manufacturing site in China conducted a root cause analysis of both the good and defective units and tested the goods, returning a sample unit to the tester to be checked and validated. The unit passed all functional tests, as shown in Figure 9: Manufacturer Tester Platform. This information was used to identify the cause of the issue and implement appropriate corrective actions.

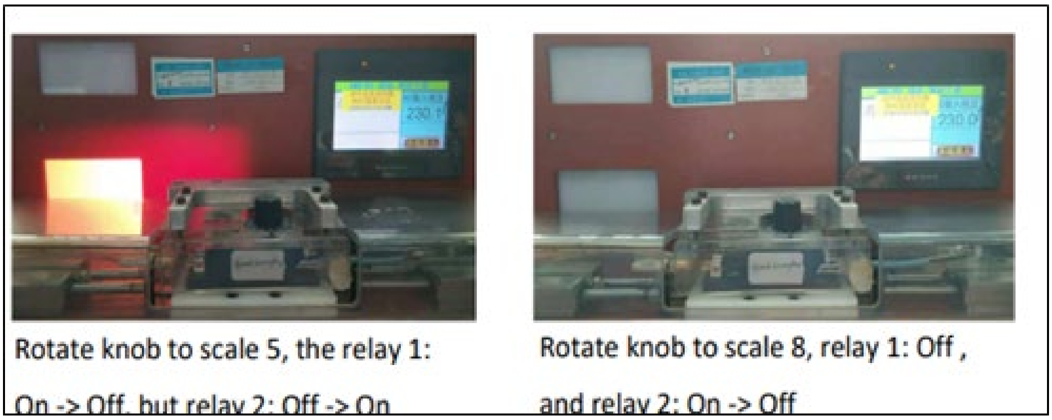

Figure 9: Manufacturer Tester Platform

As part of the 8D investigation, the defective returned units SN1 and SN2 were tested on the production floor tester by rotating the knob to scales 2, 5, and 8. The relays were unable to be activated and the final test results showed a failure, as depicted in Figure 10: Test Failure. This information was used to identify the cause of the issue and implement appropriate corrective actions.

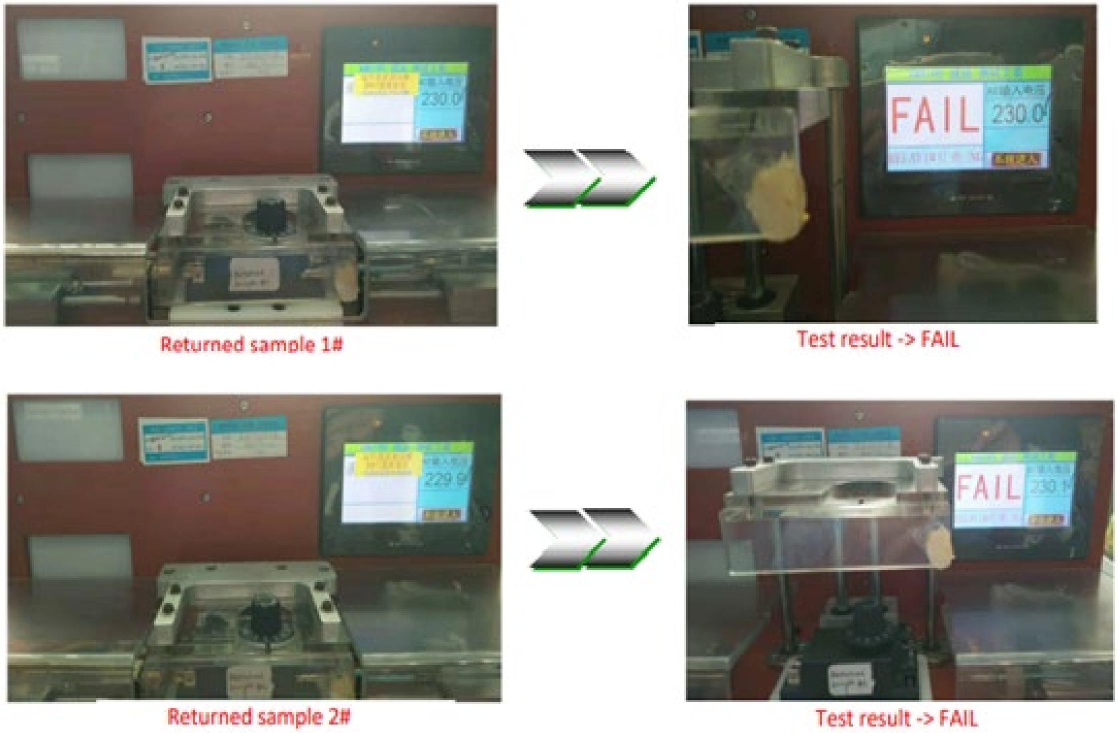

Figure 10: Test Failure

As part of the 8D investigation process, it is standard practice to measure the resistance between T8 and T9 on returned samples. In this case, the resistance of returned sample SN1 had decreased, but the resistance of returned sample SN2 was within normal limits when compared to a known good sample unit. This information was used to identify potential causes of the issue and implement appropriate corrective actions.

To further analyse the reason for the decrease in resistance in the returned SN1 and SN2 units, the bottom case of the unit and potting material were removed to expose capacitor C11. The resistance between T8 and T9 was found to be abnormal, but was corrected after replacing C11 with a new capacitor.

The original capacitor was then measured with an LC meter and found to be within the specification listed in the datasheet (1uF±10%/25V). No cracks were observed on the capacitor, as shown in Figure 11: C11 MLCC Failure. This information was used to identify the root cause of the issue and implement a corrective action.

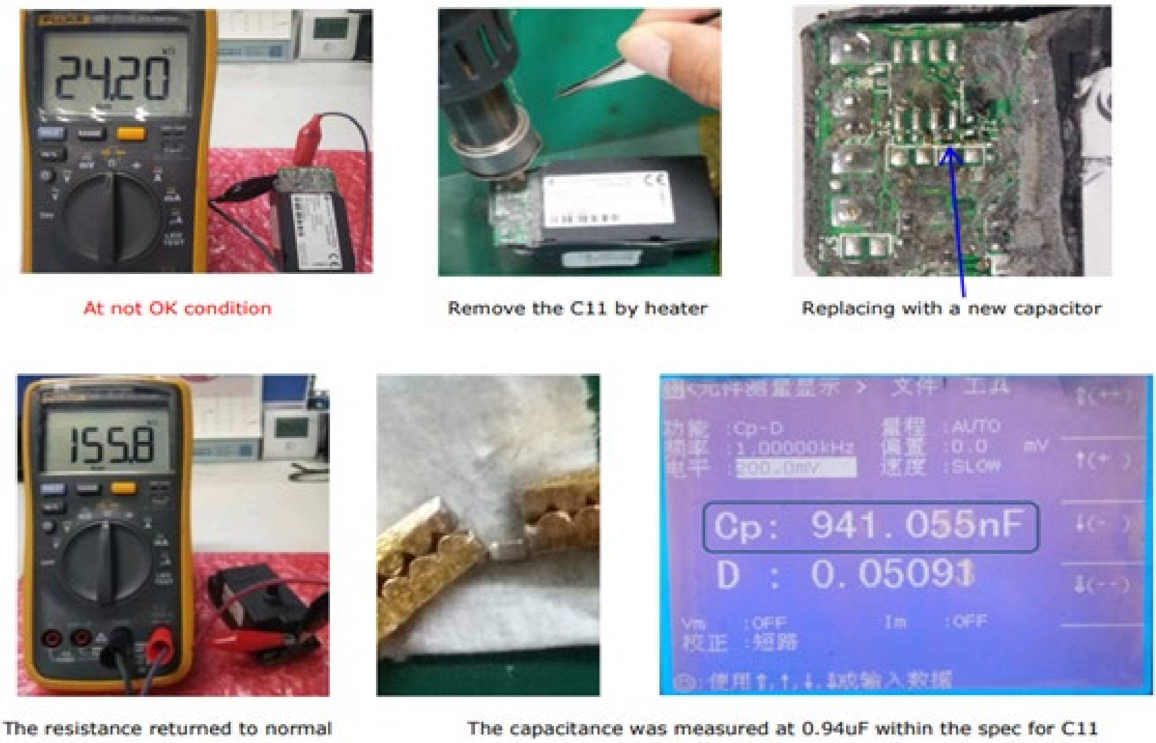

Figure 11: C11 MLCC Failure

As part of the 8D investigation, the production engineering team reviewed the manufacturing production process for week 19 of 2019 and found that all production processes were the same as the first production batch, indicating that no Engineering Change Orders had been implemented in the production units [7, 14]. This led the team to suspect that contamination of the PCB surface near capacitor C11 may be the cause of the issue in both returned SN1 and SN2 units. Further analysis and testing were conducted to confirm this hypothesis and identify appropriate corrective actions.

D5 – Permanent Corrective Action

The supplier confirmed that the OM338PT solder paste used for 0402 size SMT components was suitable and met the no-clean requirement according to IPC standards, so there was no need to clean the flux residue from the PCB boards as part of the normal production process. However, due to the flux contamination issue, a deeper clean-up of the SMT line was implemented before and after each production batch, and the line was cleaned once per week to minimize the risk of contamination. This preventive action change was implemented in the SMT production process to ensure the cleanliness of the lines.

D6 – Implementation of Permanent Corrective Action

As part of the 8D investigation, both returned samples SN1 and SN2 were tested on the tester by rotating the knob to positions 2, 5, and 8 to check the relay current level and the current in capacitor C11. After replacing C11, both units passed the functional test, as shown in Figure 12: Functional Test Pass. In order to address the issue, the solder paste SMT line clean-up change was implemented as a corrective action on the production floor. Upon completion of the functional test, both units' relays operated normally and the final test result was a pass, so the units were reprogrammed with the latest software. This information was used to confirm that the corrective actions implemented were effective in resolving the issue.

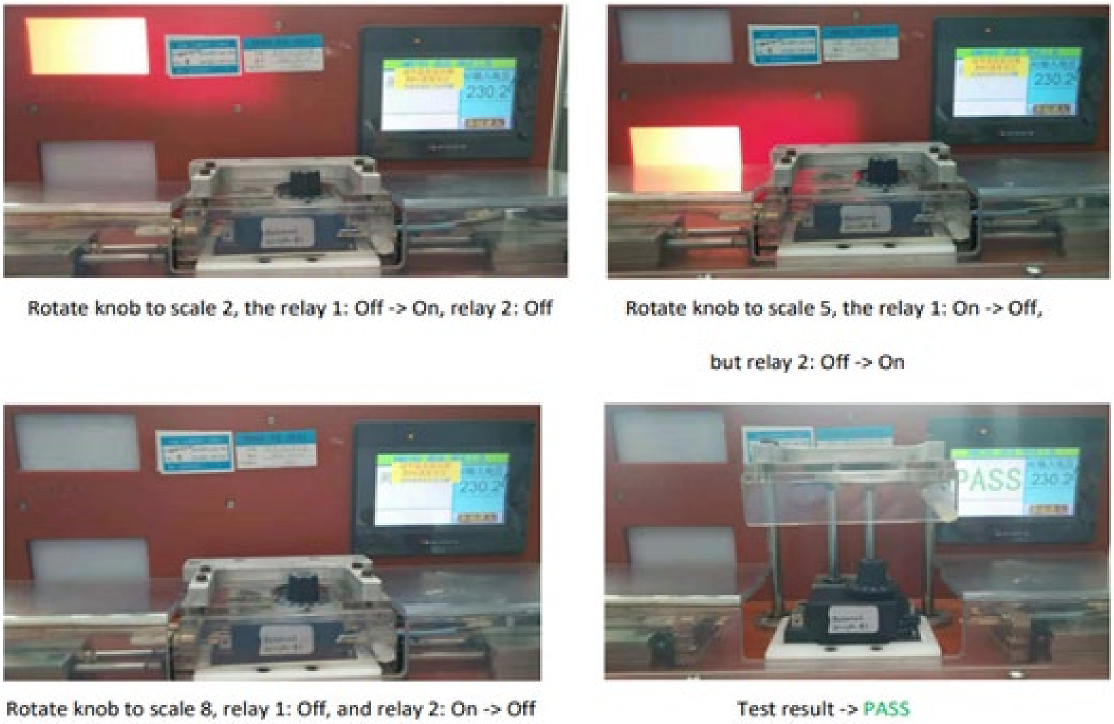

Figure 12: Functional Test Pass

The functional test was effective in detecting faults in the units with low resistance across capacitor C11 and in validating firmware issues, allowing for the resolution of this type of failure in the manufacturing process. During the functional test, the tester was able to detect failure when a 2.7MOhm resistor was fitted in parallel with T8 and T9 terminals to simulate low resistance across C11. This information was used to confirm that the implemented corrective actions were effective in addressing the issue.

D7 – Actions to Prevent the Recurrence

As a corrective action, a 100% check of the resistance value between T8 and T9 terminals was implemented as part of the final test for sensor units using a multi-meter after the potting process in all future batches. This additional quality control measure was implemented to ensure that any units with low resistance across capacitor C11 would be identified and addressed before being shipped to customers.

D8 – Closure 8D Report

The closure report for the Lean 8D investigation includes the details of the root cause analysis and corrective actions taken. This information is shared with customers to ensure quality assurance and to offer them new replacement units free of charge under the warranty. This helps to ensure that any issues with the units are fully addressed and resolved to the satisfaction of the customer.

Scanning Electron Microscopy (SEM) Analytic

The potting material adjacent to the MLCCs from the Thailand and China manufacturing sites was assessed using Scanning Electron Microscopy with energy-dispersive X-ray analysis (SEM-EDX). As shown in Figure 13: SEM analytics of potting, the defective potting material was identified as coming from the China manufacturing site. The dashed red box indicates the area where the material was in contact with the MLCC. This image is a backscatter SEM image, where lighter greyscale levels indicate higher atomic mass material. EDX analysis was performed at regions 1-4, with the results shown in the figure. This information was used to identify the source of the issue and implement appropriate corrective actions.

The energy-dispersive X-ray analysis (EDX) results showed the weight percentage of elements present at the surface of the potting compound that was in contact with the MLCC. The majority of the material was carbon and oxygen, as expected for a polyurethane material, along with aluminium, which was likely alumina filler material used in the soldering process and therefore electrically insulating. This information was used to identify the composition of the potting material and understand its potential impact on the performance of the MLCC.

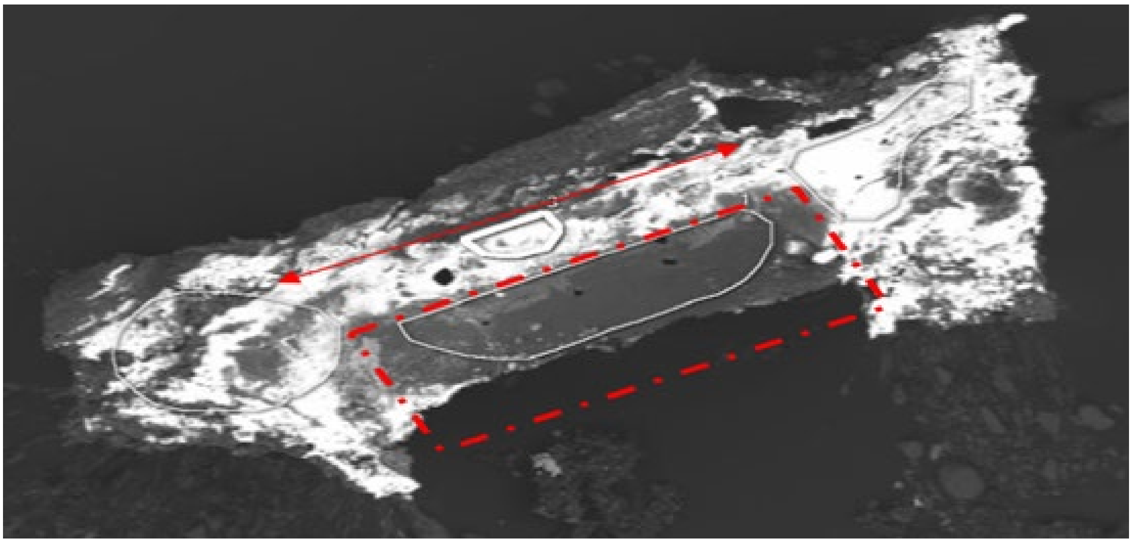

Figure 13: SEM analytic of potting material from adjacent to MLCCs - China

The energy-dispersive X-ray analysis (EDX) results of the potting material surface in contact with the MLCC showed a significant amount of tin, including at area 3 at the base of the capacitor at the interface with the PCB. The tin spanned the entire length of the MLCC, as indicated by the red arrow in Figure 13, and would have been bridging between the MLCC terminals. The SEM-EDX analytic results for the potting material surface to MLCC of the China unit are summarized in Table 5. This information was used to understand the presence and potential impact of tin on the performance of the MLCC.

Table 5: SEM-EDX analytic of potting material surface – China unit

Spectrum Label	**1**	**2**	**3**	**4**
C	69.00	65.34	73.92	67.06
O	28.35	26.23	12.95	29.32
Na	0.07	0.17	0.00	0.09
Al	0.88	2.17		1.39
Si	0.12	0.19		0.11
S		0.08		
Ca	0.19	0.38		
Sn	1.39	5.44	13.13	2.02
Total	100.00	100.00	100.00	100.00

Figure 14 shows an equivalent scanning electron microscopy (SEM) image from the MLCC from a Thailand manufacturing site, along with the energy-dispersive X-ray analysis (EDX) results in Table 3. In this sample, there was also tin present adjacent to the MLCC. However, the amount of tin was less than the sample from the China manufacturing site, and the tin did not create a bridge for the entire length of the MLCC, as indicated by the red arrow in Figure 14. This comparison was used to understand the potential impact of the presence and amount of tin on the performance of the MLCC.

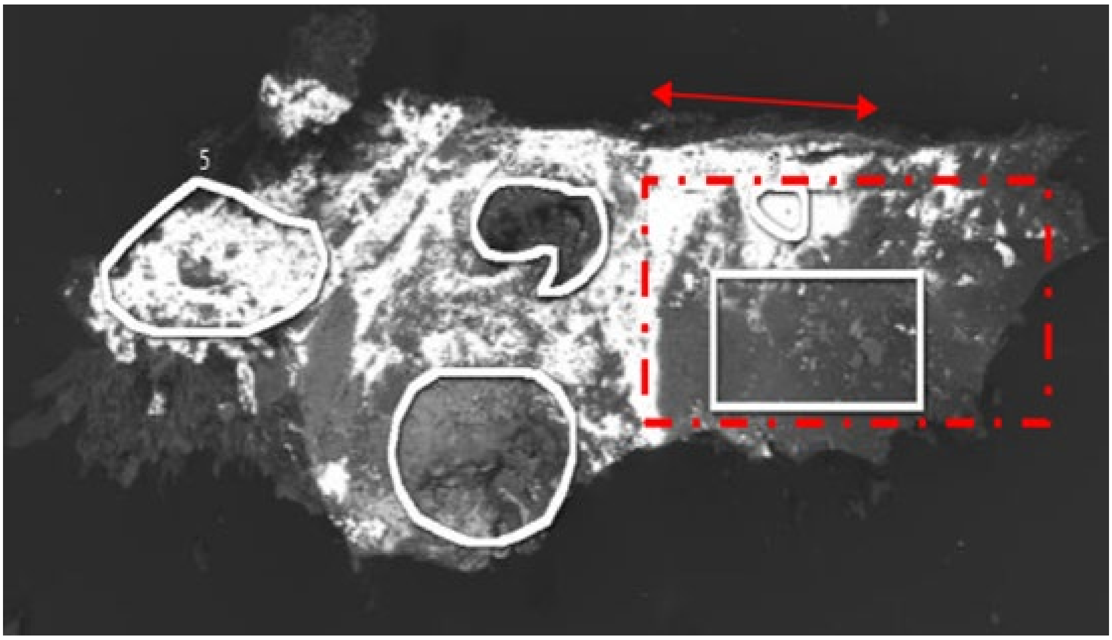

Figure 14: SEM analysis of potting material from adjacent to MLCCs - Thailand

Table 6 shows SEM-EDX analytic results of the potting material surface to MLCC of the Thailand Unit.

Table 6: SEM-EDX analytic of potting material surface – Thailand

Spectrum Label	1	2	3	4	5
C	62.64	68.89	69.28	66.40	57.54
O	34.78	25.89	28.79	27.20	35.27
Na	0.07	0.14	0.14	0.16	
Mg		0.18		0.06	
Al	1.75	0.96	0.73	0.40	5.63
Si	0.13	0.39	0.15	0.15	0.45
P		0.16		0.14	
Cl			0.06		
K					0.16
Ca	0.14	0.14	0.13		0.44
Sn	0.48	3.23	0.72	5.49	0.50
Total	100.00	100.00	100.00	100.00	100.00

Evaluation of Findings and Conclusion

After removing the potting material, abnormal leakage current across the MLCCs was not detected. It is likely that the device failure was caused by leakage of current across the MLCC due to the presence of solder flux and tin residues on the PCB board. The lead-free solder flux used in the manufacturing of these PCBs was a no-clean flux composed of isopropyl alcohol and glycol. However, other PCB surface contaminants, including tin residues, may have been present following the soldering process. In order to address this issue, the production process was changed to a two-step potting process in order to reduce the risk of contamination and air bubbles. The revised process involved the following steps:

1. Placing the products on the fixture of the dispensing machine.
2. Using 7g of epoxy on each product for a dispensing time of 8 to 15 seconds.
3. Curing the potted products for a minimum of 6 hours.
4. Placing the potted products on the fixture of the dispensing machine again.
5. Using 11g of epoxy on each product for a dispensing time of 12 to 18 seconds.
6. Curing the potted products for a minimum of 12 hours. This change in the potting process was implemented as the final solution to address the issue of MLCC leakage.

The defective units were identified as experiencing issues with the MLCCs, specifically with leakage of current. After examining the potting material surrounding the MLCCs, it was determined that the likely cause of the failure was contamination on the PCB board, specifically in the form of solder flux and tin residues. To prevent similar issues in the future, the manufacturing process was revised to include a two-step potting process that reduces the risk of contamination and air bubbles. The changes to the process are detailed in an Engineering Change Order and are depicted in Figure 15.

Figure 15: Potting Process Change

The presence of solder flux residues on the PCB can interfere with the proper adhesion and curing of potting compounds. To ensure optimal adhesion and curing, it is important to have a clean surface on the PCB. In the current case, it is possible that the potting material's cure process near the surface mount components was compromised by the presence of solder flux residues, which can act as a contaminant.

Lean 8Ds Analytic Template

The Lean 8Ds analytics template can be used by manufacturing and industrial organisations to solve the end users and customers' complaints due to product design and manufacturing issues, as shown in Table 7: 8D Analytics Template [36].

Table 7 : 8D Analytics Template

GENERAL INFORMATION					
Company M Order No:		Lean 8Ds Investigation Analytic Template		***Report***	Sensor
Start Date:	Q1 2022	***Status Date:***	Q1 2022	***Revision:***	
Name of issuer:	KM	***E-mail Address:***	XX	***Tel.-No:***	EXT -
All replies shall be sent to Company M Production address:					
Supplier INFORMATION					

<table>
<tr><td>Supplier:</td><td>China S1</td><td>BP No:</td><td>XX</td><td colspan="2" rowspan="2">Supplier / Customer Site Address</td></tr>
<tr><td>Contact Name:</td><td>XX</td><td>Function / Position:</td><td>Manufacturing Director</td></tr>
<tr><td>Tel.-No.:</td><td></td><td>E-Mail:</td><td></td><td></td><td></td></tr>
<tr><td colspan="6">MATERIAL INFORMATION</td></tr>
<tr><td>Company M Part No:</td><td colspan="2">FCR Sensor</td><td colspan="2">Description:</td><td>Temperature Sensor</td></tr>
<tr><td>Serial Numbers</td><td colspan="4">4906913946, 4796134553, 4906935146</td><td>3 Units</td></tr>
<tr><td>Quantity sends out:</td><td colspan="2">6 PCS</td><td colspan="2">Quantity received by supplier:</td><td>6 PCS</td></tr>
<tr><td>Date of sending:</td><td colspan="2">Q1 2022</td><td colspan="2">Date received:</td><td>MFG Date 38/2019</td></tr>
<tr><td colspan="6">PROBLEM REALISATION</td></tr>
<tr><td colspan="4">Problem description of the customer</td><td colspan="2">5W +2H (Problem facts if known)</td></tr>
<tr><td colspan="4">Temperature Sensor Controller faulty causes freezing for bottle coolers</td><td colspan="2">This issue has occurred in many different cities and with several different cooler models</td></tr>
<tr><td colspan="4" rowspan="7">Customer-failed units were returned for the lean 8D investigation, which has identified that the problem is related to the C11, which is a 0402 MLCC used as a filter capacitor on the probe input circuit.</td><td>Who</td><td>QC Inspection team</td></tr>
<tr><td>What</td><td>The freezing issue needs to be solved.</td></tr>
<tr><td>When</td><td>Production batch of 2019 units</td></tr>
<tr><td>Where</td><td>Lean 8D investigation Report</td></tr>
<tr><td>Why</td><td>C11 failure due to access flux in potting</td></tr>
<tr><td>How</td><td>Production floor failure causes issues</td></tr>
<tr><td>How many</td><td>6 PCS return for the RCA investigation</td></tr>
<tr><td colspan="6">D1. TEAM (within two days after the complaint is received by the supplier)</td></tr>
<tr><td colspan="2">Name</td><td colspan="2">Team function</td><td colspan="2">Department</td></tr>
<tr><td colspan="2">XXX</td><td colspan="2">XXX</td><td colspan="2">XXX</td></tr>
<tr><td colspan="6">D2. PROBLEM DESCRIPTION (within two days after the complaint is received by the supplier)</td></tr>
<tr><td colspan="3">Problem description – observed problem</td><td colspan="3">Picture</td></tr>
<tr><td colspan="3">Manufacturer in China received 6 PCS defective units</td><td colspan="3">As shown in the D2</td></tr>
<tr><td colspan="6">D3. CONTAINMENT ACTION(S) (within two days after the complaint received by the supplier)</td></tr>
<tr><td colspan="4">Actions until the implementation of PERMANENT CORRECTIVE ACTIONS</td><td>Responsibility</td><td>Due Date</td></tr>
<tr><td colspan="4">Finished Goods are zero in the factory, and nothing is in stock items in the warehouse</td><td>XX</td><td>XX</td></tr>
<tr><td colspan="6">D4. ROOT CAUSE ANALYSIS (within one week after the complaint was received by the supplier)</td></tr>
<tr><td colspan="5">The root cause for OCCURRENCE</td><td>% Contribution</td></tr>
<tr><td colspan="5">The final test results showed failure units due to relays issue, as shown in D4 of the Lean 8D investigation</td><td rowspan="3">100</td></tr>
<tr><td colspan="5">Verification</td></tr>
<tr><td colspan="5">After replacing C11, capacitor failure units passed the functional test, as shown in D5</td></tr>
<tr><td colspan="5">The root cause of ESCAPE</td><td>% Contribution</td></tr>
</table>

The functional tester has shown defective units with low resistance across cap C11				100
Verification				
The factory has conducted GR&R evaluation for the tester, fitted a 2.7 M Ohm resistor between T8 and T9				
D5. DEFINITION OF PERMANENT CORRECTIVE ACTION(S) (*Within two weeks after the complaint received by the supplier*)				
Permanent Corrective Action for OCCURRENCE				*% Contribution*
Potting material showed flux contamination				100
Verification of effectiveness				
The design team verified it				
Permanent Corrective Action for ESCAPE				*% Contribution*
Verification of effectiveness				
D6. IMPLEMENTATION OF PERMANENT CORRECTIVE ACTION (*Provide an implementation plan within two weeks after a complaint is received by the supplier*)				
Actions			***Who***	***Due date***
PQC implemented the resistance test between T8 and T9 with a multi-meter after the potting			xx	
D7. ACTIONS TO PREVENT RECURRENCE (within three weeks after a complaint is received by the supplier)				
Review and update documents	Action			
☑ Process instructions	XXXXXX			
☐ FMEA	The production process changed using ECO			
☐ Others – specify				
Lessons Learned				
Lessons Learned Card issued? ☐ Yes ☐ No		Ref.-No.:	XXX	
Does process / Product audit plan? ☐ Yes ☐ No		Date:	XXX	
Comments?				
Successfully implemented corrective and preventive actions and validation tests implemented after potting to check for flux after potting.				
D8. *CLOSURE OF 8D REPORT* (*Depending on point 6, but latest four weeks after the complaint is received by the supplier*)				
The team has been informed of action results and their effectiveness.				
8D report closure date:	XX		***Approved by (COMPANY M):***	XX

The Lean 8D analysis template is a method used by manufacturing and industrial organizations to solve customer complaints related to product design and manufacturing issues. It consists of eight steps: defining the problem, establishing a team, developing a temporary containment plan, identifying the root cause, implementing a permanent corrective action, verifying the effectiveness of the corrective action, implementing preventive actions, and documenting the results. The 8D steps are described in the Table 8 below summarizes the 8D steps:

Table 8 : 8D Steps

Step	Description
D1	Define the problem
D2	Establish a team
D3	Develop a temporary containment plan
D4	Identify the root cause
D5	Implement a permanent corrective action
D6	Verify the effectiveness of the corrective action
D7	Implement preventive actions
D8	Document the results

The root cause of the failure was identified to be a leaky or low resistance C11 capacitor, which caused a DC shift in the probe measurement and resulted in a shift in temperature. Removing the potting material around C11 reduced the current leakage and improved sensor performance.
Two defective units and one good unit from the same production batch were returned to the manufacturing site in China for further investigation and analysis. Upon testing, the good unit passed all functional tests, but the returned units both failed the functional test.

The supplier confirmed that there were no semi-finished or finished goods in the warehouses, and the production process for the defective units was the same as the first production batch, with no Engineering Change Orders implemented. Further analysis revealed that the root cause of the failure was likely contamination of the PCB surface near the C11 capacitor, possibly due to the presence of tin residues on the PCB board. As a corrective action, the production process was changed to include a two-step potting process and a 100% resistance check between the T8 and T9 terminals.

These changes were implemented as the final solution to prevent similar failures from occurring in the future. The findings and corrective actions were shared with the customer to ensure quality assurance and to offer new replacement units under warranty. The 8D problem-solving framework is a systematic method for identifying and addressing manufacturing issues. It involves a cross-functional team working together to perform a thorough Root Cause Analysis and identify the root causes of problems using the 5 Whys technique and other cause-and-effect tools. Once the root causes have been identified, the team can implement appropriate Corrective and Preventive Actions to prevent similar issues from occurring in the future. The 8D framework can be used in conjunction with Six Sigma methodology to ensure a thorough and effective resolution of problems. This case study demonstrates the effectiveness of the 8D framework in improving manufacturing quality and encourages managers and practitioners in manufacturing and product design organizations to adopt this approach.

Recommendations

It is also recommended that the potting process be changed to a two-step process to reduce the risk of contamination and air bubbles. The potting compound should be applied in two stages, with a curing time in between, to ensure that the compound adheres properly to the PCB surface. This will help to reduce the risk of problems such as abnormal leakage current across the MLCCs. In addition, it is recommended that a 100% check of the resistance value between T8 and T9 terminals be implemented as part of the final test for all sensor units after the potting process. This will help to detect any faults in the units that may have low resistance across C11 and validate any firmware issues.

Finally, it is recommended that the 8D problem-solving framework be embraced by manufacturing and product design organizations to improve quality. The framework allows cross-functional teams to work together to identify and resolve issues using root cause analysis, 5Whys, and corrective and preventive actions. This will help to prevent similar problems from occurring in the future and ensure that customer complaints are effectively addressed.

Permanent Corrective Actions for Returned Unit 1, SN 1

To ensure that all PCBs are thoroughly cleaned following solder assembly, it is recommended that a cleaning process be implemented for all PCBs. This process should involve the use of a solvent specifically designed to remove flux residues, as recommended by the solder paste supplier (ALPHA). Additionally, the production engineering team should follow the IPC620 standards, which require the cleaning of flux residues. This will help to prevent contamination of the MLCCs and ensure the proper functioning of the devices. It is also important to regularly check and maintain the cleaning equipment to ensure that it is functioning properly.

Permanent Corrective Actions for Returned Unit 2, SN2

The issue of freezing in bottle coolers has been reported in various locations and with various models of coolers. The quality control inspection team has been tasked with finding a solution to this issue. Upon review of the production batch of 2019 units, it was determined that the root cause of the failure was the C11 component, which experienced an excess of flux in the potting process. A lean 8D investigation report was conducted on 6 returned units to further analyse the cause of the failure. The production floor process was identified as the source of the issue, and corrective actions have been implemented to prevent similar failures from occurring in the future.

It is recommended that the design and software engineering teams create a firmware installation kit to address the software installation issue found in Returned Unit 2, SN2. In addition, it is suggested that the 8D analytics template be modified to include clauses from the ISO 9001 quality standard to enhance the investigation process. This will ensure that the investigations are carried out in accordance with quality standards and help prevent similar issues from occurring in the future.

Verification of the Effectiveness

To verify the effectiveness of the implemented corrective actions, an additional step has been added to the production process. This step involves measuring the resistance between the T8 and T9 terminals using a multi-meter on a sample of 5 units every 2 hours after the potting process. This will help ensure that the issue with low resistance across the C11 capacitor has been resolved and that the units are functioning properly.

The 8D problem-solving process is a detailed, cross-functional method used to resolve manufacturing, product design, service, and production process issues in factories and the supply chain of sub-suppliers to protect customers and implement corrective actions. Manufacturing companies need to operate effectively to control sustainability and reduce carbon footprint and waste from defects, in line with government policies and the environmental impacts of the Paris Agreement and the 2030 Agenda for Sustainable Development. To verify the effectiveness of the implemented solutions, an additional step for the production floor is to measure the resistance value between T8 and T9 terminals with a multi-meter after the potting process for a sample of 5 units every 2 hours. This case study demonstrates the usefulness of the 8D problem-solving framework for quality improvement in manufacturing and product design organizations.

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Conflict of Interest

The author declares that there is no conflict of interest.

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