

University of Wales Trinity Saint David

School of Engineering



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Failure Mode & Effects Analysis – Technical Report

Engineering Applications and Study Skills ACMA4007

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1 Introduction

1.1 Aims

This technical report aims to inform the reader of the importance that the use of risk management tools in the manufacturing sector, to help mitigate risks in manufacturing processes and adhere to correct health and safety legislations.

Additionally, the report will specifically focus on the use of a powerful risk management tool called FMEA (Failure Mode and Effects Analysis), to eliminate process failures at the Diamond Centre of Wales Limited. The specific process being analysed is the removal of VisiJet Wax Jewel Red wax models from a ProJet2500W 3D printer, with post-processing techniques used to prepare the wax models for lost-wax casting.

1.2 Objectives

The main objective of this report is to give the reader the knowledge of the major benefits that the relevant use of risk management tools can have, during manufacturing processes.

The reader should be able to successfully perform the process of removing wax models from a ProJet2500W 3D printer and prepare them for lost-wax casting, by following a process FMEA created by the author in tangent with fellow design engineers at the Diamond Centre of Wales.

2 Literature Review

2.1 Risk Management

“Risk management is a critical aspect of any manufacturing sector's operations. It involves identifying, evaluating, and prioritizing potential risks to minimize the impact of unexpected events. Effective risk management can enhance efficiency, ensure safety, and contribute to the business's overall profitability.” **(Leonardo Selvaggi 2023)** The manufacturing industry requires the use of risk management tools to minimize the potential failures that occur during processes. Companies in the manufacturing industry use various methods for identifying risks. These include - Failure Mode and Effects Analysis (FMEA) & Root Cause Analysis (RCA). **(Adrian Camara 2024)**

2.2 Risk Management Tools

2.2.1 Root Cause Analysis (RCA)

Root Cause Analysis is a powerful tool used widely in the manufacturing process for identifying the main causes of failures in processes, as without identifying the root cause of the problem then it is likely the process will continuously fail. The RCA process involves realising the problem, gathering data, determining possible factors, identifying the root cause and finally implementing solutions to fix the problem. **(MindTools, 2023)** The RCA procedure involves gathering evidence based on facts, stating the root cause of the problem, analysing the cause, generating solutions to solve the problem and then documenting findings. **(Sologic, 2021)**

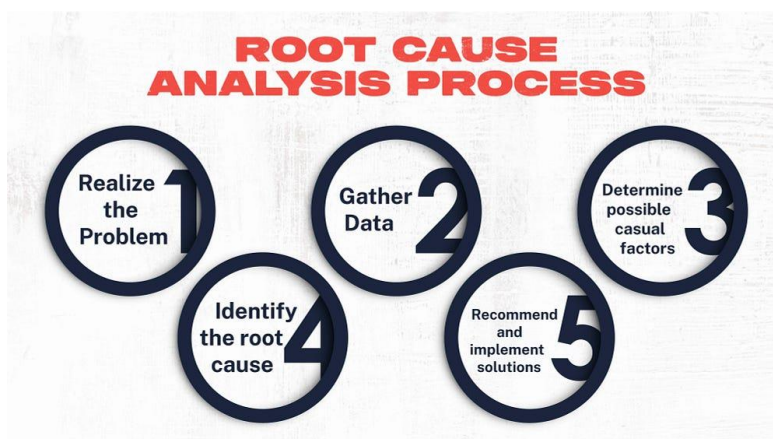


Figure 1 Root Cause Analysis Process **(Carlos Almonte, 2023)**.

2.2.2 Failure Mode and Effects Analysis (FMEA)

Failure Mode and Effects Analysis is another powerful tool used in risk management in the manufacturing industry. FMEA's are used to break down a design, system or process to identify the risk elements involved. It is used widely in many manufacturing industries to improve the products and services. An FMEA can be categorized into design, process and system. **(Vijay Kanade, 2023)**

The first step of an FMEA is to create a team of employees who have a good wealth of experience in a specific design, system or process. The purpose of the design, system or process needs to be identified before breaking it down into components. The teams must determine each possible risk or failure. The failures that have been highlighted need to be analysed to figure out the causes and effects of the failures. The different components then need to have ranking scores given to them for severity, occurrence and detection probability. Corrective actions need to be given for each failure to reduce the likelihood of them occurring again. A separate ranking is given for severity, occurrence and detection for after the introduction of the corrective actions. An FMEA is a live document which should be continuously improved on. **(Alexander S. Gillis, 2022)**

The severity ranking in an FMEA is based on a team's knowledge of the system, process or design function failure that is in the spotlight. The rankings are based on a 1-10 scale, with 10 being hazardous and 1 being ineffective on the process. The occurrence score refers to how the frequency of failures with a particular function. This is also on a 1-10 scale with 10 being almost inevitable that it will occur and 1 being extremely unlikely that it will occur. The detection figure is an evaluation of how easily detectable the failure is. A Risk Priority Number is then calculated by multiplying the severity, occurrence and detection figures together. **(Open Source Six Sigma (n.d))**

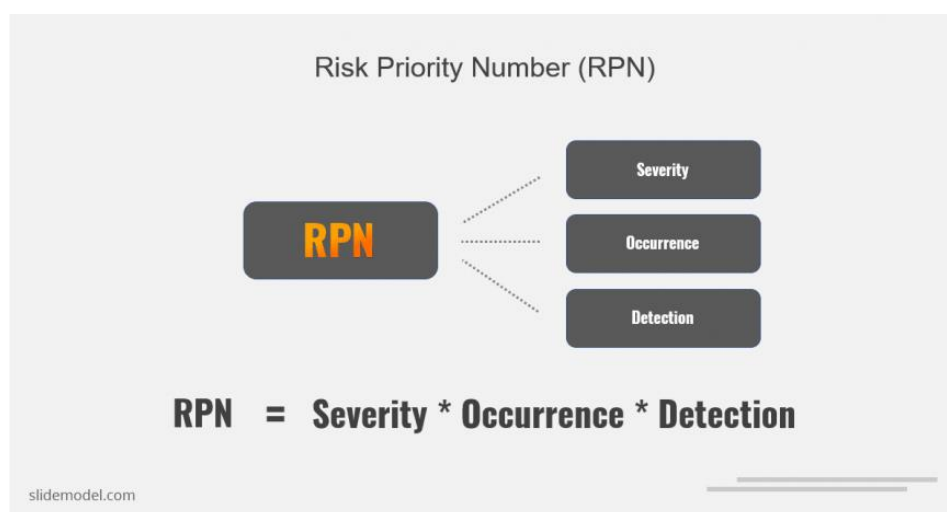


Figure 2 RPN Formula (SlideModel 2019).

Tools such as FMEA help engineers in the manufacturing industry to adhere with the IMechE Code of Conduct principle “We should act with care and competence.” This principle states that engineers should “Quantify and limit risk in all aspects of professional work, including with those who are working under our authority.” (*Institution of Mechanical Engineers 2023*)

2.2.3 Health and Safety

Risk management tools also help to underline health & safety risks. The use of a PFMEA helped identify risks to individuals at the Diamond Centre of Wales when using a hot plate and isopropanol. Through that, the team now uses an industry standard face mask, rubber gloves, heat resistant gloves and eyewear to protect themselves. It helped alert team members to health and safety risks which they can find via post-processing documentation at 3DSystems. (*3DSystems 2024*)



Figure 3 Heat Resistant Gloves.

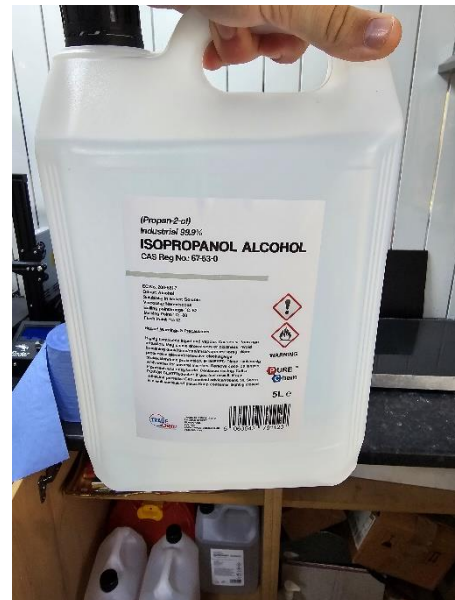


Figure 4 Isopropanol Alcohol.

3 Methodology & Discussion

3.1 PFMEA Results

Process / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Class
Removing print bed from ProJet2500W printer	Dropping the print bed	Damage to the bed and the wax models	8	Procedural
Placing print bed onto the hot plate to melt support material for 7 minutes	Plate too hot and time not recorded	Melted wax models	8	Controllable
Once support material melted, remove models from print bed (which is on hot plate)	Models too warm	Deformity to wax models as flimsy when hot	8	Procedural
Placing wax models into an Isopropanol bath for 15 minutes	Isopropanol bath contaminated	Wax models won't be clean for quality investment casting	7	Procedural
Removing wax models from isopropanol bath once support material has dissolved	Models left in isopropanol bath for too long	Wax models will be very fragile	8	Procedural
Drying models with an air compressor	Compressor not releasing enough air	Isopropanol not dried off the models	3	Procedural
Placing waxes into small plastic bags using tweezers	Tweezers too sharp	Tweezer marks on models	2	Procedural

Figure 5 - Part 1 of FMEA carried out by Diamond Centre of Wales.

Potential Cause(s)/ Mechanism(s) of Failure	Occ	Current Controls	Det	RPN
Print bed wasn't cleaned and dried properly before so could be slippy	1	Visual inspection	1	8
Heat dial on too high and time not recorded	3	Timer on phone	1	24
Print bed left on the hot plate for too long	3	Timer on phone	3	72
Isopropanol bath not clean	7	Visual inspection	3	147
Time not recorded	4	Timer on phone	3	96
Nozzle on compressor clogged	2	When not releasing much air it gets de-clogged	4	24
Employee Carelessness	6	None	5	60

Figure 6 - Part 2 of FMEA carried out by Diamond Centre of Wales.

Recommended Action(s)	Responsibility and Target Completion Date	Action Results				
		Actions Taken	S e v	O c c	D e t	R P N
Have a second team member inspect the printed to ensure clean and dry	Meurnyn, Adam and Steve 19/01/2024	The plate gets checked by a 2nd team member after cleaning	8	1	1	8
Use speaker as well as phone timer	Meurnyn, Adam and Steve 19/01/2024	Speaker used in conjunction with phone timer	8	2	1	16
Use speaker as well as phone timer	Meurnyn, Adam and Steve 19/01/2024	Speaker used in conjunction with phone timer	8	2	3	48
Empty and clean bath every 2 months	Meurnyn, Adam and Steve 19/01/2024	Bath emptied and replaced with fresh isopropanol to be changed every 2 months	7	2	3	42
Use speaker as well as phone timer	Meurnyn, Adam and Steve 19/01/2024	Speaker used in conjunction with phone timer	8	2	3	48
Check nozzle before each use to ensure no materials clogged/have a spare nozzle for emergency	Meurnyn, Adam and Steve 19/01/2024	Nozzle gets checked and cleaned weekly/spare nozzle ordered	3	1	4	12
Purchase plastic/soft-tipped tweezers	Meurnyn, Adam and Steve 19/01/2024	Plastic-tipped tweezers purchased for handling of models	2	2	5	20

Figure 7 - Part 3 of FMEA carried out by Diamond Centre of Wales.

3.2 Removal of Print Bed to be Placed onto Hot Plate

The removal and post-processing of VisiJet Wax Jewel Red waxes from a Projet2500W involves manually removing the print bed from the 3D printer with two hands and placing the print bed onto a hot plate. The dial on the hot plate then gets turned to roughly 9 o'clock and a timer is set for 7 minutes. This makes the support material melt slightly for removal from the print bed.



Figure 8 Print bed in the Projet2500W.

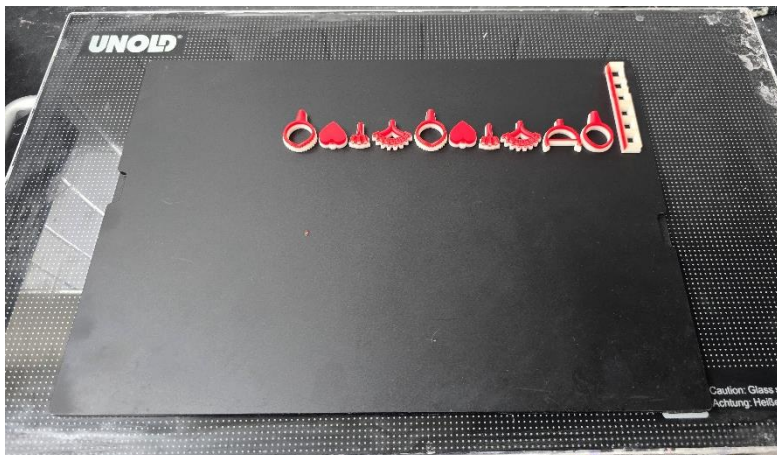


Figure 9 Print bed on the hot plate.

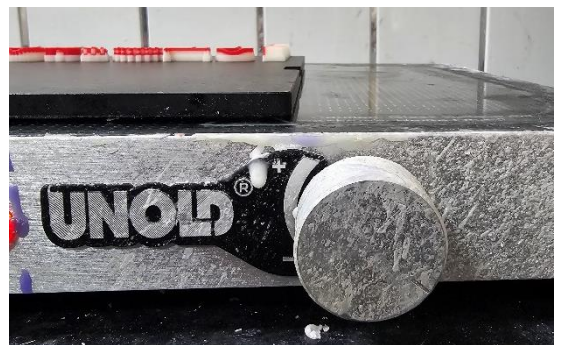


Figure 10 Dial turned to 9 O'clock.

3.3 VisJet Wax Jewel Red Models Timed on Hot Plate

The method for timing the wax models on the hot plate was for an individual to a timer on their phone in conjunction with a speaker. Prior to the PFMEA only a phone was used.



Figure 11 - New speaker used as a timer.



Figure 12 - Support material melting

3.4 VisiJet Wax Jewel Red Models Placed in Isopropanol Water Bath

Once the support material starts melting slightly, they are placed into the water bath. A timer of 15 minutes is set for the isopropanol to dissolve the support material away from the models. A speaker was used in conjunction to time the 15 minutes required.



Figure 13 - Slightly contaminated water bath.



Figure 14 - Clean water bath.

3.5 Removal of VisiJet Wax Jewel Red Models from Isopropanol Bath

After 7 minutes, the wax models are ready to remove from the water bath with tweezers for drying with an air compressor.

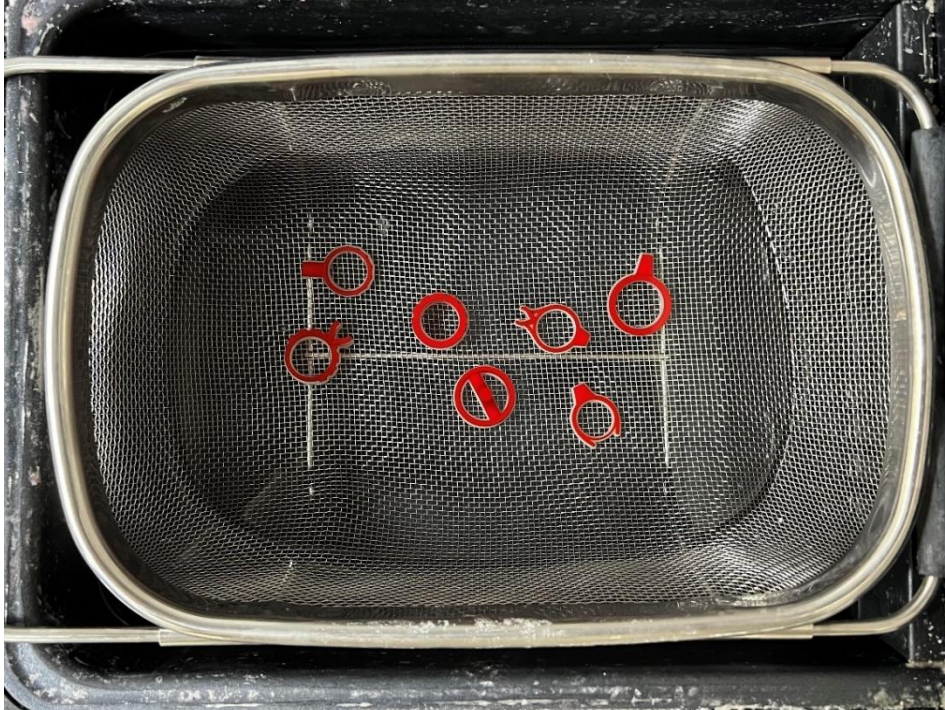


Figure 15 Models in water bath.

3.6 Drying the Models with an Air Compressor

Once the models are removed from the water bath, they are dried using an air compressor. The air compressor nozzle clogs after a while, so, after the PFMEA it now gets cleaned every day to ensure it is releasing an optimal amount of air for drying the wax models.



Figure 16 Air compressor nozzle clogged.



Figure 17 Air compressor nozzle after being cleaned.

4 Combined Results and Analysis

Table 1 Average waxes passed/rejected.

(BASED ON 1 WEEK)	Prior to PFMEA	After PFMEA
No. of Waxes	76	64
No. of Rejected Waxes	16	2
Average % of Rejected Waxes	21.053%	3.13%
Average % of Passed Waxes	78.947%	96.87%

It is clear to see that using a PFMEA in a process at the Diamond Centre Wales Limited that the process has improved drastically. The percentage of waxes that were not of the required quality to send for lost-wax casting was 21.053% before the PFMEA and 3.13% after the PFMEA was enforced.

5 Discussion

The severity and detection scores stay the same for before and after the PFMEA in every step as it is an already refined process. An exception is made with the placing of the models into plastic bags.

The Risk Priority Number (RPN) reduces for each step apart from the first.

5.1 Removal of Print Bed to be Placed onto Hot Plate

A severity score of 8 was applied due to potential damage to print bed and wax models. Occurrence and detection are given a 1 as it is obvious if the print bed gets dropped. Nothing was changed to these scores after the PFMEA. RPN before = 8. After = 8.

5.2 Wax Models Timed on Hot Plate

Prior to the PFMEA the only measuring device was a phone timer. If the models are on the bed for too long, they will melt, which gave a severity score of 10. An occurrence score of 3 was given as it rarely happens and a detection score of 1 was applied as you can visually see melted waxes. After PFMEA a speaker was introduced for dual devices timing the 7 minutes, reducing the occurrence score from 3 to 2 as technology is not always dependable. RPN before = 30. After = 20.

5.3 Wax Models Placed in Isopropanol Water Bath

A severity of 5 was scored due to the fact that unclean models only end up giving the castings a rough surface which can be sorted by goldsmiths. The occurrence score was 7 as the bath wasn't cleaned out often. The detection score was 3 as it isn't clear to the naked eye. The change made after the PFMEA was to clean the bath out bi-monthly. The occurrence score changed to 2. RPN before = 105. After = 42.

5.4 Removal of Wax Models from Isopropanol Bath

Severity is 5 as tweezer marks can damage models for casting. Occurrence is 8 as it is difficult to not mark the models due to fragility. Detection is 4 as not easy to see marks. Plastic-tipped tweezers are used after the PFMEA which reduces occurrence to 1. The severity changes to 2 as plastic-tipped tweezers cause minimal damage. The detection increases as the new tweezers leave more subtle marks. RPN before = 120. After = 30.

5.5 Drying the Models with an Air Compressor

The severity score is 3 as the models can eventually dry on their own. Occurrence is 6 as the nozzle gets clogged roughly every 2/3 weeks. Detection is 4 as not always easy to tell unless try on hands. After PFMEA the occurrence reduces to 1 as the nozzle gets cleaned before every single use. RPN before = 72. After = 6.

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7 Appendices

7.1 Personal Development Plan

Personal Development Plan

Name – Meuryn Nelson

Degree – BEng (Hons) Advanced Manufacturing Operations

Previous Qualifications – ILM Team Leading Level 3

Previous Experience – Diamond Centre of Wales CAD/CAM Engineer Jan 2018 - Present

Goal	Objective	Resources Required	Measurement	Target Date
Conduct intensive research into risk <u>management</u>	Gain good knowledge and understanding on risk management in manufacturing	Ebooks via UWTSD library, online resources such as internet, own knowledge	Compare against a range of different resources	12/02/2024
Hand in the assignment on time	Hand the assignment documents in before 11.59pm on 12/02/2024	Make a plan and timetable for researching and actually carrying out tasks	Deadline date	12/02/2024
Produce an FMEA for my place of <u>work</u>	Create a live document in the form of a PFMEA for identifying failures in a work process	A team to help with the PFMEA and use of knowledge gained through research	Carry out task and see if the PFMEA has made improvements to the process	12/02/2024
Ensure accurate <u>referencing</u>	Reference correctly to the Harvard standard	Websites like Mybib and Mendeley	UWTSD reference checking via Turnitin	12/02/2024
Produce technical <u>report</u>	Produce a technical report following the UWTSD guidelines for academic	Documents provided from lecturers to correctly write a technical report	Documents provided from lecturers to correctly write a technical report	12/02/2024

7.2 Technical Poster



Failure Mode and Effects Analysis

Meuryn Nelson

School of Engineering

BEng (Hons) Advanced Manufacturing Operations

Introduction

At the Diamond Centre of Wales Limited, a Process Failure Mode and Effects Analysis has been created to identify failures and provide solutions, for the post-processing of VisiJet Wax Jewel Red wax models after 3D printing on a Projet 2500W printer.

Project Aims

The aim of this project was to identify failures in a vital process, to be able to provide solutions via a powerful risk management tool called an FMEA. Research was also carried out on the relevancy of risk management in general in manufacturing.

Methodology

An experiment was carried out based on 1 weeks' worth of recordings. The experiment recorded how many waxes were not up to the required standard for lost-wax casting for 1 week before the FMEA was carried out, and 1 week after it was carried out.

Results

The results from carrying out this experiment were astounding and proved how effective the use of risk management tools can be in the manufacturing industry.

The table below shows the results from the experiment undertaken at the Diamond Centre of Wales. The number of waxes that were not suitable for lost-wax casting drastically reduced after the introduction of a Process Failure Mode and Effects Analysis. Photo courtesy of Diamond Centre of Wales engineers.

Wax Type / Model	Before FMEA	After FMEA
Wax Type A	15	10
Wax Type B	10	5
Wax Type C	10	5
Wax Type D	10	5
Wax Type E	10	5
Wax Type F	10	5
Wax Type G	10	5
Wax Type H	10	5
Wax Type I	10	5
Wax Type J	10	5



This image shows a 3D printed wax model being heated by a hot plate which is being used to melt away the white support material. Photo courtesy of Diamond Centre of Wales Engineers.



The above image shows a 3D printed wax model in a tray, showing the support material being melted away from the wax.



The image on the left shows a nozzle from an air compressor which has been cleaned with Isopropyl alcohol to ensure working at an optimal level for drying wax models. Photo courtesy of Diamond Centre of Wales engineers.



The above image shows an isopropyl bath which has been slightly contaminated due to not being cleaned out for so long.

Conclusions

The research and experiment proved how effective the use of risk management tools can be in the manufacturing industry. The FMEA carried out significantly improved the process and mitigated all risks involved whilst also highlighting health & safety concerns. Risk management tools should be compulsory in all manufacturing companies.



The above image shows an isopropyl bath which has been cleaned.

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7.3 FMEA Table

Item:	Visijet Wax JewelRed			Responsibility:			Removing wax models from plate					FMEA number: 1				
Model:	Project2500W			Prepared by: Meuryn Nelson								Page : 1				
Core Team: Meuryn Nelson, Adam Evans and Steve Davies. (Weekly rota for removing models from Project2500W)																
FMEA Date (Orig): 27/01/2024																
Rev: Adam Evans																
Process / Function	Potential Failure Mode	Potential Effect(s) or Failure	Severity	Criticality	Potential Cause(s) / Mechanism(s) of Failure	Occurrence	Current Controls	Detection	Risk Priority Number	Recommended Action(s)	Responsibility and Target Completion Date	Action Results				
												Actions Taken	Severity	Occurrence	Detection	Risk Priority Number
Removing print bed from Project2500W printer	Dropping the print bed	Damage to the bed and the wax models	8		Print bed wasn't cleaned and dried properly before so could be slippery	1	Visual inspection	1	8	Have a second team member inspect the print bed to ensure clean and dry	Meuryn, Adam and Steve 19/01/2024	The plate gets checked by a 2nd team member after cleaning	8	1	1	8
Pacing print bed onto the hot plate to melt support material for 7 minutes	Plate too hot and time not recorded	Melted wax models	10		Heat dial on too high and time not recorded	3	Timer on phone	1	30	Use speaker as well as phone timer	Meuryn, Adam and Steve 19/01/2024	Speaker used in conjunction with phone timer	10	2	1	20
Once support material melted, remove models from print bed (which is on hot plate)	Models too warm or melted	Deformity to wax models as flimsy when hot	10		Print bed left on the hot plate for too long	3	Timer on phone	3	90	Use speaker as well as phone timer	Meuryn, Adam and Steve 19/01/2024	Speaker used in conjunction with phone timer	10	2	3	60
Pacing wax models into an isopropanol bath for 15 minutes	Isopropanol bath contaminated	Wax models won't be clean for quality investment casting	5		Isopropanol bath not clean	7	Visual inspection	3	105	Empty and clean bath every 2 months	Meuryn, Adam and Steve 19/01/2024	Bath emptied and replaced with fresh isopropanol to be changed every 2 months	7	2	3	42
Removing wax models from isopropanol bath once support material has dissolved	Tweezers too sharp	Tweezer marks on models	5		Tweezers squeezed too hard	8	Visual inspection	3	120	Use plastic-tipped tweezers	Meuryn, Adam and Steve 19/01/2024	Plastic-tipped tweezers purchased and used	5	2	3	30
Drying models with an air compressor	Compressor not releasing enough air	Isopropanol not dried off the models	3		Nozzle on compressor clogged	6	When not releasing much air it gets de-clogged	4	72	Check nozzle before each use to ensure no materials clogged/have a spare nozzle for emergency	Meuryn, Adam and Steve 19/01/2024	Nozzle gets cleaned before every use	1	1	6	6