To reduce tool breakage in primary bending line (Machine#3)

Sarah Miller

Overview

Define

Measure

Analyse

Improve

Control

OVERVIEW

Background

The primary bending line (Machine #3) has been experiencing excessive and unpredictable tool wear and breakage during the cold bending of aluminum profiles, resulting in rising operational costs and frequent production interruptions. The current tool breakage rate stands at approximately 3%, which is significantly above the acceptable level. This issue has been traced to three major causes—material impurities, incorrect machine pressure settings, and misalignment of dies/rollers—all of which contribute to premature tool failure and inconsistent bending performance.

Reducing tool breakage is critical not only to minimize waste and tool replacement expenses but also to improve machine uptime, enhance product quality, and stabilize throughput. Addressing these issues through a structured Lean Six Sigma approach will enable the organization to bring tool breakage down to 1%, ensuring measurable cost savings, improved process reliability, and stronger customer satisfaction.
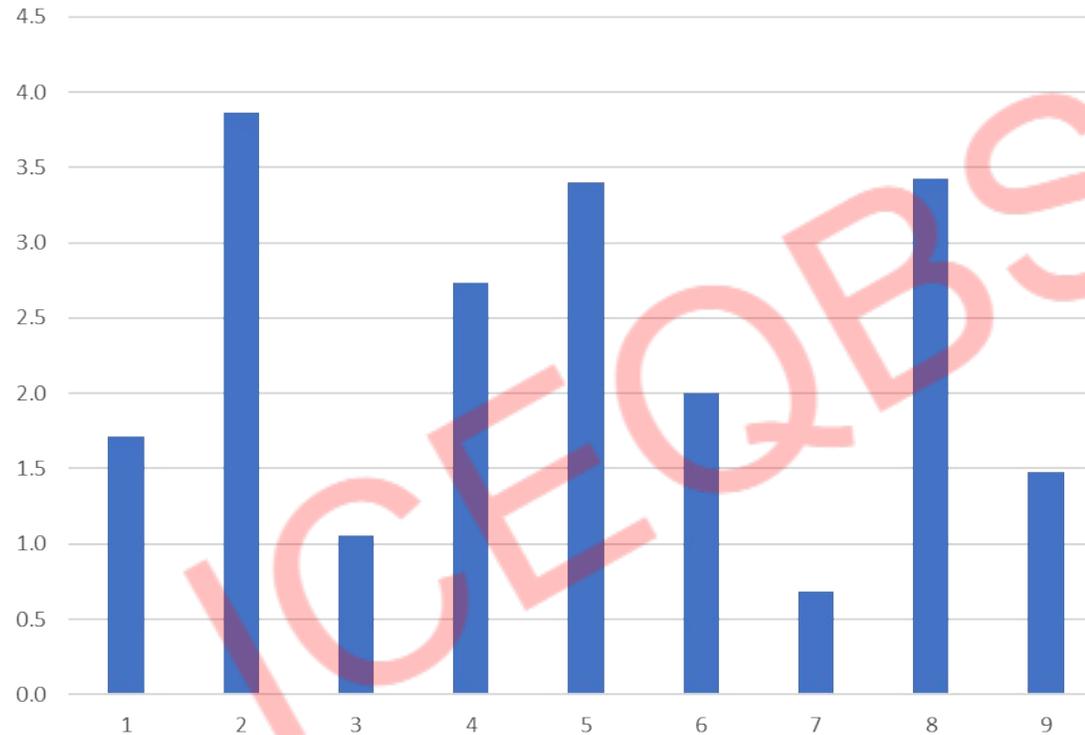
DEFINE PHASE
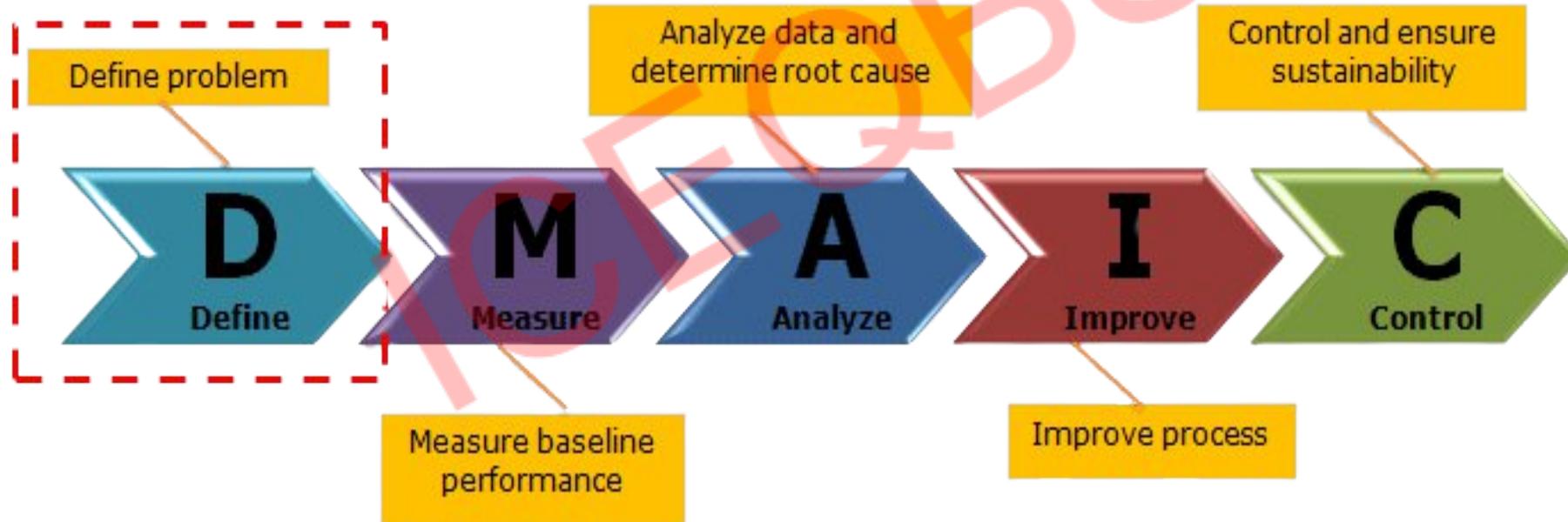
CTQ Tree :

| Voice of customer	Critical to X	Primary Metric for improvement
The dies are breaking or wearing out prematurely and unexpectedly	CTC – Cost	**Primary Metric -** Y = High Tool Wear and Breakage % **Secondary Metric -** Productivity

Baseline Performance of Primary Metric

Inference :
- Last 9 months data shows a significant variation and hence ideal problem to be taken up as a Six Sigma Project.
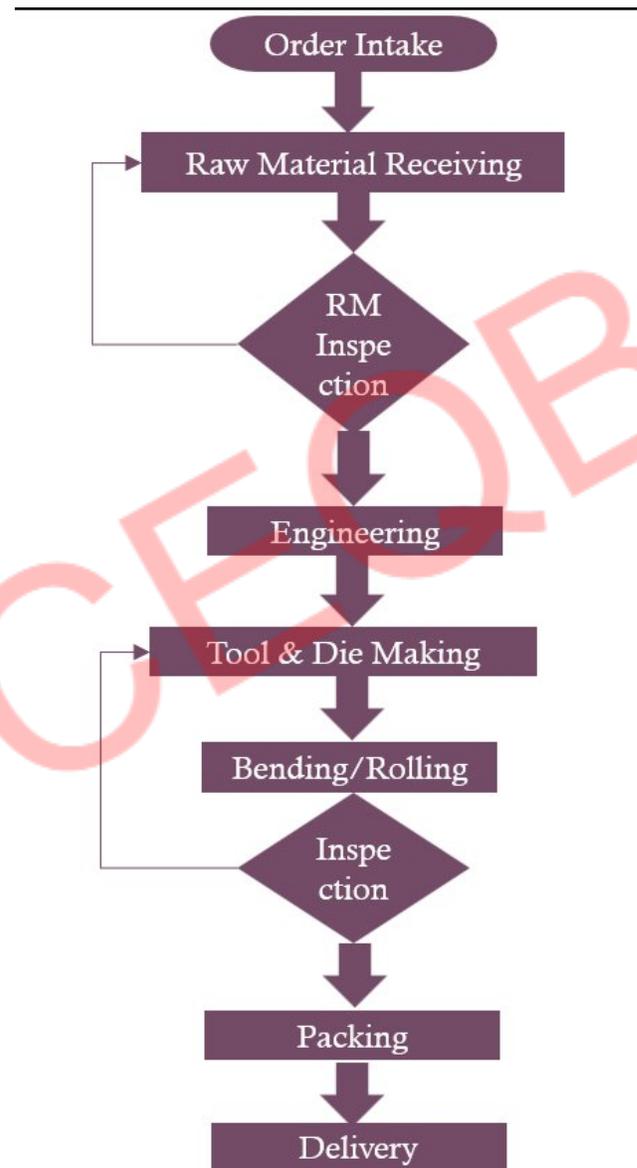
Pareto chart

Pareto Chart of Tool Wear and Breakage Causes
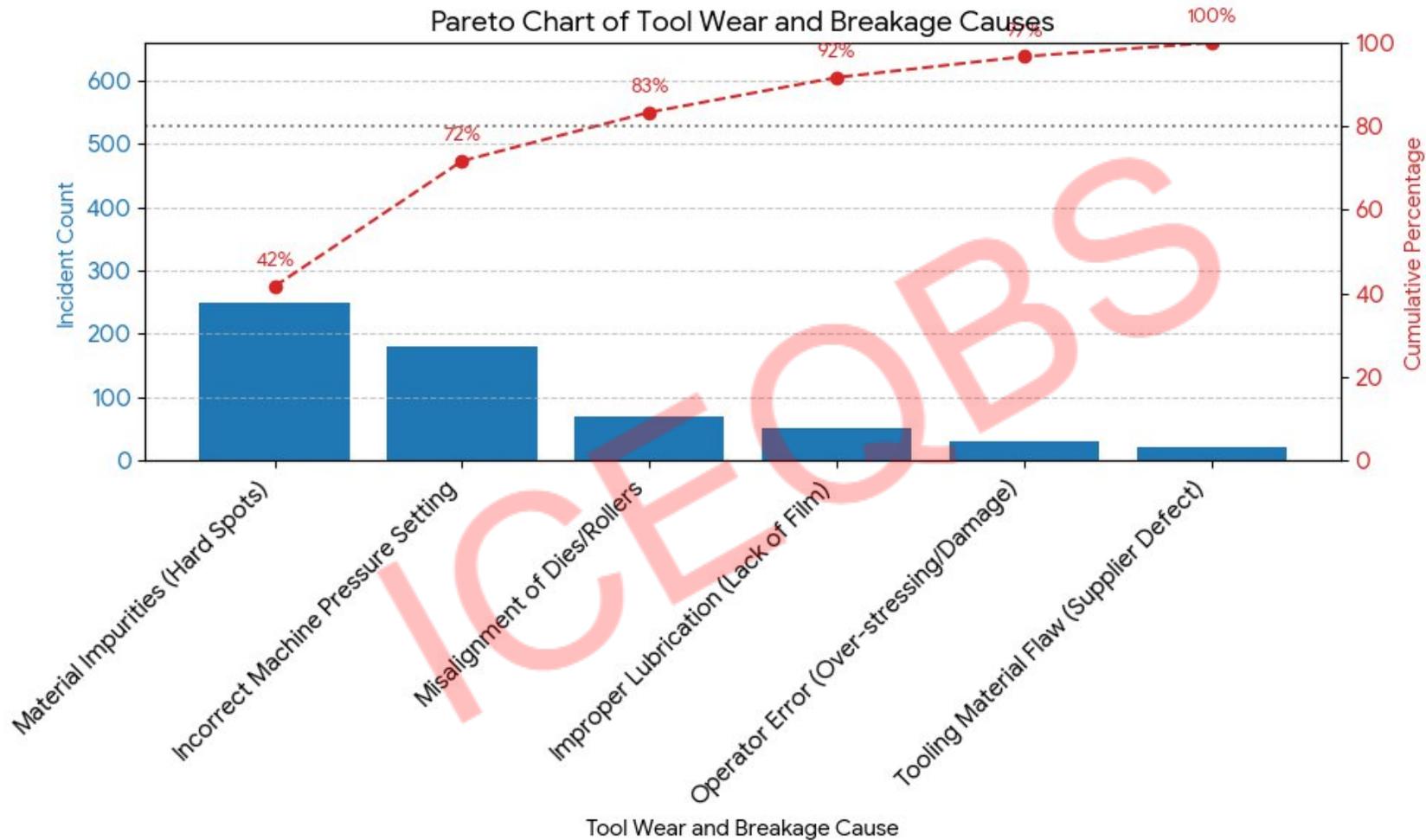
Inference :
•Material Input contributes substantially for the issue and included in the scope of the project

SIPOC

Suppliers (S)	Inputs (I)	Process (P)	Outputs (O)	Customers (C)
1. Tooling Vendors: Provide new/refurbished bending dies, rollers, and mandrels.	1. Tool Quality: Correct die material, geometry, and hardness.	1. Tooling Setup: Installing and aligning dies/rollers (High Risk of Misalignment).	1. Bent Profiles: The final product (Output Y).	1. End Customer: Receives the final bent profile.
2. Material Suppliers: Provide extruded aluminum profiles (e.g., 6061, 6063).	2. Material Quality: Correct alloy, temper, and absence of Hard Spots/Impurities.	2. Process Start/Ramp Up: Applying initial pressure based on material specs (Risk of Incorrect Pressure).	2. Waste/Scrap: Rejected profiles due to dimension/surface defects.	2. Maintenance Team: Receives broken tools that require urgent repair/replacement.
3. Maintenance Dept.: Provides properly calibrated machine parts and lubrication.	3. Machine Settings: Correct Pressure/Force settings, speed, and lubrication.	3. Bending Cycle: Running the material through the machine.	3. Used/Worn Tooling: Dies/rollers ready for replacement or refurbishment.	3. Quality Control: Receives bent profiles for inspection.
4. Engineering/Design: Provides approved tooling designs and bending specifications.	4. Procedures: Clear Setup/Alignment instructions, SOPs.	4. Tool Degradation/Failure: The die/roller wears or breaks prematurely (The Low MTBF result).	4. Downtime Event: An unscheduled stop due to tool breakage.	4. Production Scheduling: Receives updated downtime and throughput data.

Process Map

Project Charter

Project Title:	Increasing MTBF for Bending Dies on Cold Bending Line 3

Project Leader	Project Team Members:
Sarah Miller	John Davis, Ben Carter Maria Rodriguez

Champion/Sponsors:	Key Stake Holders
David Lee, Production Manager	Production Department Maintenance Team Quality Department Suppliers / Vendors

Problem Statement:	Goal Statement:
The primary bending line (Machine#3) is experiencing excessive and unpredictable tool wear and breakage during the cold bending of aluminum profiles. The current % tool breakage is @ 3%	To reduce tool breakage 5 from 3% to 1%.

Secondary Metric	Assumptions Made:
Productivity	Incoming material quality will remain consistent and within

Project Charter

| Tangible and Intangible Benefits:		Risk to Success:	
Reduced tooling replacement cost. Lower downtime and scrap-related losses. Improved process reliability. Better product quality and customer satisfaction.		Unexpected variations in material quality. Operator errors in machine settings. Unplanned machine issues or breakdowns.	
In Scope:		**Out of Scope:**	
MACHINE OPERATORS / BENDING TECHNICIANS MAINTENANCE TEAM QUALITY CONTROL (QC) DEPARTMENT PRODUCTION/SHOP FLOOR MANAGE		Other machines beyond Machine #3. Tool design or new tooling. Supplier material quality improvements. Upstream or downstream processes.	
Signatories:		**Project Timeline:**	
Project Head : Sarah Miller, Quality Engineer Sponsor : Alex Chen, VP of Operations		6 Months	

MEASURE PHASE
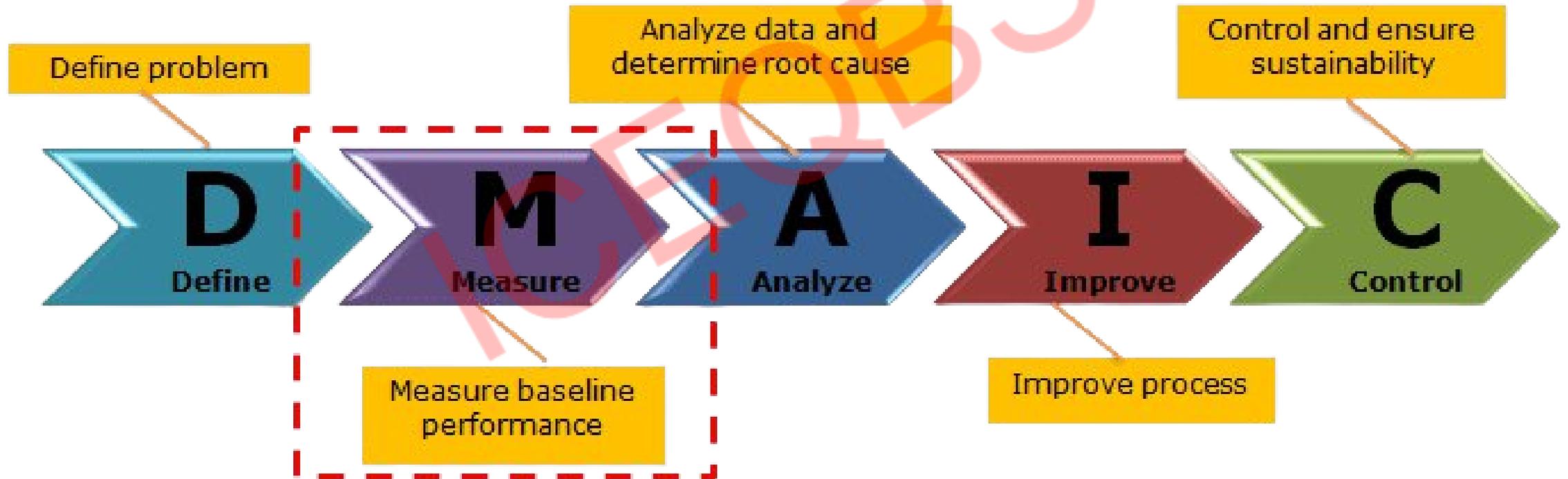
Data collection – Histogram (Before improvement)

Histogram of Before
Normal

Mean 2.262
StDev 1.139
N 9
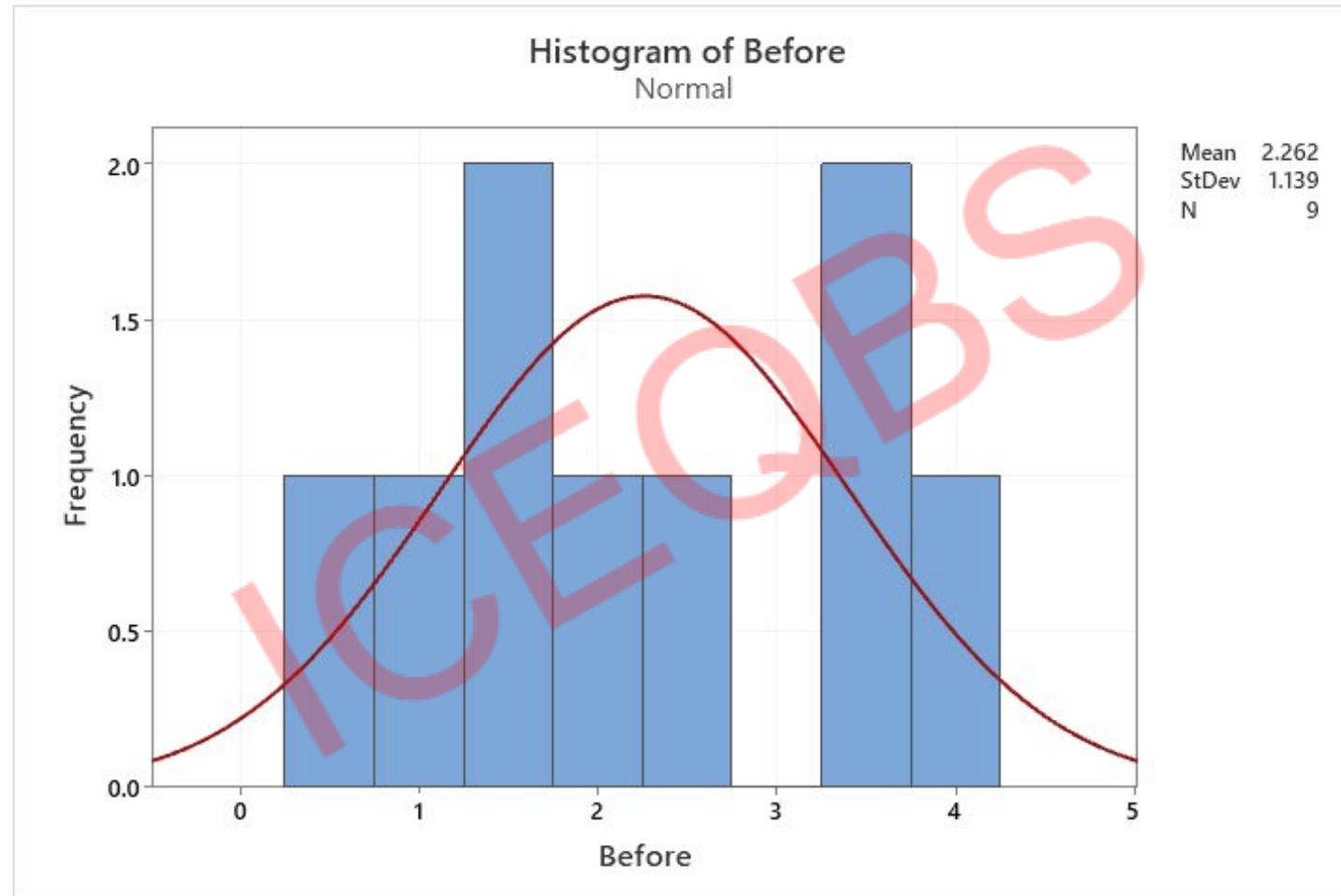
Inference :
•Data is normally distributed over the mean

Data collection – Run Chart (Before improvement)

Run Chart of Before

Number of runs about median:	7	Number of runs up or down:	6
Expected number of runs:	5.4	Expected number of runs:	5.7
Longest run about median:	2	Longest run up or down:	2
Approx P-Value for Clustering:	0.870	Approx P-Value for Trends:	0.616
Approx P-Value for Mixtures:	0.130	Approx P-Value for Oscillation:	0.384
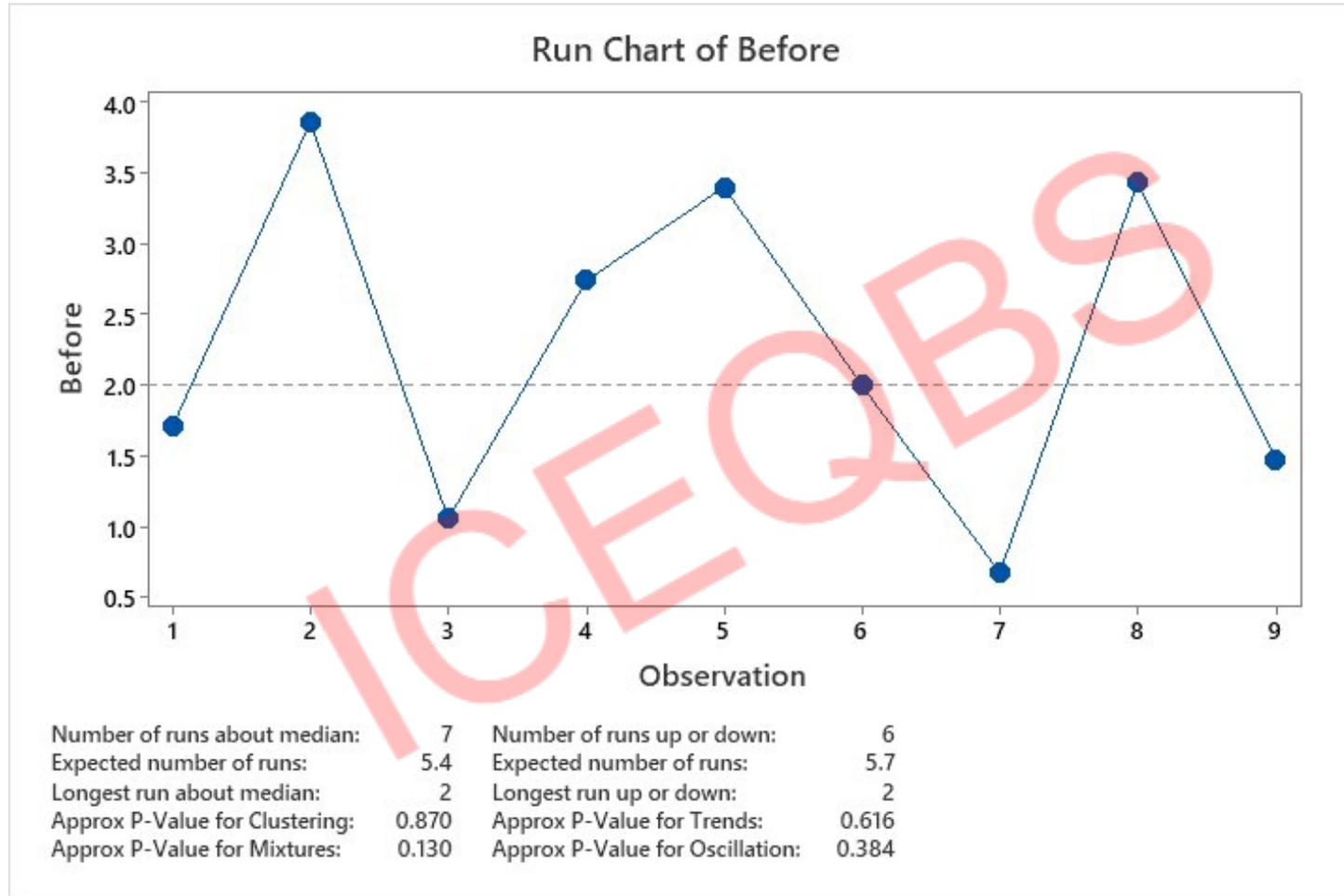
Inference :
P > 0.05 – No special causes in the process. Data can be used for further analysis

Data collection – Normality plot (Before improvement)

Probability Plot of Before
Normal

Mean 2.262
StDev 1.139
N 9
AD 0.274
P-Value 0.570
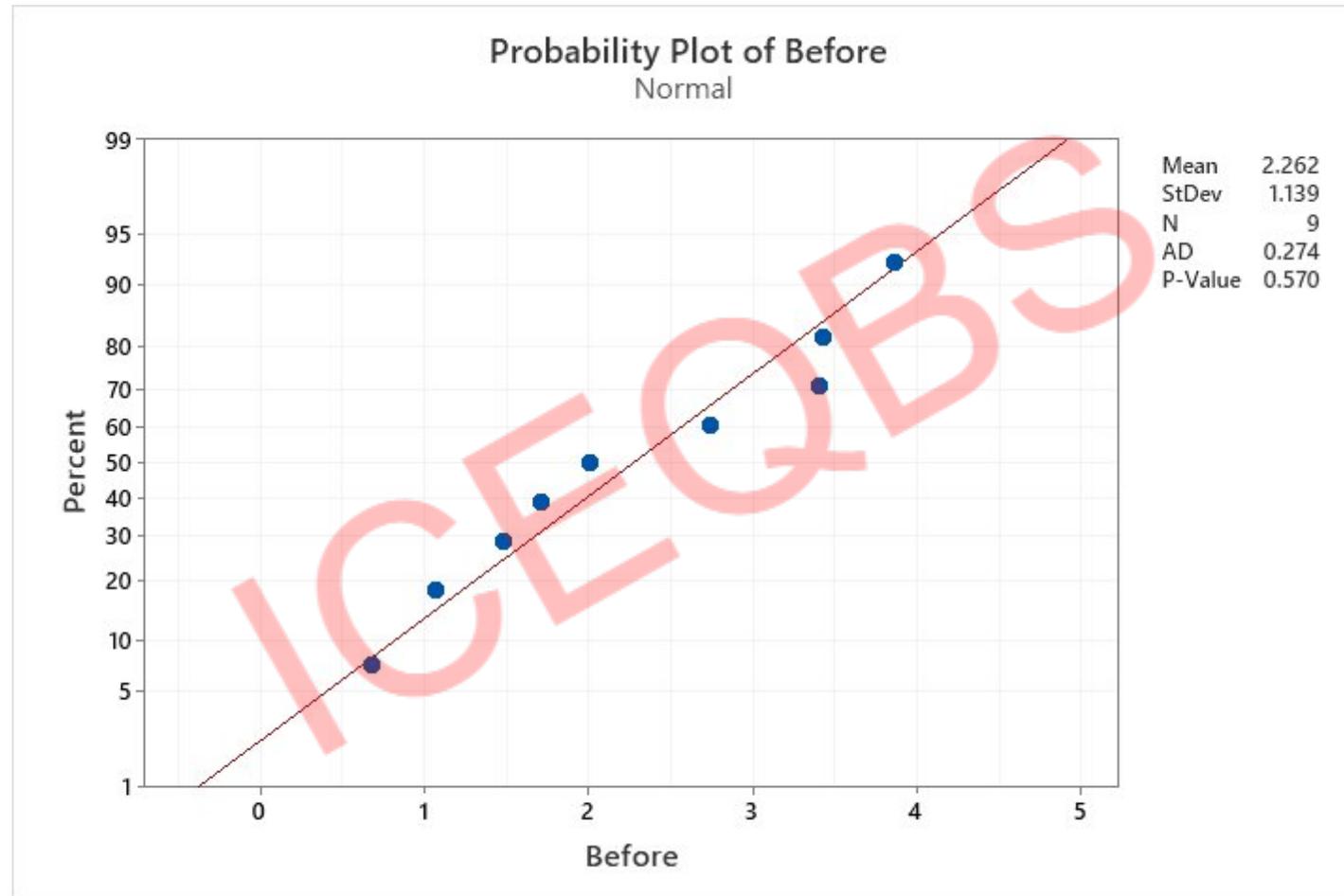
Inference :
- P > 0.05 in all scenarios, thus all the data is normally distributed

Fish Bone Diagram

ENVIRONMENT

1. Temperature Fluctuations near the machine (affects material properties).

2. High Humidity (accelerates surface corrosion on tools).

3. Dust/Debris contamination in the bending area (abrasive particles).

4. Poor Lighting for accurate die/roller alignment checks.

5. Floor Vibration from adjacent heavy machinery.

METHOD

1. Lack of a Preventative Maintenance Schedule for tooling calibration.

2. No Standardized Setup Procedure for complex profiles (misalignment cause).

3. Reactive Bending Adjustments (over-bending to compensate for spring-back).

4. Incorrect Lubrication Type/Flow Rate specified for the alloy.

MAN

1. Inadequate Tooling Setup Training (leading to misalignment).

2. Lack of Lubrication SOP compliance (under-lubrication).

3. Fatigue/Rushing during changeovers (leading to quick, poor alignment).

4. Incorrect Pressure Calculation by operator (manual entry error).

MEASUREMENT

1. No In-Line Pressure Monitoring or recording capability.

2. Lack of Profile Inspection for hard spots/impurities upon receipt.

3. Poor Calibration Frequency for critical alignment instruments.

4. Tool Life Tracking system is manual or inaccurate (no proactive replacement).

5. Inconsistent Surface Finish Measurement (failing to catch early wear signs).

MACHINE

1. Poor Alignment Control system (loose guide rails/jaws).

2. Low Machine Rigidity/Age (vibration amplification).

3. Insufficient Power/Torque capacity (machine stalls, increasing stress).

4. Inaccurate Pressure Gauges/Sensors (misleading operator input).

5. Worn Mandrel/Die Surfaces (causing friction and uneven wear).

MATERIAL

1. High frequency of Hard Spots/Impurities in incoming profiles.

2. Inconsistent Yield Strength (batch-to-batch variation in spring-back).

3. Surface Oxidation/Scale (acts as an abrasive between tool and material).

4. Incorrect Alloy Temper selected for the radius (too brittle, leading to cracking/breakage).
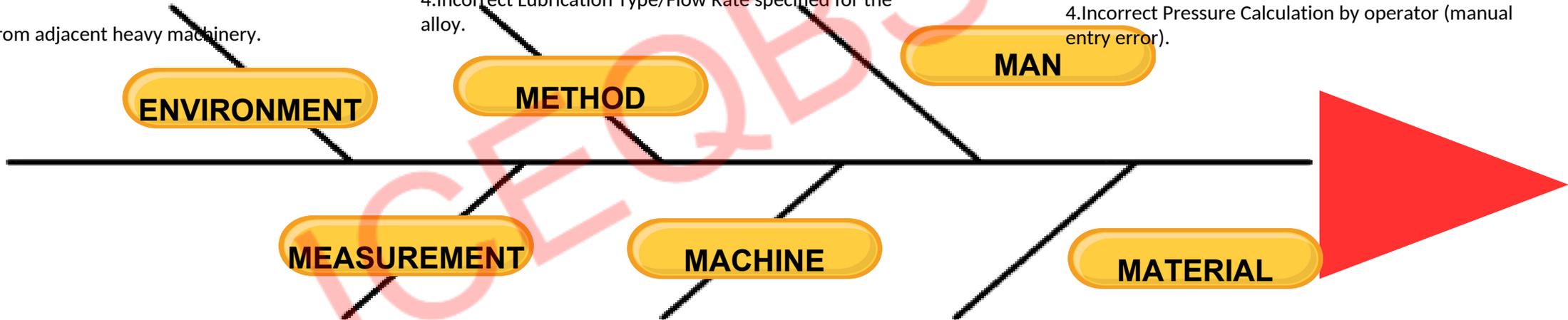
3M Analysis for Waste

MUDA

- Reworking parts due to out-of-tolerance machining.
- Excessive material scrap from trial cuts and tool offsets.
- Waiting time for inspection approval before moving to the next operation.

Mura

- Variation in cycle time between operators for the same CNC program.
- Inconsistent surface finish quality across different machining shifts.
- Fluctuations in raw material hardness from different suppliers/lots.

Muri

- Overloading operators with multiple machines simultaneously.
- Forcing cutting tools to run beyond recommended life, causing tool breakage.
- Running machines continuously without scheduled maintenance, leading to sudden breakdowns.

3M Analysis for Waste

Common Causes (Systemic Variation)	Special Causes (Assignable Variation)
Inconsistent Yield Strength (batch-to-batch variation).	High frequency of Hard Spots/Impurities in a specific batch.
Material Dimensional Tolerances too wide (requires constant adjustment).	Incorrect Alloy Temper delivered for the specified job.
Low Machine Rigidity/Age (systemic vibration).	Inaccurate Pressure Gauges/Sensors (sudden failure/drift).
Worn Mandrel/Die Surfaces (expected tool degradation).	Poor Alignment Control system (a specific mechanical failure).
Lack of Lubrication SOP compliance (general inconsistent adherence).	Ignoring Early Warning Signs (a specific, correctable human choice).
Fatigue/Rushing during high-volume changeovers (systemic human factor).	Incorrect Pressure Calculation by a single, undertrained operator.
Lack of a Preventative Maintenance Schedule for calibration.	No Standardized Setup Procedure for complex profiles (a missing document/process).
Reactive Bending Adjustments (process relying on operator reaction).	Tool Changeover Time pressure (a temporary, unmitigated scheduling issue).
Tool Life Tracking system is manual or inaccurate (systemic flaw).	Poor Calibration Frequency for a critical alignment instrument (an inadequate schedule).
Inconsistent Surface Finish Measurement (failing to catch early wear).	No In-Line Pressure Monitoring capability (a lack of equipment/method).
Temperature Fluctuations near the machine.	Dust/Debris contamination from an external, uncontained source.
High Humidity (general atmospheric condition).	Floor Vibration from an adjacent, newly started heavy machine.

8 Wastes Analysis

Defects
- Tool breakage/failure resulting from bending a profile with an uninspected Hard Spot/Impurity.

Overproduction
- Continuing to bend a profile for 15 minutes after a minor Misalignment issue has begun, but before it causes a tool break.

Waiting
- The bending machine is idle, waiting for a Maintenance Technician to complete the urgent repair and replacement of a broken die.

Non-Utilized Talent
- Highly skilled machine operators spending $60-90$ minutes on manual die alignment and pressure calibration instead of using their skills for process optimization or training.

Transportation
- Moving finished profiles back and forth from the bending machine to a Quality Check area repeatedly for dimensional verification.

Inventory
- Holding a large surplus of expensive bending dies "just in case" one breaks (due to the low, unpredictable MTBF).

Motion
- An operator walking across the work cell multiple times because the setup tools and gauges needed for alignment checks aren't organized locally.

Overprocessing
- Requiring the operator to manually perform five distinct, non-value-added alignment checks using hand tools when a single digital jig or sensor could automate the verification.

Action Plan for Low Hanging Fruits

Special Causes (sudden failures / abnormalities)

Special Cause Addressed	Lean Tool Applied	Action Step (Low Hanging Fruit)	Expected Benefit (Metric Impact)
Misalignment of Dies/Rollers	5S (Set in Order) & Visual Control	Tooling Shadow Board/Standardized Storage: Create a labeled location for every alignment jig and tool to ensure the right tools are always used and are immediately accessible.	Reduces the Motion and Waiting waste; improves setup time consistency (Mura).
Misalignment of Dies/Rollers	Standard Work/Visual Aids	"Go/No-Go" Alignment Gauge/Checklist: Develop a simple, visual, 3-step checklist for operators to verify die alignment after every setup, using a dedicated, pre-set gauge.	Directly targets the special cause; reduces Defect and subsequent Scrap Rate.
Incorrect Pressure Setting	Visual Control & Poka-Yoke	Color-Coded Pressure Zones: Mark the hydraulic pressure gauge with Green (optimal), Yellow (warning), and Red (stop) zones for the most common profiles.	Prevents operator error (Muri and Defect waste) from manual calculation mistakes; provides immediate feedback.

Action Plan for Low Hanging Fruits

Muda (Waste)

Waste Type	Lean Tool	Action Plan
5(Sort & Shine) to misalignment; machine idle during repair.	Poka-Yoke	Daily Tool Inspection & Cleaning: Implement a quick 5-minute end-of-shift routine for the operator to clean the dies and check for early signs of wear/damage (e.g., surface scratches, debris).

Mura (Unevenness)

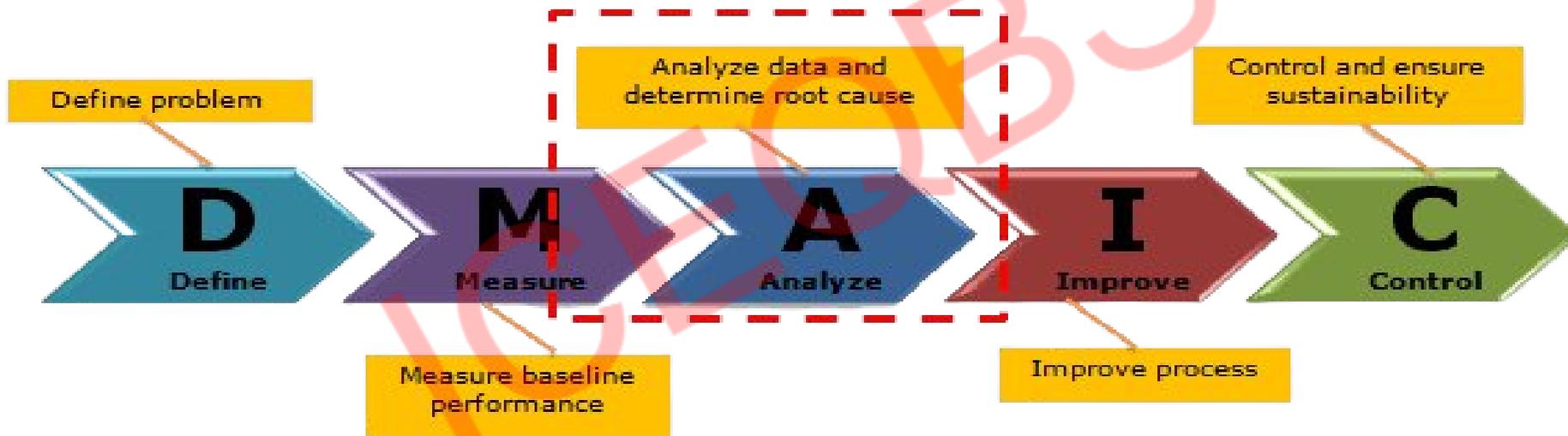| Issue	Lean Tool	Action Plan
Setup time varies widely by operator due to lack of standardization.	Standardized Work	Documented Best Practice Setup SOP: Video-record the most efficient technician performing a tool change and create a one-point lesson to train all other operators.

Muri (Overburden)

Issue	Lean Tool	Action Plan
Operator required to constantly manually adjust pressure and compensate for spring-back.	Jidoka (Automation/Error-Proofing)	Standardized Digital Look-up Chart: Provide a simple digital tablet or laminated chart near the machine that instantly gives the target pressure based on the profile alloy/radius.

Top 12 Prioritized Root Causes (Based on Net Score)

Rank	Root Cause (X)	Weighted Score	Primary Actionable Category
1	Hard Spots/Impurities in profiles (X1)	270	Incoming Material Control
2	Misalignment of Dies/Rollers (X3)	222	Setup/Method
3	Incorrect Pressure Setting (Manual Entry Error) (X2)	183	Man/Machine Interface
4	Poor Alignment Control system (Machine) (X13)	192	Machine System (Design/Maintenance)
5	Inconsistent Yield Strength (Material variation) (X4)	141	Material/Supplier Control
6	Incorrect Alloy Temper delivered for the job (X14)	132	Supplier/Incoming Inspection
7	Inaccurate Pressure Gauges/Sensors (X6)	111	Machine Calibration
8	Lack of Alignment SOP compliance (X5)	66	Method/Standard Work
9	Inadequate Tooling Setup Training (X7)	66	Man/Training
10	Reactive Bending Adjustments (Over-bending) (X8)	60	Method/Operator Reliance
11	Worn Mandrel/Die Surfaces (Expected Wear) (X10)	51	Machine/Maintenance
12	Lack of a Lubrication SOP compliance (X9)	41	Method/Maintenance

ANALYSE PHASE

Define problem

Analyze data and determine root cause

Control and ensure sustainability

D Define

M Measure

A Analyze

I Improve

C Control

Measure baseline performance

Improve process

Analyse – Hypothesis testing

Regression Analysis: Tool_Wear_Breakage_pct versus Hard_Spots_Impurities

Regression Equation

Tool_Wear_Breakage_pct = -0.115 + 0.03131 Hard_Spots_Impurities_ppm
+ 9.637 Misalignment_Dies_Rollers_mm
+ 1.631 Incorrect_Pressure_Setting_pct

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-0.115	0.449	-0.26	0.799	
Hard_Spots_Impurities_ppm	0.03131	0.00159	19.64	0.000	1.01
Misalignment_Dies_Rollers_mm	9.637	0.771	12.50	0.000	1.01
Incorrect_Pressure_Setting_pct	1.631	0.115	14.16	0.000	1.00

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	75.904	25.3014	267.57	0.000
Hard_Spots_Impurities_ppm	1	36.468	36.4677	385.65	0.000
Misalignment_Dies_Rollers_mm	1	14.783	14.7831	156.34	0.000
Incorrect_Pressure_Setting_pct	1	18.966	18.9662	200.57	0.000
Error	26	2.459	0.0946		
Total	29	78.363			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.307507	96.86%	96.50%	95.84%

Inference :
•Since p < 0.05, thus not all means are equal
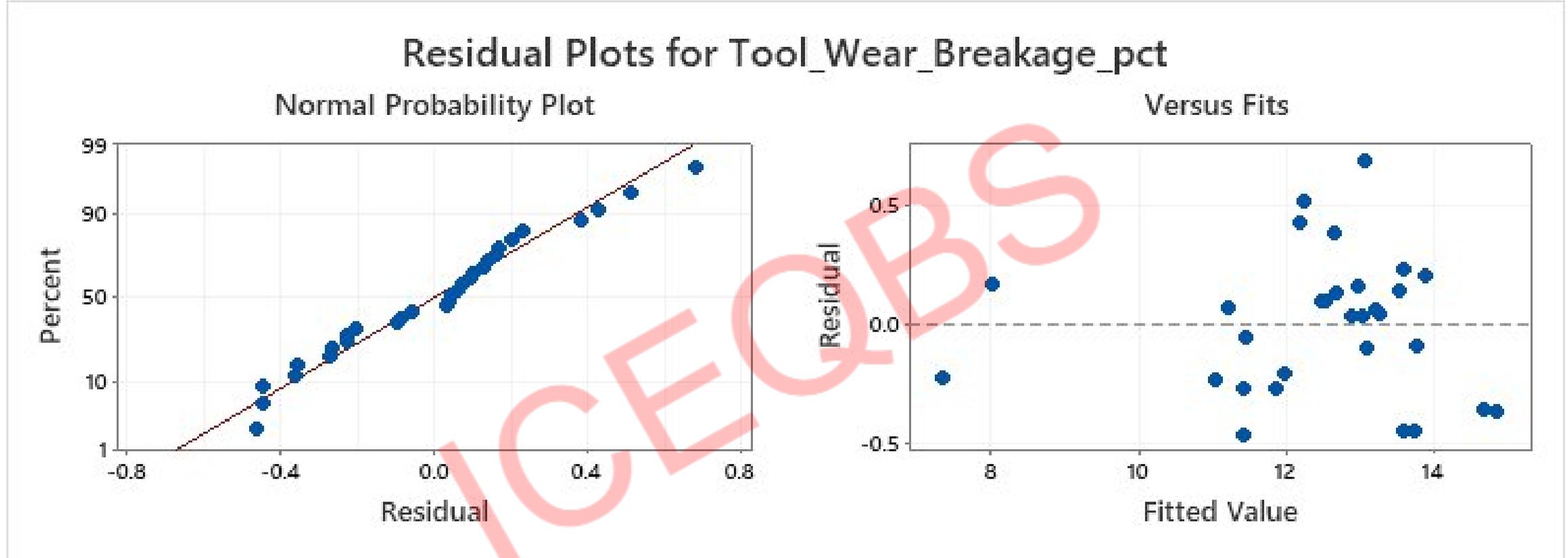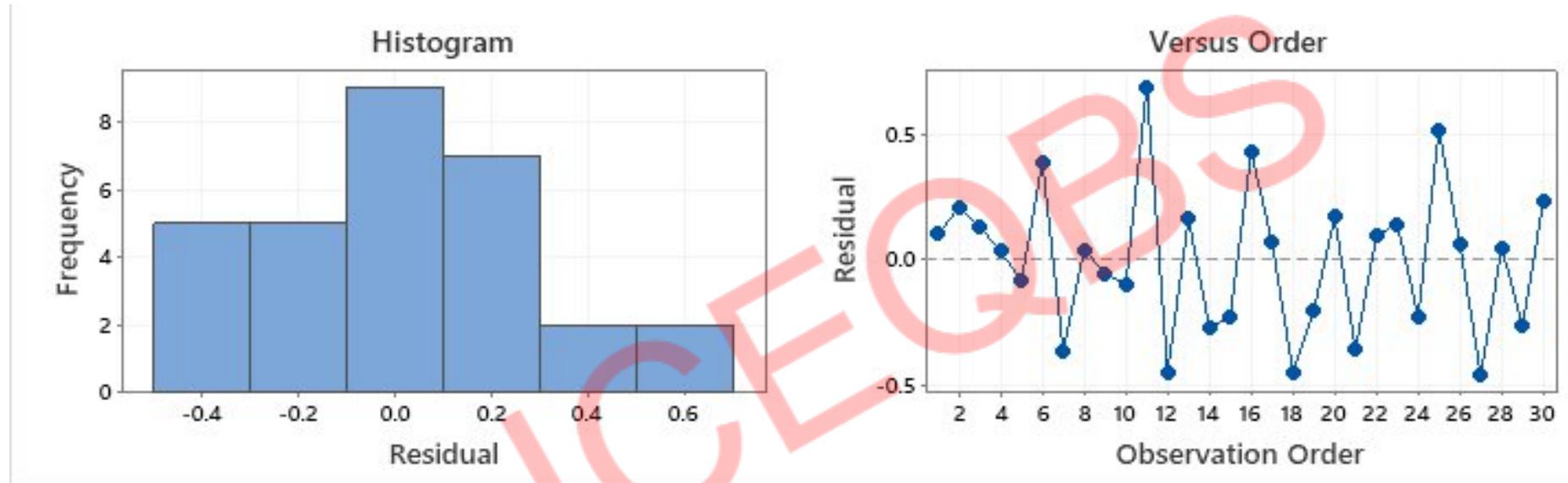
Residual Plots for Tool_Wear_Breakage_pct

Inference :
•Both plots confirm that the residuals are normal, independent, and random — meaning the model fits the data well, and the underlying assumptions for regression or process analysis are satisfied.

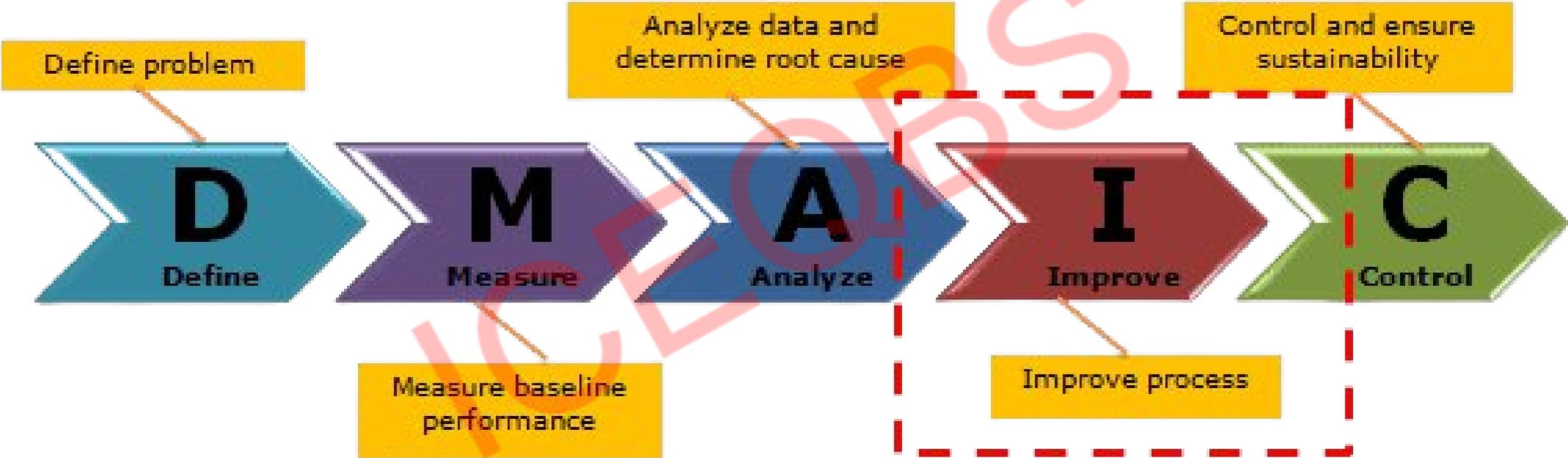# Analyse – Hypothesis testing

Residual Plots for Tool_Wear_Breakage_pct

Inference :
• Both plots confirm that the residuals are normal, independent, and random — meaning the model fits the data well, and the underlying assumptions for regression or process analysis are satisfied.

Summary of Statistically validated Root causes

- **Impurities in profiles, Misalignment of Dies/Rollers and Incorrect Pressure Setting are validated as critical root causes**
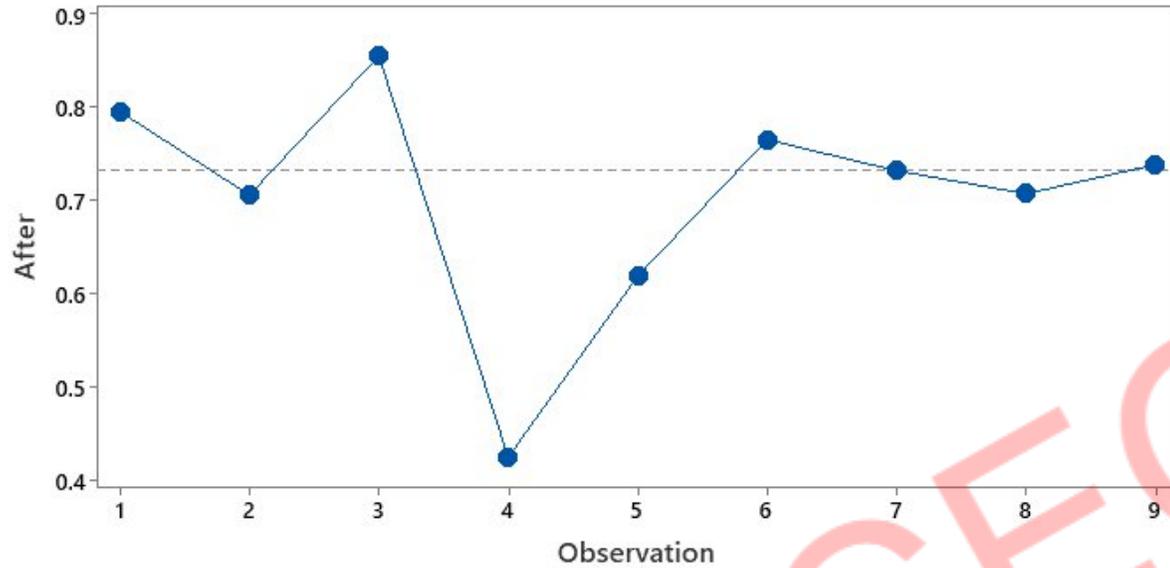
IMPROVE PHASE

Improve

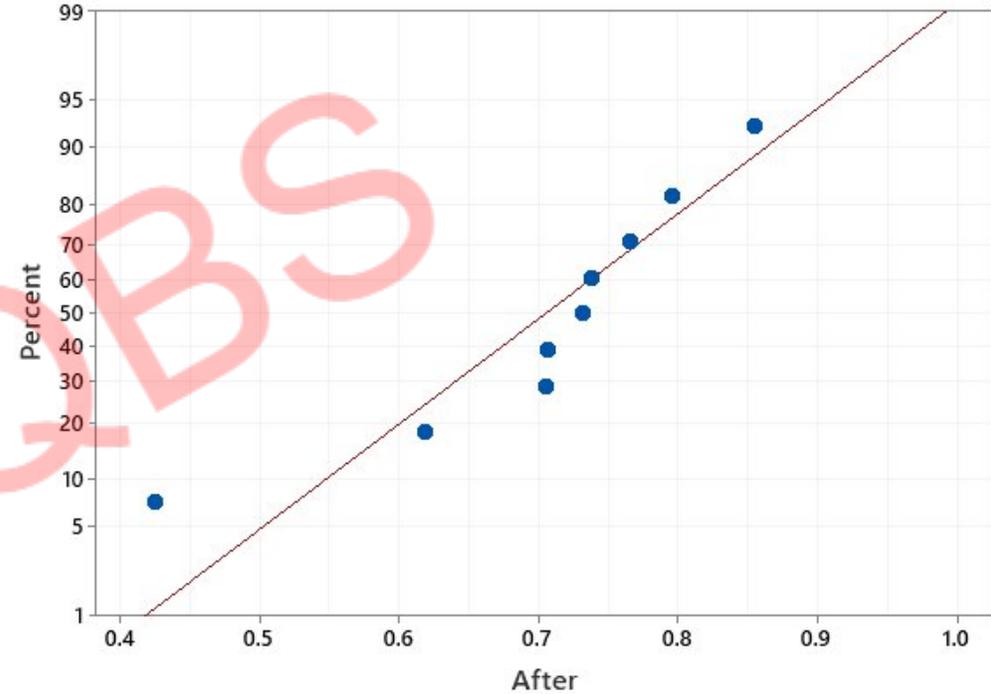| Critical Root Cause	Improvement Actions / Solutions	Action Steps
Hard Spot / Impurities in Profiles (X1)	Improve incoming material quality & implement hardness control	1. Develop a material inspection checklist including hardness and impurity test before production.2. Introduce spectro analysis for each batch of raw material.3. Establish supplier quality audit and feedback system for impurity rate >1%.
		4. Train inspection team on NDT (eddy current / ultrasonic) methods for early detection of inclusions.5. Track and trend impurity-related rejections using SPC charts.
Misalignment of Dies / Rollers (X3)	Ensure precise roller and die alignment before every setup	1. Prepare standard alignment procedure (SOP) using dial indicators / laser alignment tools.2. Implement setup verification checklist to be signed by shift supervisor.
		3. Schedule preventive maintenance every 200 operating hours for alignment inspection.4. Maintain historical alignment deviation data to identify trends and prevent recurrence.
Incorrect Pressure Setting (Manual Entry Error) (X2)	Standardize and automate pressure setting system	1. Replace manual entry with digital pressure controllers integrated with PLC feedback loops.2. Develop a pressure range reference chart for different section profiles.
		3. Introduce double verification system before production start (operator + supervisor signoff).4. Conduct training and skill test for operators on setting accuracy and error prevention.

Improve

Run Chart of After

Number of runs about median:	7
Expected number of runs:	5.4
Longest run about median:	2
Approx P-Value for Clustering:	0.870
Approx P-Value for Mixtures:	0.130

Number of runs up or down:	6
Expected number of runs:	5.7
Longest run up or down:	2
Approx P-Value for Trends:	0.616
Approx P-Value for Oscillation:	0.384

Probability Plot of After
Normal

Mean	0.7043
StDev	0.1234
N	9
AD	0.573
P-Value	0.097

Inference:
- Run chart – process is stable there is no special causes in the process (p value > 0.05)

Inference:
- Normality test – Data are normally distributed

Improve – Process capability – Before & After Improvement

Two-Sample T-Test and CI: Before, After

μ_1: population mean of Before
μ_2: population mean of After
Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Before	9	2.26	1.14	0.38
After	9	0.704	0.123	0.041

Estimation for Difference

Difference	95% CI for Difference
1.558	(0.678, 2.438)

Test

Null hypothesis	$H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis	$H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
4.08	8	0.004

Inference :
"The t-test confirms a statistically significant improvement, with the 'After' mean being much lower than 'Before' ($p = 0.004$), proving the solution effectively reduced the measure."

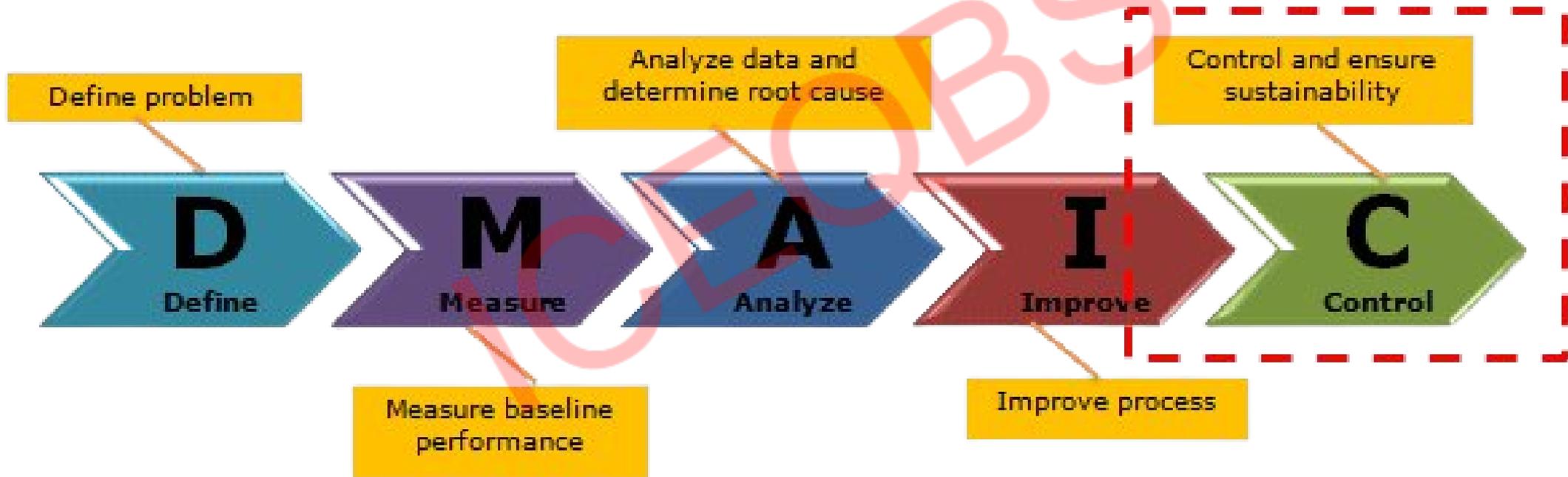**Inference:**

- "Process capability improved significantly after the project, with Cpk increasing from 0.26 to 0.81, showing the process is now much more stable and closer to meeting specification limits."

CONTROL PHASE

Improve (Statistical validation for Improvement – I-MR Chart)
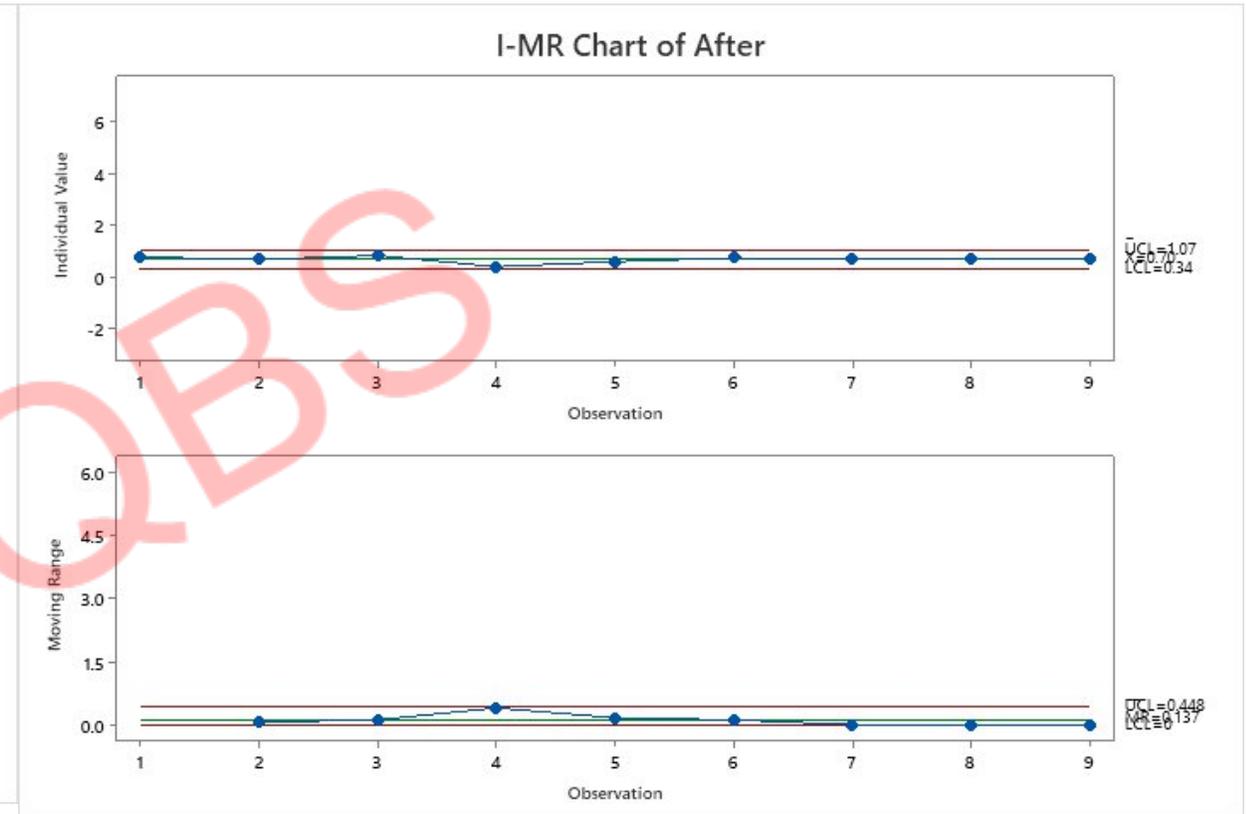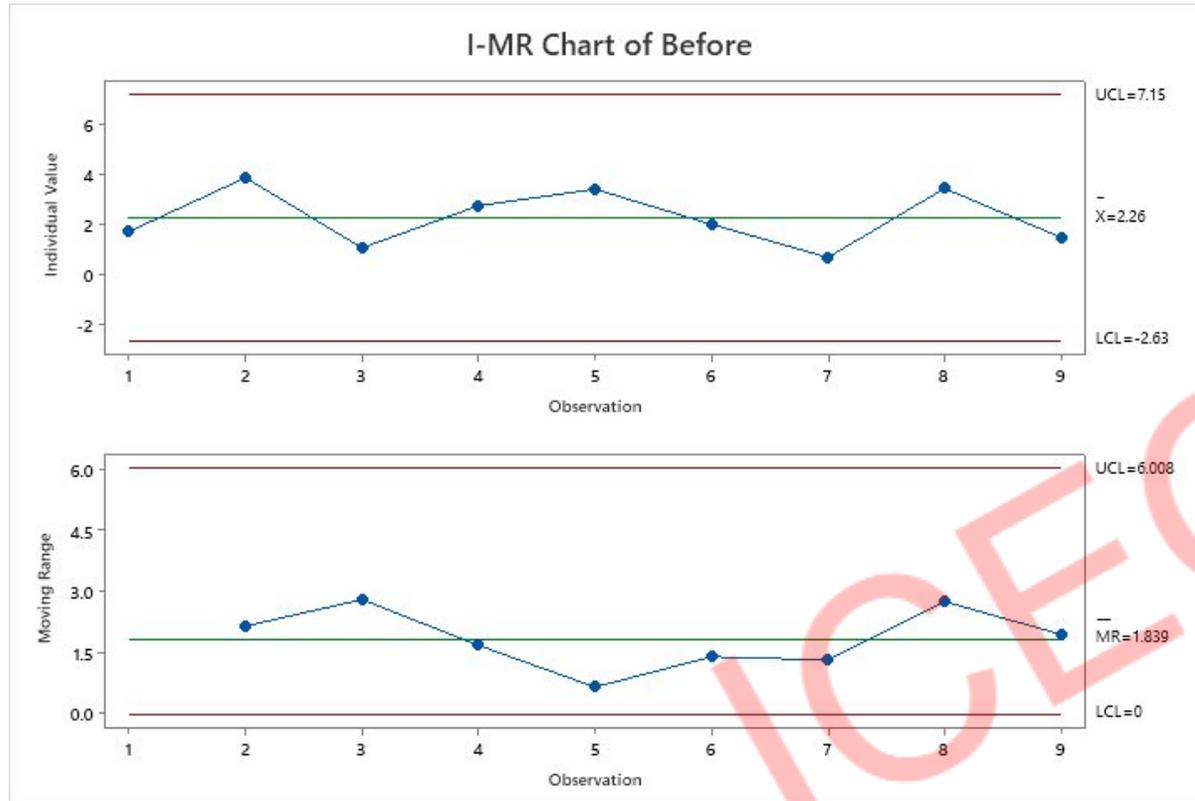
Inference:

•As seen in control chart, before improvement mean was high and there was high variability in the **process** and after improvement, it has achieved its target

Control Plan

5S Stage	Application Area	Sustaining Mechanism / Action	Expected Benefit
1. Seiri (Sort)	Tool storage, raw material inspection area	Identify and remove all unused / worn-out tools and mis-matched dies from tool racks. Maintain a "Red Tag Zone" for damaged or out-of-spec tools.	Eliminates confusion and ensures only usable tools are available for setup.
2. Seiton (Set in Order)	Tool & die storage racks, pressure gauge panels	Implement shadow boards for tool storage with clear visual outlines and color codes (e.g., blue for roller dies, yellow for bending dies). Label pressure controllers and gauges with correct ID and range.	Prevents misplacement and ensures quick identification.
3. Seiso (Shine)	Rolling line, calibration station	Create daily cleaning checklist for dies, rollers, and hydraulic lines. Use visual tags to confirm cleaning status before shift start.	Reduces contamination, wear, and material impurities.
4. Seiketsu (Standardize)	Workstation SOPs and inspection	Display laminated setup SOPs for pressure setting and die alignment. Standardize color coding for die alignment tools. Maintain calibration tags for all gauges and sensors.	Ensures uniformity and compliance to process standards.
5. Shitsuke (Sustain)	Operator discipline & audits	Introduce monthly 5S audit checklist with scoring. Recognize best 5S zone / operator. Incorporate visual boards showing daily defect and tool-wear trend.	Builds ownership, reinforces habits, and sustains discipline.
Error Source	Proposed Poka-Yoke Mechanism	Implementation Detail	Expected Outcome
Hard Spot / Impurities	Material bar-code linked to supplier QC data	Scanning prevents untested or non-approved batches from entering production.	Prevents use of impure or off-spec material.
Misalignment of Dies / Rollers	Mechanical limit pins or key-slots for correct die seating	Physical stops ensure proper die fitment; misaligned dies cannot be locked.	Eliminates setup errors leading to misalignment.
Incorrect Pressure Setting (Manual Entry)	Pressure controller interlock with pre-set job parameters	PLC retrieves correct pressure limits for each section profile and locks adjustment beyond range.	Prevents operator entry outside safe limit.
Inaccurate Gauges / Sensors	Digital gauge auto-calibration alarm	Alarm triggers if calibration drift exceeds ±2%.	Ensures measurement reliability.
Tool mix-up / wrong die usage	QR code labeling of each die linked to machine HMI	Machine allows operation only when correct die ID is scanned.	Prevents wrong tool-job combinations.

Control Plan

#	Process Step / Area	Potential Failure Mode	Potential Effect (on tool wear / safety / quality)	S	Potential Cause	O	Current Controls	D	RPN	Recommended Action (Proactive)	Resp.
1	Incoming material inspection for hard spots	Hard / impure profiles not detected	High tool wear, tool breakage, profile cracks, rework	9	Inadequate hardness/impurity checks; rushed inspection	6	Visual checks only; random sampling	6	324	Introduce hardness & impurity test plan (e.g. Brinell + spectro); increase sampling frequency; train inspectors; supplier rejection criteria.	QA Head
2	Supplier management	Use of non-approved / new supplier	High variability in material → erratic tool life	8	No supplier rating; cost-based purchase	5	Approved vendor list (not maintained)	6	240	Implement supplier qualification & periodic audits; introduce vendor performance scorecard linked to impurity & tool-wear data.	Purchase / QA
3	Die/roller setup	Dies/rollers not aligned to spec	Local overload on tools → chipping, breakage	9	Skipping alignment procedure; lack of tools	5	Informal visual check by operator	6	270	Standardize alignment SOP; use dial/laser alignment; mandatory signoff; provide alignment jigs & gauges.	Maintenance / Prod. Sup.
4	Preventive maintenance	Alignment drifts between PMs	Gradual increase in tool wear, product defects	8	PM interval too long; only breakdown-based	5	PM schedule (not tracked)	5	200	Define PM frequency based on hours; digital PM calendar; adherence tracking; MTBF analysis.	Maintenance
5	Pressure setting during setup	Wrong pressure value keyed in	Excessive loading or underforming tools → wear /	9	Manual entry error; confusion of units/job code	6	Paper sheet with set-points	5	270	Implement PLC-based recipe management; interlock to prevent out-of-range settings; HMI shows only job-specific pressure	Automation / Process Engg.

Control Plan

#	Process Step / Area	Potential Failure Mode	Potential Effect (on tool wear / safety / quality)	S	Potential Cause	O	Current Controls	D	RPN	Recommended Action (Proactive)	Resp.
6	Pressure monitoring in running	Drift in actual pressure vs setpoint	Fluctuating load → accelerated wear, scrap	8	Faulty valves; sensor drift; leaks	5	Gauges on panel; operator checks	5	200	Fit digital transmitters with alarms & trend logging; periodic calibration schedule; low/high pressure interlock to stop line.	Maintenance / Process
7	Gauge / sensor calibration	Calibration not done / overdue	Inaccurate reading → mis-set pressure	8	Missed calibration dates; no register	4	Sticker on gauge	6	192	Maintain calibration register; color tags (Green/Red) for due dates; system alert; outsource if needed.	QA / Metrology
8	Operator adherence to new SOPs	Operators revert to old practices	Improvements not sustained; tool wear creeps back to 3%	8	Inadequate training; no reinforcement; shift gap	6	One-time training	5	240	Structured training with skill test; visual SOP at machine; periodic refresher; link adherence to appraisal / recognition.	Production Manager
9	5S at tool & material areas	Poor 5S – wrong dies/tools picked	Wrong die/profile → overload & breakage	7	Mixed storage; no labels/shadows	5	Racks exist, but not labeled	6	210	Shadow boards; die ID & color coding; QR code scanning of die linked to job; 5S audits.	Production / 5S Champion
10	Data collection & review	Tool wear data not recorded correctly	Delayed detection of trend worsening	7	Manual log errors; no review	5	Logbook at machine	6	210	Create simple sheet / e-log; weekly review of Tool Wear % and RPN; corrective action meeting if Tool Wear >1%.	QE / Prod. Engg.

Control Plan to sustain improvements

Process Step	Control Characteristic / Parameter	Specification / Target	Measurement Method / Tool	Frequency	Reaction Plan / Corrective Action	Responsibility
Incoming Material Inspection	Hardness / Impurity content	Hardness: 80–90 HRBImpurity < 0.5%	Portable hardness tester, spectrometer	Every batch	Reject if out of spec; inform supplier; conduct RCA	QA Inspector
Material Grade Verification	Alloy temper & chemical composition	Within supplier COA tolerance	Spectro analysis report	Every batch	Stop material usage; quarantine batch; supplier feedback	QA / Purchase
Die / Roller Alignment	Alignment deviation	≤ 0.05 mm	Dial gauge / laser alignment tool	Each setup	Realign before start; record in setup log	Maintenance / Production Supervisor
Machine Pressure Setting	Hydraulic pressure range	±2% of nominal pressure	PLC / HMI pressure display	Each job setup	Adjust within limits; verify using checklist	Process Engineer
Pressure Monitoring During Operation	Pressure fluctuation	≤1% deviation from setpoint	Digital gauge trend chart	Hourly / shift	Stop machine if alarm triggers; check for leaks / sensor fault	Operator / Maintenance
Tool Condition	Tool wear measurement	≤ 1% wear rate per 1000 m length	Visual + micrometer	Daily	Replace if above threshold; record in wear log	Operator
Sensor Calibration	Pressure gauge accuracy	±0.5% FS	Calibration certificate / master gauge	Monthly	Replace or recalibrate sensor	QA / Metrology
5S & Workplace Audit	5S Audit Score	≥ 90%	5S audit checklist	Monthly	Initiate corrective actions; review during monthly meeting	5S Champion
Training & SOP Adherence	Operator compliance	100% adherence	Training log / observation	Quarterly	Retrain non-compliant operators	HR / Production Head
Tool Wear Trend Review	Tool wear % vs time	≤ 1% average per month	Control chart / SPC	Weekly	Trigger CAPA if trend increasing	Quality Engineer

Results after improvement

- **Project has achieved its intended results after reduce tool breakage in primary bending line**