MRF Polishing Process Improvement

VIMAL

ROADMAP

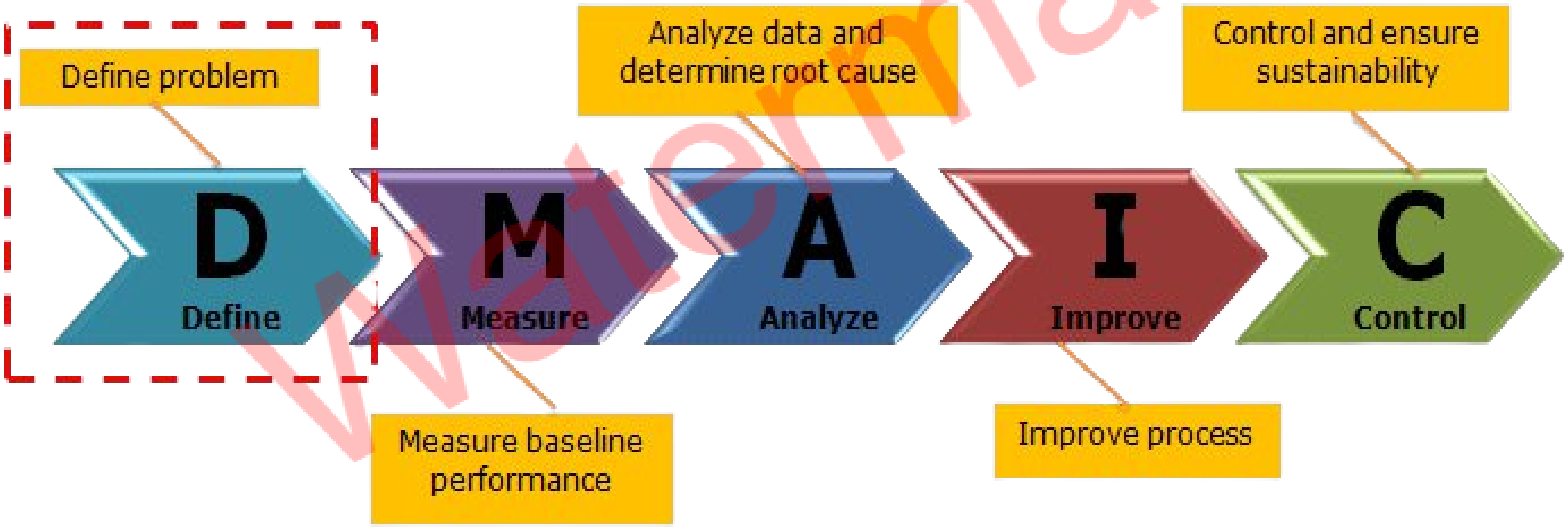
- Overview
- Define
- Measure
- Analyse
- Improve
- Control

OVERVIEW

Background

The MRF (Magnetorheological Finishing) polishing process currently shows high variability, leading to a 25% rework rate and frequent surface defects caused during manual cleaning. These issues increase production time by nearly 30% and result in additional costs of approximately 6000 Euro per month. By stabilizing the polishing parameters and optimizing the cleaning procedure, the project aims to significantly reduce rework and improve surface quality. This improvement is expected to enhance delivery adherence, strengthen customer satisfaction, and generate annual savings of around 72,000 Euro.

DEFINE PHASE

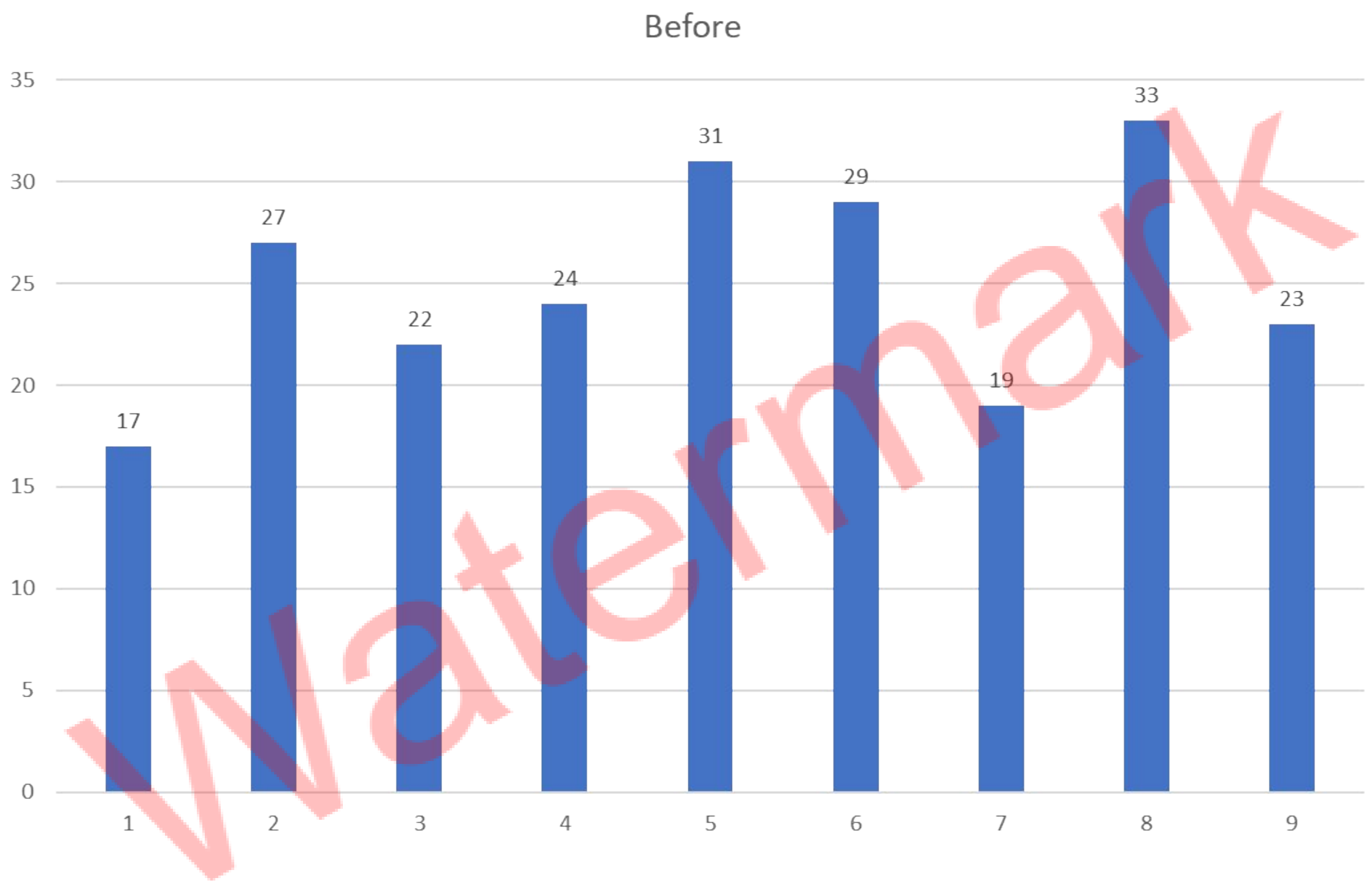


VOC & CTQ

CTQ Tree :

Voice of customer	Critical to X	Primary Metric for improvement
We want Zero defect and Non Confirm Parts	CTC – % Rework (Defect rate)	**Primary Metric -** Y = Rework Rate (Direct Metric) **Secondary Metric -** Productivity

Baseline Performance of Primary Metric (9 months data as Line chart)



Inference :

•Last 9 months scrap percentage data shows a significant variation and hence ideal problem to be taken up as a Six Sigma Project.

SIPOC

Suppliers	Inputs	Process	Outputs	Customers
• Raw Material Vendor (Metal Optics Blanks) • Slurry Supplier • Cleaning Solvent Vendors (IPA, Acetone, DI Water) • Maintenance Team • Process Operators	• Metal optic blanks • MRF slurry (controlled viscosity) • Machine calibration data • Cleaning materials (lint-free cloths, IPA, acetone, DI water) • Process parameters (speed, magnetic field strength, polishing time) • Work instructions & SOPs	1. Receive and inspect metal optic blanks 2. Set up and calibrate MRF machine 3. Load part and run polishing cycle 4. Inspect polished surface 5. Perform manual cleaning (IPA → acetone → DI water) 6. Final inspection under microscope 7. Record performance data and defects	• Polished metal optics • Surface quality reports (Ra, PV, etc.) • Defect records (scratches, white foggy layer) • Process performance metrics (yield %, rework rate) • Continuous improvement report	• Gold Coating Optical Assembly Department • Quality Assurance Team • End Customers (Aerospace / Defense optics clients) • Management / Production Planning Team

Project Charter

Project Title:	MRF Polishing Process Improvement

Project Leader	**Project Team Members:**
Vimal	R. Kumar P. Reddy S. Naresh M. Harsha
Champion/Sponsors:	**Key Stake Holders**
Plant Head – Production	
Problem Statement:	**Goal Statement:**
Over the last 9 months, the MRF (Magnetorheological Finishing) process for metal optics has shown high variability in polishing performance, averaging 25% rework with fluctuations between 18% and 33%. In addition, manual cleaning scratches and white foggy layers appear after cleaning with IPA, acetone, and DI water, further reducing optical surface quality and rework rates.	To improve MRF polishing consistency and reduce post-cleaning surface defects such that: •Average rework reduces from 25% to 10% within 4 months, and •Surface defects (scratches/foggy layer) are reduced by 60% through optimized cleaning procedures and operator training.
Secondary Metric	**Assumptions Made:**
Productivity	Operators will follow the optimized cleaning procedure and training plan. No major design or material changes will occur in incoming optical

Project Charter

Tangible and Intangible Benefits:

Reduction of rework from 25% to 10%, resulting in ~72,000 Euro/year cost savings.
Lower consumable usage and reduced time spent on repolishing and inspection.
Improved throughput and increased machine availability for production.

Risk to Success:

Variability in slurry composition, tool wear, or machine stability may affect polishing consistency.
Inconsistent cleaning technique or operator non-adherence could continue to introduce scratches/fogging.

In Scope:

- MRF process parameters (slurry viscosity, polishing time, magnetic field intensity).
- Manual cleaning methods and solvents used (IPA, acetone, DI water).
- Surface defect analysis and root cause identification.

Out of Scope:

Upstream optical grinding process.
Design modifications of the optical components.

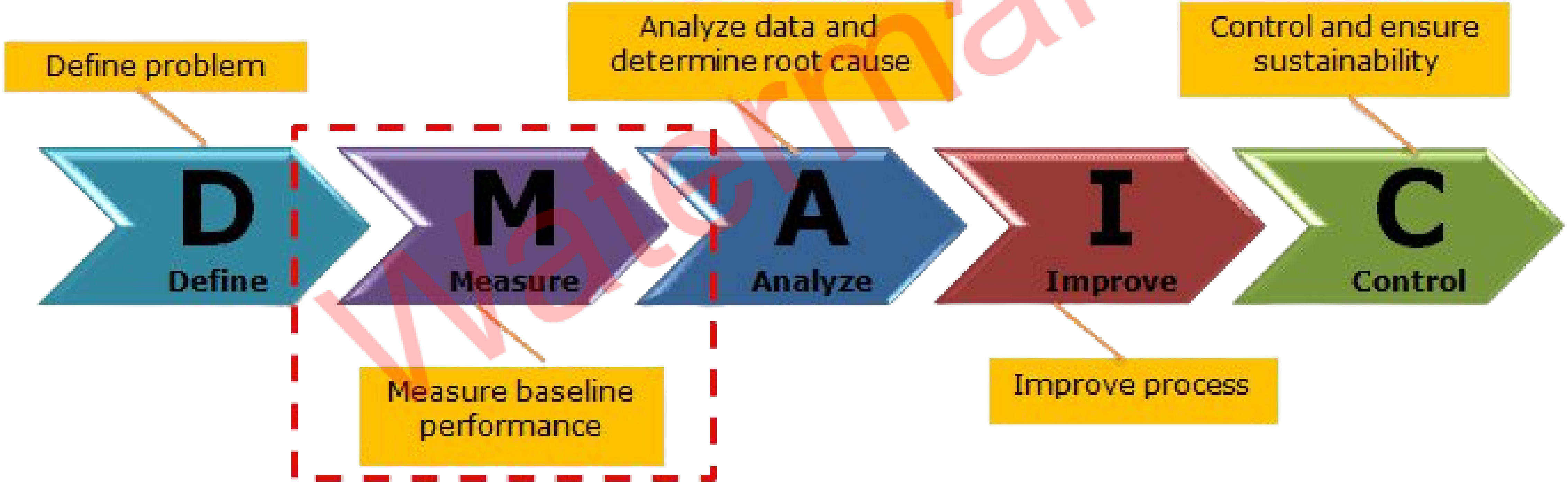
Signatories:

Kiran - Head – Manufacturing

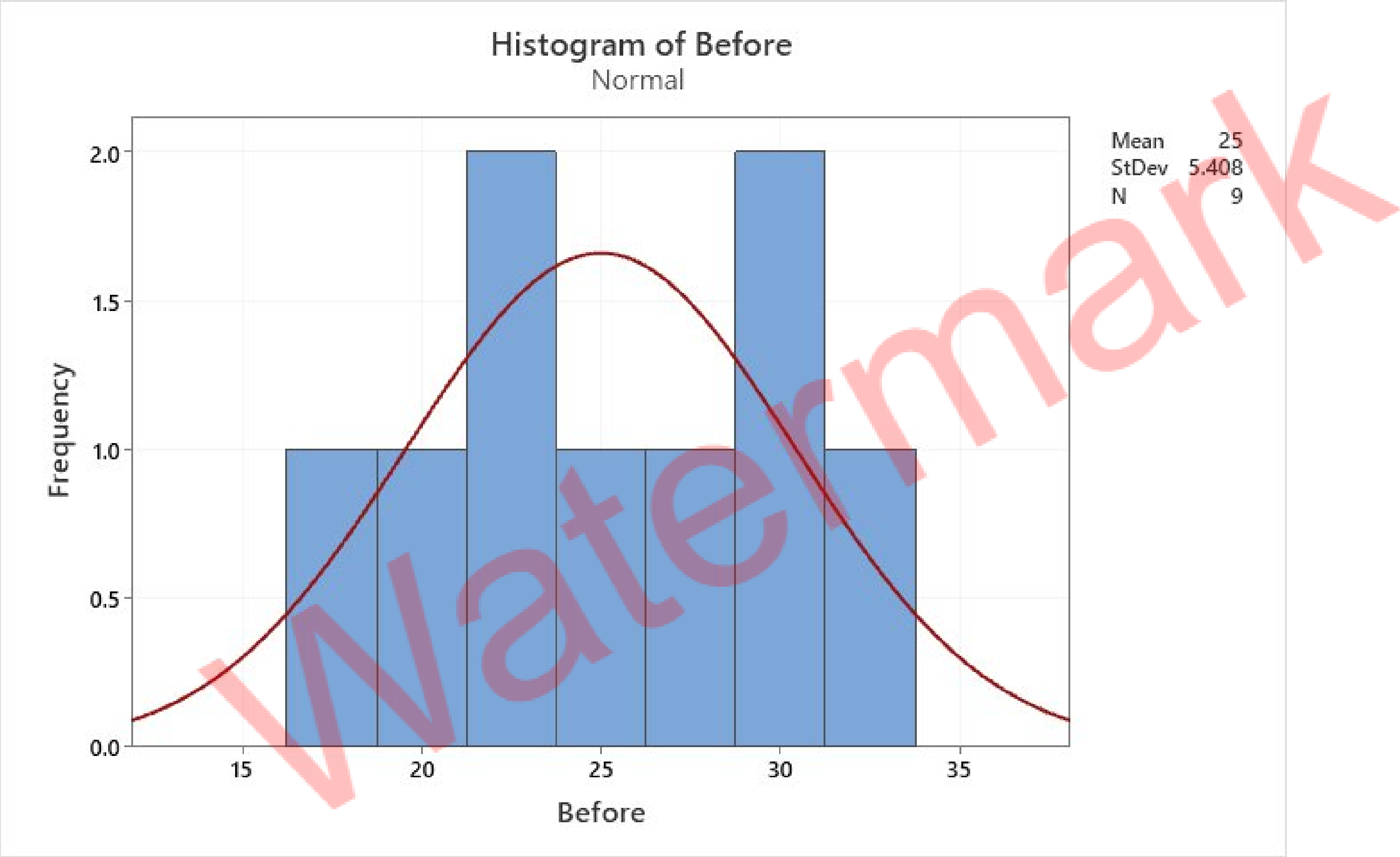
Project Timeline:

6 Months

MEASURE PHASE



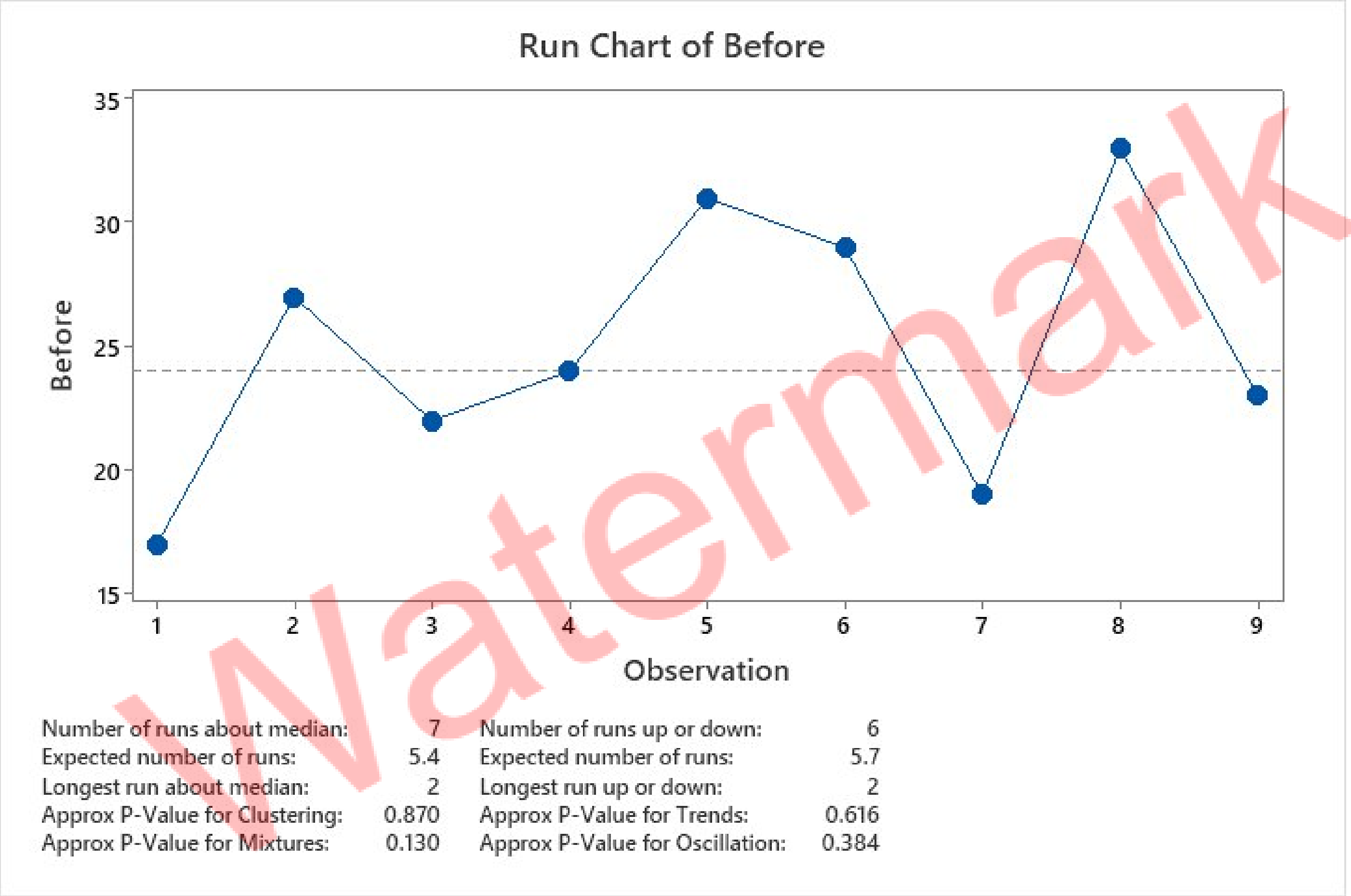
Data collection – Histogram (Before improvement)



Inference :

•Data is normally distributed over the mean

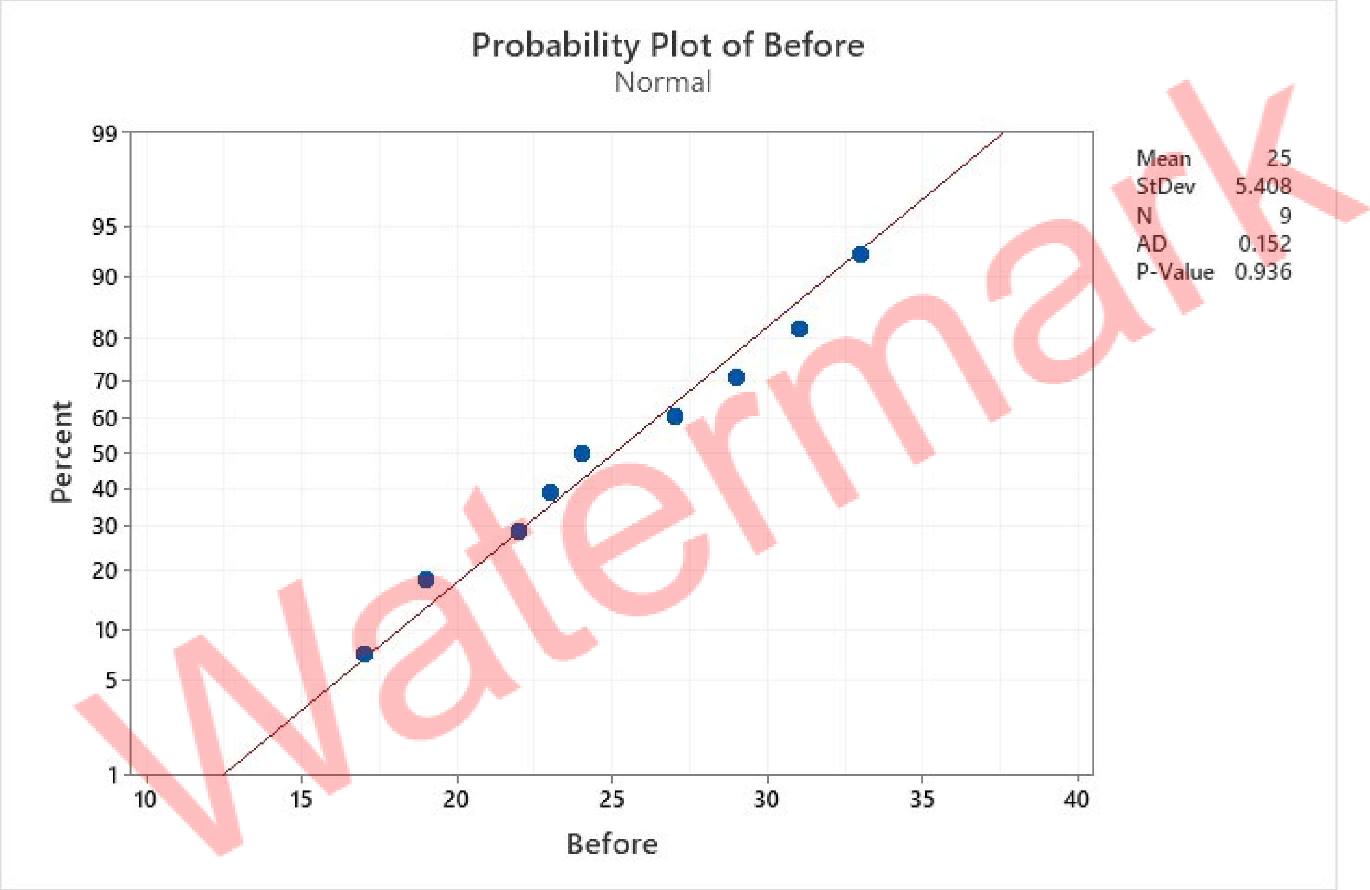
Data collection – Run Chart (Before improvement)



Inference :

P > 0.05 – No special causes in the process. Data can be used for further analysis

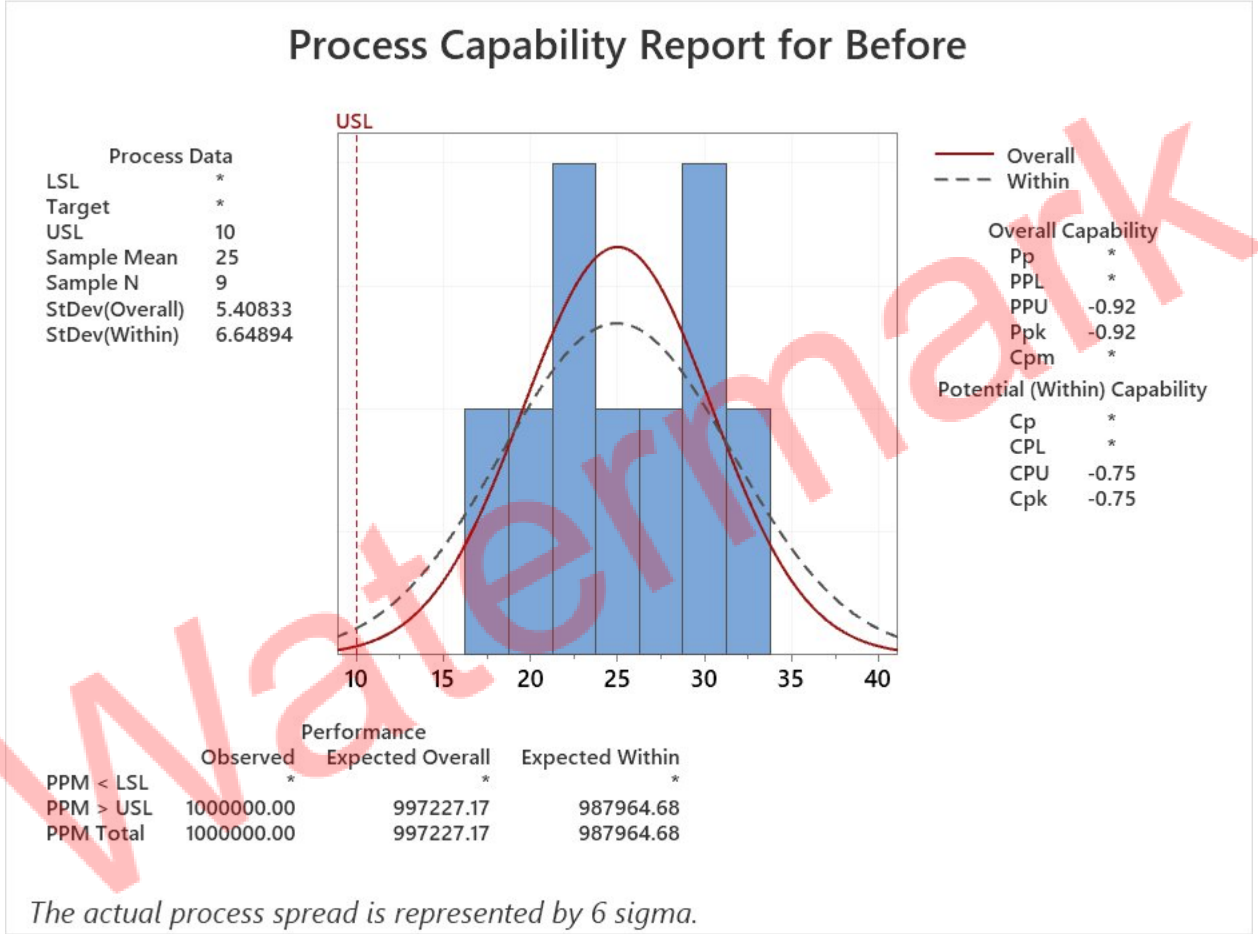
Data collection – Normality plot (Before improvement)



Inference :

•P > 0.05 in all scenarios, thus all the data is normally distributed

Data collection – Normality plot (Before improvement)



Inference :

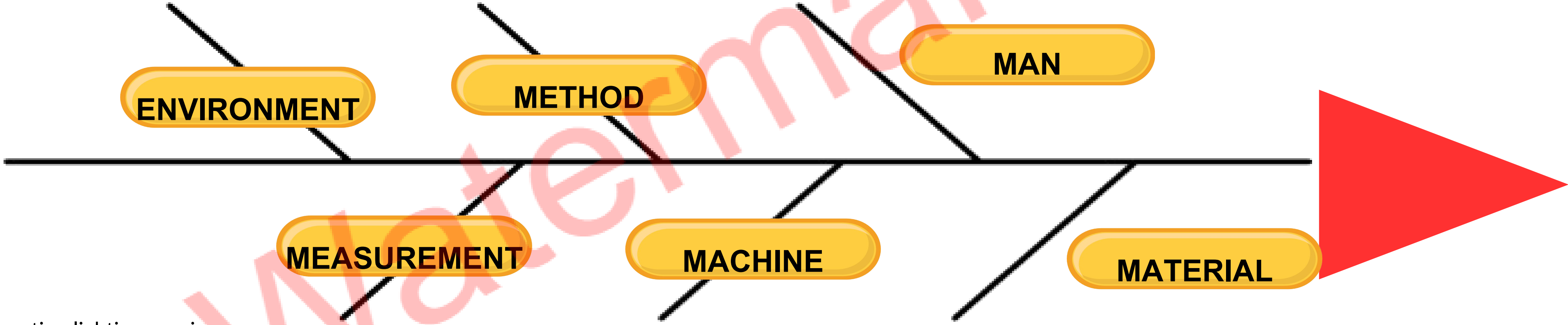
•The process is not capable, as the mean is far from the USL and the low Cpk (–0.75) indicates a high rate of parts falling outside specification limits.

Fish Bone Diagram

1. Humidity fluctuations affecting surface drying and solvent evaporation.
2. Dust contamination from nearby processes.
3. Temperature variation in polishing and cleaning areas.

1. Non-standardized cleaning sequence (IPA → acetone → DI water not consistently followed).
2. Variation in polishing cycle time and feed rate between shifts.
3. No defined control limits for slurry viscosity or polishing time.

1. Inconsistent manual cleaning technique (excessive pressure or improper wiping pattern).
2. Lack of standardized training on cleaning and polishing parameters.
3. Operator fatigue leading to inconsistent part handling.



1. Inconsistent inspection lighting or microscope calibration.
2. Lack of repeatability in Ra (roughness) measurements.
3. No SPC (Statistical Process Control) applied to MRF performance metrics.

1. MRF machine calibration drift (magnetic field strength not verified regularly).
2. Polishing head misalignment causing uneven material removal.
3. Slurry circulation pump malfunction or clogging.

1. Slurry viscosity variation due to improper storage or mixing.
2. Contaminated cleaning solvents (old IPA/acetone used repeatedly).
3. Lint residue from non-approved cleaning cloths.

Common Causes vs Special Causes

Common Causes

- Operator fatigue
- Slurry viscosity variation
- Humidity fluctuations
- Variation in polishing cycle time and feed rate
- Cooling system temperature variation
- Optical substrate surface hardness variation
- Inconsistent lighting inspection
- Dust contamination
- Minor machine wear and tear
- Normal solvent evaporation rate differences

Special Causes

- Manual cleaning scratches due to improper wiping
- Contaminated cleaning solvents
- Calibration drift of MRF machine
- Polishing head misalignment
- Worn-out polishing pad
- Clogged slurry circulation pump
- Use of non-approved cleaning clothes
- Incorrect cleaning sequence (IPA → acetone → DI water)
- Untrained or newly assigned operators
- Environmental control failure (HVAC malfunction)

3M Analysis for Waste

MUDA

- Rework due to manual cleaning scratches.
- Re-polishing caused by white foggy layer after cleaning.
- Excessive use of solvents (IPA, acetone, DI water).

Mura

- Variation in polishing performance (18–33%).
- Inconsistent cleaning methods between operators.
- Fluctuating slurry viscosity and magnetic field strength

Muri

- Operators manually clean delicate optics for extended hours.
- Running MRF machine continuously without cool-down time.
- Overuse of polishing pads beyond recommended life.

8 Wastes Analysis

Defects

- Parts scrapped due to out-of-tolerance dimensions.
- Surface defects like scratches, chatter marks, or poor finish.

Overproduction

- Polishing extra optics "just in case" of defects.
- Running multiple polishing cycles even when surface finish already meets specification.

Waiting

- Waiting for MRF machine calibration or setup before next batch.
- Parts waiting in queue for manual cleaning and inspection.

Non-Utilized Talent

- Operators' feedback on process improvements not being collected or implemented.
- Skilled technicians are not involved in root cause analysis or process optimization

Transportation

- Moving optics unnecessarily between polishing, cleaning, and inspection areas.
- Transferring solvent containers multiple times between workstations.

Inventory

- Stockpiling of partially polished or uncleaned optics waiting for rework.
- Over storage of cleaning solvents and polishing slurry beyond usage rate.

Motion

- Operators frequently reaching or walking to get tools and cleaning materials.
- Manual rotation or repositioning of optics during cleaning due to poor workstation layout.

Overprocessing

- Excessive manual cleaning with multiple solvent wipes beyond requirement.
- Repeated polishing passes on already acceptable surfaces.

Action Plan for Low Hanging Fruits

Issue Category	Specific Issue	Lean Tool / Technique	Proposed Action	Expected Benefit
Special Causes / Defects	Scratches during manual cleaning	5S / Standard Work	Introduce cleaning fixtures, microfiber cloths, and SOPs	Reduced rework, improved yield
	White foggy layer formation	Standard Work / Poka-Yoke	Optimize solvent application; controlled drying process	Reduced re-polishing, higher throughput

Issue Category	Specific Issue	Lean Tool / Technique	Proposed Action	Expected Benefit
8 Lean Wastes (examples)	Overproduction	Kanban / Pull System	Produce based on demand only	Reduced inventory, less rework
	Motion	5S / Workstation Redesign	Place tools and materials within reach	Reduce operator fatigue, faster process
	Inventory	Kanban	Implement FIFO and limit WIP	Lower storage cost, reduced obsolete parts
	Unused Talent	Kaizen / Suggestion System	Encourage operator feedback for improvements	Process innovation, morale boost

Action Plan for Low Hanging Fruits

Issue Category	Specific Issue	Lean Tool / Technique	Proposed Action	Expected Benefit
MUDA (Waste)	Excessive solvent use	Kaizen / 5S	Implement metered solvent dispensers and proper storage	Cost saving, environmental compliance
	Waiting for machine calibration	SMED (Quick Changeover)	Schedule preventive maintenance and setup parallelization	Reduced idle time, increased machine utilization
	Over-inspection	Visual Management / Standard Work	Define clear inspection criteria, use calibrated tools	Time saving, consistent quality
	Handling / movement of parts	5S / Layout Optimization	Reorganize workstations to minimize transport	Reduced damage risk, improved flow
MURA (Unevenness / Inconsistency)	Variation in polishing performance	Standard Work / SPC	Define process parameters; monitor viscosity & magnetic field	Stable quality, less rework
	Inconsistent cleaning methods	Training / SOP	Train operators on standardized cleaning SOPs	Consistent surface finish
	Uneven workload between shifts	Line Balancing / Heijunka	Adjust shift tasks to distribute work evenly	Reduced fatigue, consistent output
MURI (Overburden / Overload)	Long hours of manual cleaning	Job Rotation / Ergonomics	Rotate operators and provide ergonomic tools	Lower fatigue, fewer errors
	Continuous MRF machine operation	TPM (Total Productive Maintenance)	Schedule cooldown periods, preventive maintenance	Longer machine life, fewer breakdowns

Action Plan for Low Hanging Fruits

Muda (Waste)

Waste Type	Lean Tool	Action Plan	Benefit
Rework due to defects	Poka-Yoke	Error-proof clamping and tool offset checks	Lower rework hours
Waiting for inspection	Point-of-Use Inspection	Provide in-line gauges / go-no-go tools at CNC	Reduced waiting time

Mura (Unevenness)

Issue	Lean Tool	Action Plan	Benefit
Variation in cycle times	Standard Work + SMED	Standardize CNC setup parameters and quick-change tooling	Consistent productivity
Inconsistent finish quality	SPC Control Charts	Monitor process stability and provide operator feedback	Stable surface quality

Muri (Overburden)

Issue	Lean Tool	Action Plan	Benefit
Overused cutting tools	Kanban for Tool Change	Visual tool life tracking and Kanban cards	Prevents tool breakage, reduces scrap
Operators overloaded	Work Balancing / Line Balancing	Redistribute machine responsibilities	Reduced errors, improved focus

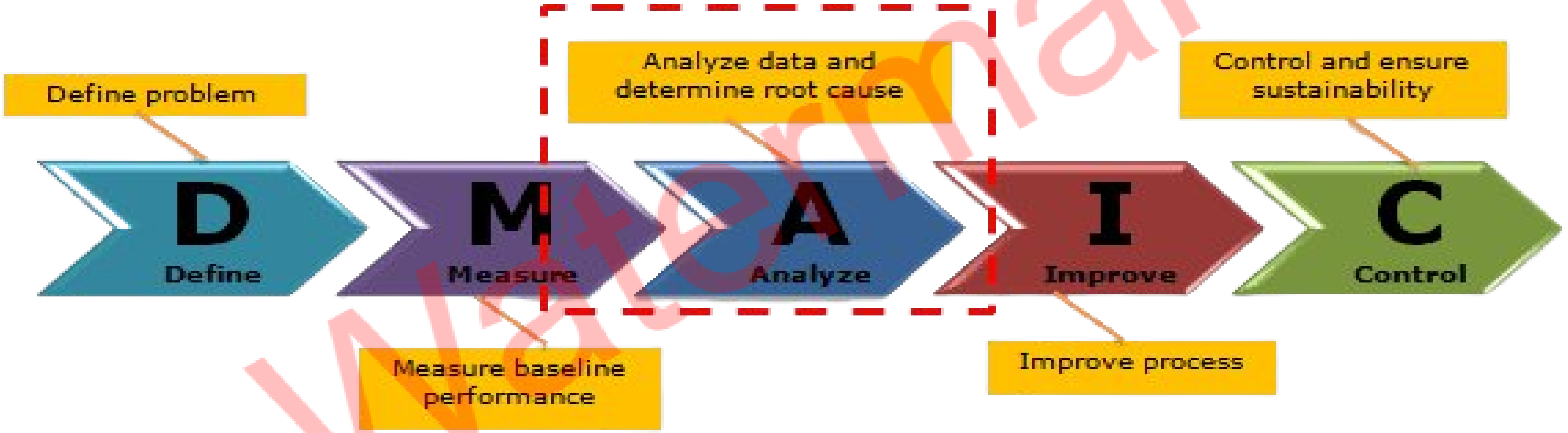
Top 12 Prioritized Root Causes (Based on Net Score)

Root Cause	Score
Poor fixture design / handling	235
Operator skill variation	230
Variation in polishing parameters	225
Overuse of polishing pads	225
Inconsistent cleaning methods	220
Slurry contamination	220
Lack of standard cleaning SOP	220
Ineffective process monitoring / SPC	210
Machine calibration delay	120
Poor workstation layout	132
Uneven workload distribution	108
Poor inspection standards	30

Data Collection Plan

Output / Input	Type of Data	Measurement Method	Unit	Frequency	Responsibility
% Scrap (Primary Y)	Continuous	Scrap count / production log	%	Daily	Production Engineer
Surface Finish (Ra)	Continuous	Surface profilometer	µm	Daily	Quality Inspector
Tool Wear	Continuous	Tool inspection (flank/length wear)	mm	Daily	Operator / QC
Cutting Parameters (speed, feed, depth)	Continuous	CNC machine readout	rpm / mm/min	Daily	Production Engineer
Machine Vibration	Continuous	Vibration meter	mm/s	Weekly	Maintenance Eng.
Machine Calibration	Attribute	Calibration record	Yes/No	Monthly	Maintenance Eng.
Fixturing / Clamping Method	Attribute	Visual check / setup log	Std/Non-std	Daily	Operator
Raw Material Hardness	Continuous	Rockwell hardness tester	HRC	Lot-wise	QC Lab
Raw Material Defects	Attribute	Visual inspection	Pass/Fail	Lot-wise	QC Lab
Operator Skill	Attribute	Training record	Certified/Not	Once / operator	HR / Training
SOP Adherence	Attribute	Audit checklist	Yes/No	Weekly	Supervisor / QA
Gauge Calibration	Attribute	Calibration certificate	Pass/Fail	Monthly	QC
First Pass Yield (FPY)	Continuous	Production & inspection log	%	Daily	Production Engineer

ANALYSE PHASE



Analyse – Hypothesis testing

Regression Analysis: Yield_Percent versus Poor_Fixture_Handling_Score,

Backward Elimination of Terms

α to remove = 0.05

Regression Equation

Yield_Percent = 55.05 - 0.328 Poor_Fixture_Handling_Score - 3.493 Polishing_Param_Dev_Index + 2.027 Cleaning_Consistency_Score - 3.071 Slurry_Contamination_Index

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	55.05	1.56	35.23	0.000	
Poor_Fixture_Handling_Score	-0.328	0.157	-2.08	0.048	1.03
Polishing_Param_Dev_Index	-3.493	0.303	-11.54	0.000	1.05
Cleaning_Consistency_Score	2.027	0.134	15.15	0.000	1.03
Slurry_Contamination_Index	-3.071	0.156	-19.72	0.000	1.03

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.944646	96.79%	96.27%	95.13%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	672.236	168.059	188.33	0.000
Poor_Fixture_Handling_Score	1	3.871	3.871	4.34	0.048
Polishing_Param_Dev_Index	1	118.921	118.921	133.27	0.000
Cleaning_Consistency_Score	1	204.891	204.891	229.61	0.000
Slurry_Contamination_Index	1	346.988	346.988	388.85	0.000
Error	25	22.309	0.892		
Total	29	694.545			

Fits and Diagnostics for Unusual Observations

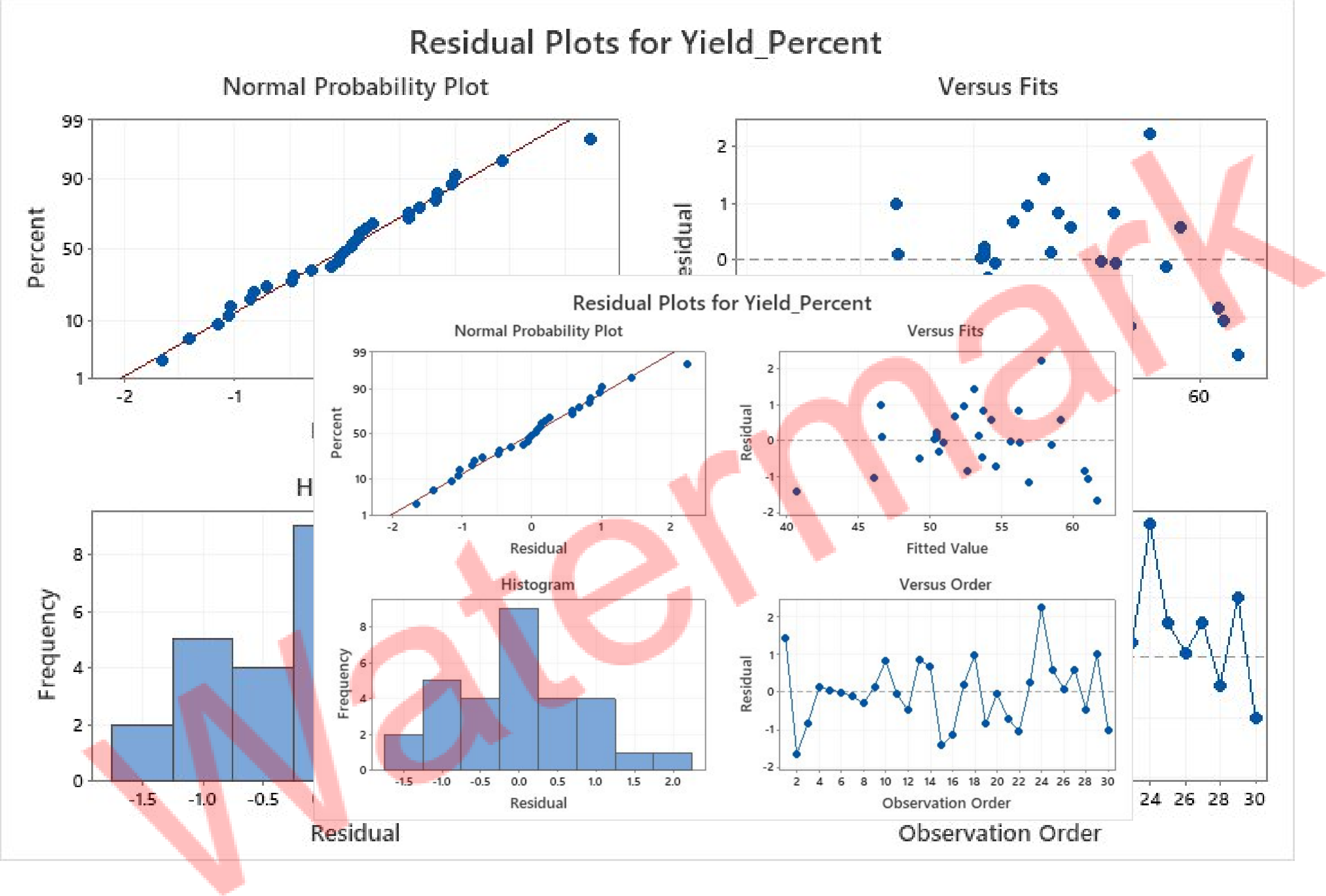
Obs	Yield_Percent	Fit	Resid	Std Resid	
24	60.000	57.768	2.232	2.53	R

R Large residual

Inference :

- The regression model is highly significant ($p < 0.001$, $R^2 \approx 96\%$), showing that fixture handling, polishing parameter deviation, cleaning consistency, and slurry contamination all have strong and statistically significant effects on yield.

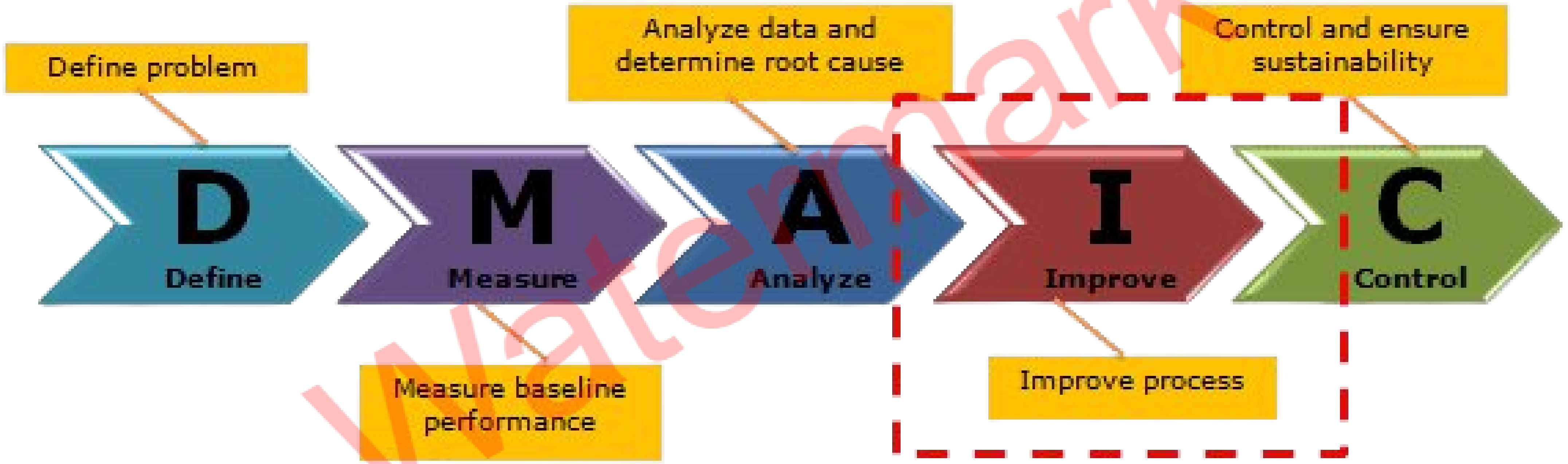
Analyse – Hypothesis testing



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.

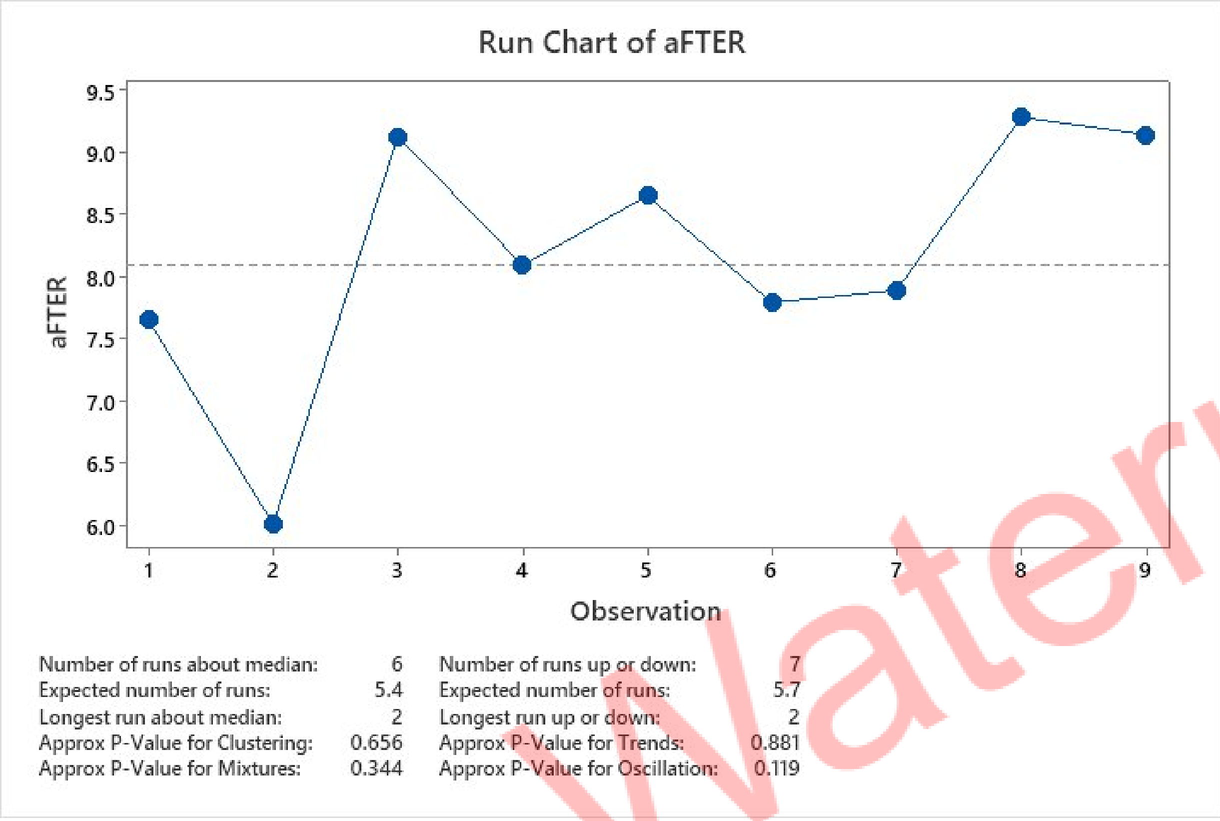
IMPROVE PHASE

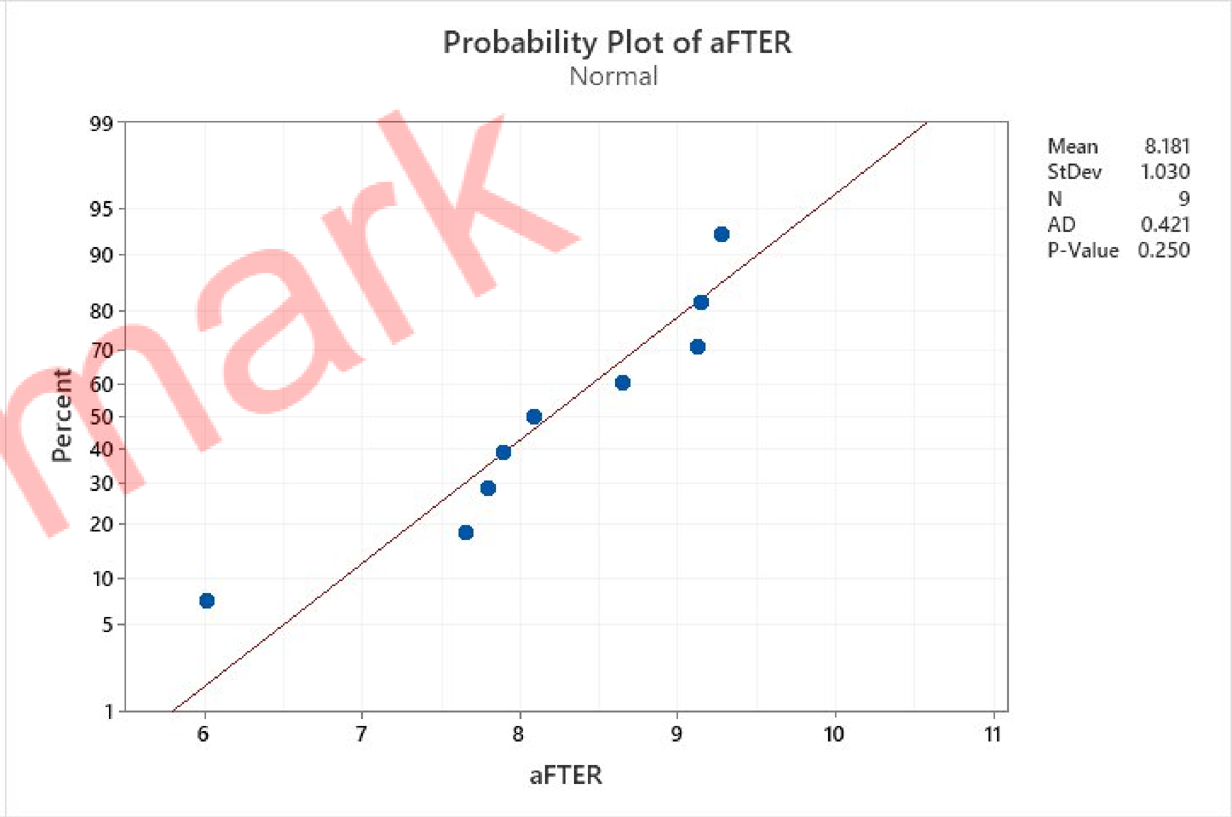


Improve

Root Cause	Improvement Action	Specific Steps	Responsibility
Variation in polishing parameters	Standardize parameter windows & recipes	• Define target & allowable range for dwell time, wheel speed, spot pressure, immersion depth for each product type• Create “MRF Recipe Cards” (laminated sheets / HMI screens) with clear settings• Lock parameter limits in machine PLC/HMI to prevent out-of-range inputs	Process Engineer + MRF Engineer
	Reduce setup variability	• Introduce a structured setup checklist for each job changeover• Use pre-set programs for common part families instead of manual entry• Run initial capability study (Cpk) for key parameters and adjust controls	Production Supervisor + Operators
	Implement real-time monitoring & reaction plan	• Enable data logging for key parameters (dwell time, speed, pressure, slurry temp/viscosity if available)• Define trigger limits and reaction plan (stop, adjust, inform engineer)• Display trend charts near machine to give visual feedback to operators	Process Engineer + Quality
Inconsistent cleaning methods	Create and implement a standard cleaning SOP	• Define cleaning steps before and after MRF (chemicals, sequence, time, tools, drying method)• Include photos/visual work instructions at the cleaning station• Classify “acceptable / not acceptable” surface conditions with sample parts	Process Engineer + Quality
	Standardize tools, materials & conditions	• Fix standard cleaning agents, wipes, brushes, and DI water quality• Mark dedicated, clearly labelled cleaning zones (pre-MRF, post-MRF)• Define maximum allowed time between cleaning and loading in MRF	Production Supervisor
	Train, audit & sustain	• Train all operators on the new SOP with demo & practical check-off• Introduce a simple 5S audit / layered process audit checklist for cleaning steps• Track “Cleaning_Consistency_Score” or audit score weekly and review in daily/weekly production meetings	Training Coordinator + Line Leaders
Slurry contamination	Improve slurry preparation & handling	• Define controlled procedure for slurry make-up: sequence, stirring time, filtration• Use dedicated, labelled containers and lines for each slurry type• Implement basic filtration (inline filters, periodic filter change schedule)	Process Engineer + Maintenance
	Introduce contamination control & monitoring	• Define contamination criteria (particle size limits, visual inspection, test coupon checks)• Perform regular checks (e.g., weekly particle check or surface test on dummy piece)• Record “Slurry_Contamination_Index” per batch/lot in a simple log	Quality + Lab / Metrology
	Define slurry life, storage & disposal rules	• Set maximum slurry life (hours or number of parts processed) based on trials• Define storage conditions (covered, agitated, temperature limits)• Create a tagging system: “Fresh / In Use / To be Disposed” with date and operator ID	Process Engineer + Production Supervisor

Improve





The run chart shows no special-cause variation and the probability plot confirms normality, indicating the after-improvement data is stable, random, and statistically sound.

Improve – Run chart and Normality Test (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	25.00	5.41	1.8
aFTER	9	8.18	1.03	0.34

Estimation for Difference

Difference	95% CI for Difference
16.82	(12.59, 21.05)

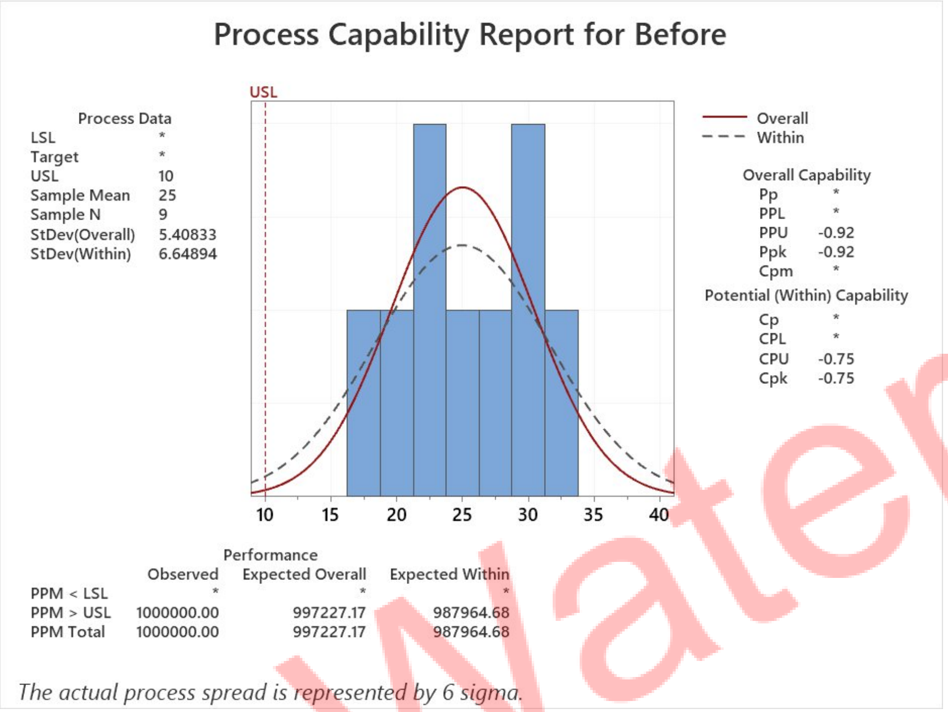
Test

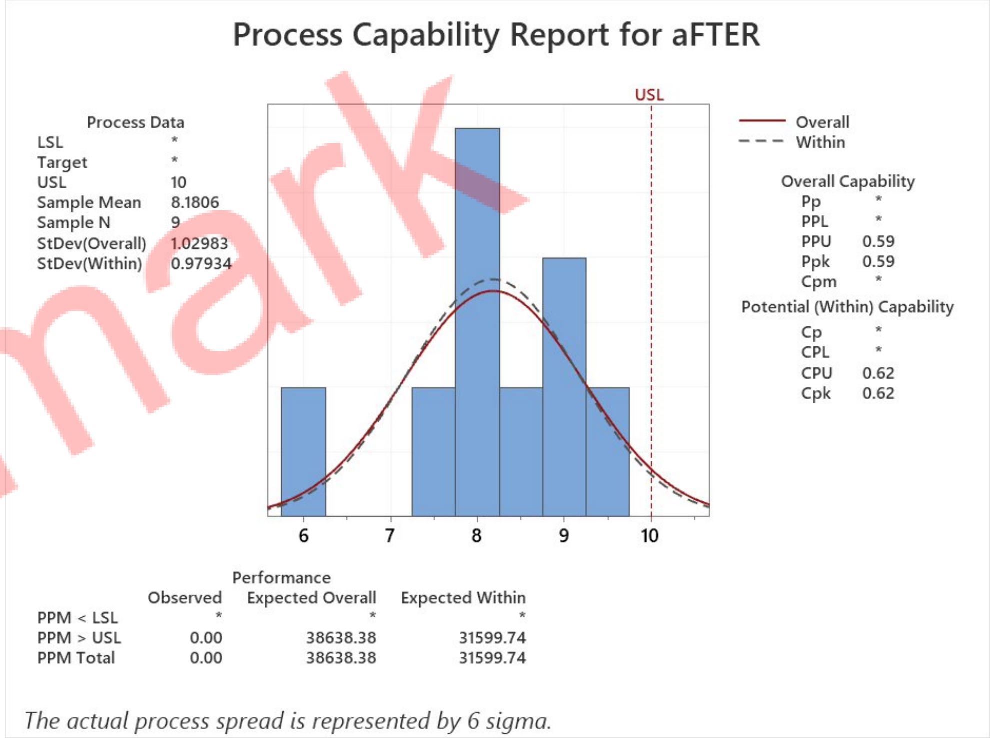
Null hypothesis $H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis $H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
9.17	8	0.000

Inference:
- Normality test – Data are normally distributed

Improve – Process capability – Before & After Improvement





Inference :

- Before Cpk < After Cpk, which shows process is much more capable after improvement
- There is less variability in system since stdev reduced after improvement
- After improvement the data are normally distributed near the target within specified limit

Improve –After Improvement (Statistical validation for Improvement – Hypothesis Testing)

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

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Before	9	2.75	1.05	0.35
After	9	0.6998	0.0480	0.016

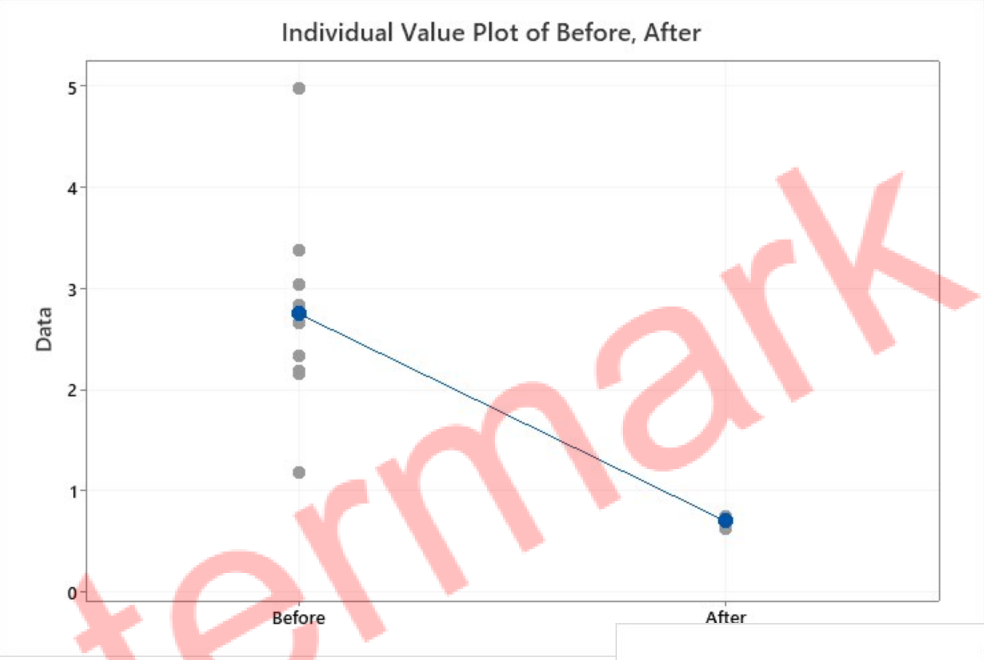
Estimation for Difference

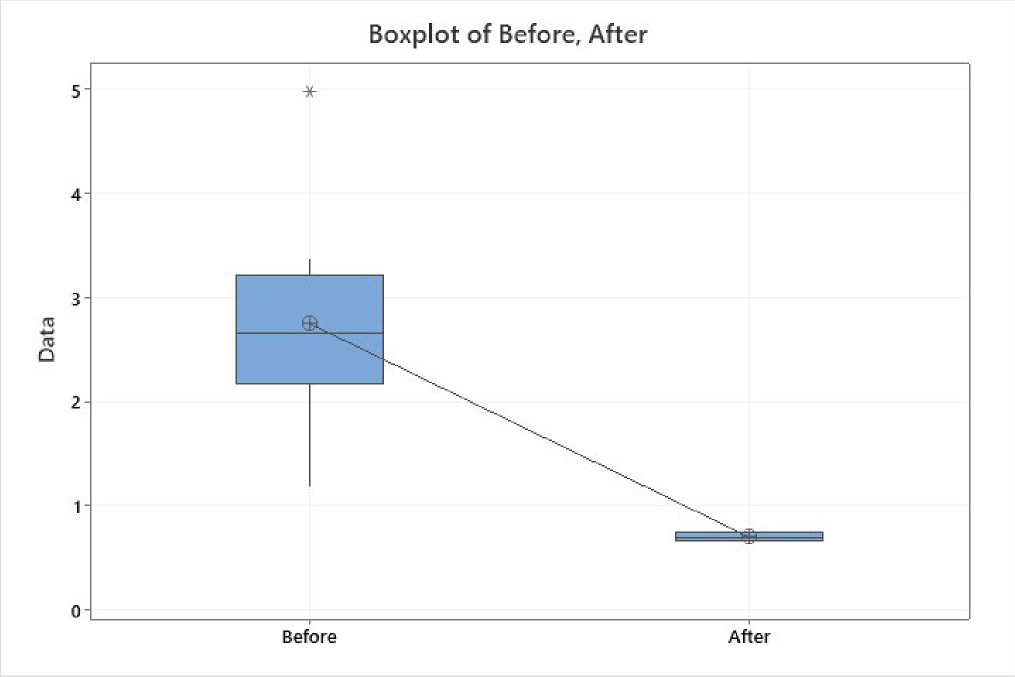
Difference	95% CI for Difference
2.049	(1.243, 2.855)

Test

Null hypothesis H₀: $\mu_1 - \mu_2 = 0$
Alternative hypothesis H₁: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
5.86	8	0.000





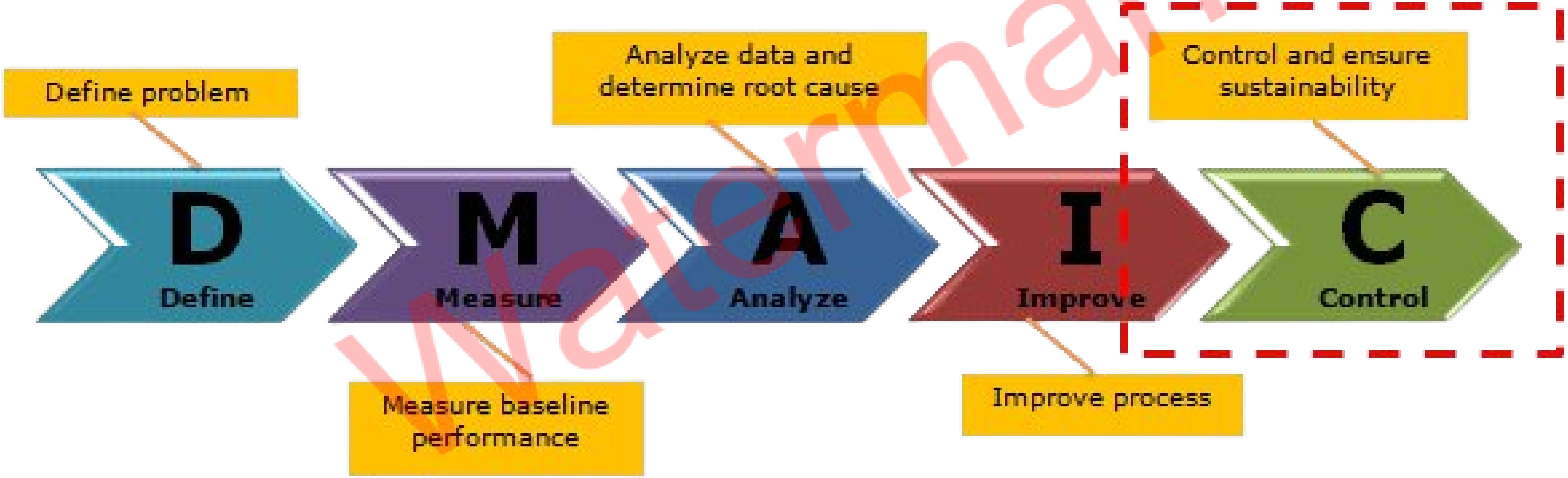
Inference:

- Since P value is less than 0.05, there is enough evidence to reject the null hypothesis and we can conclude that the difference between the population means is statistically significant.
- It is also visible from the individual value plot & box plot, there is clear difference in mean after improvement which is closer to required % scrap

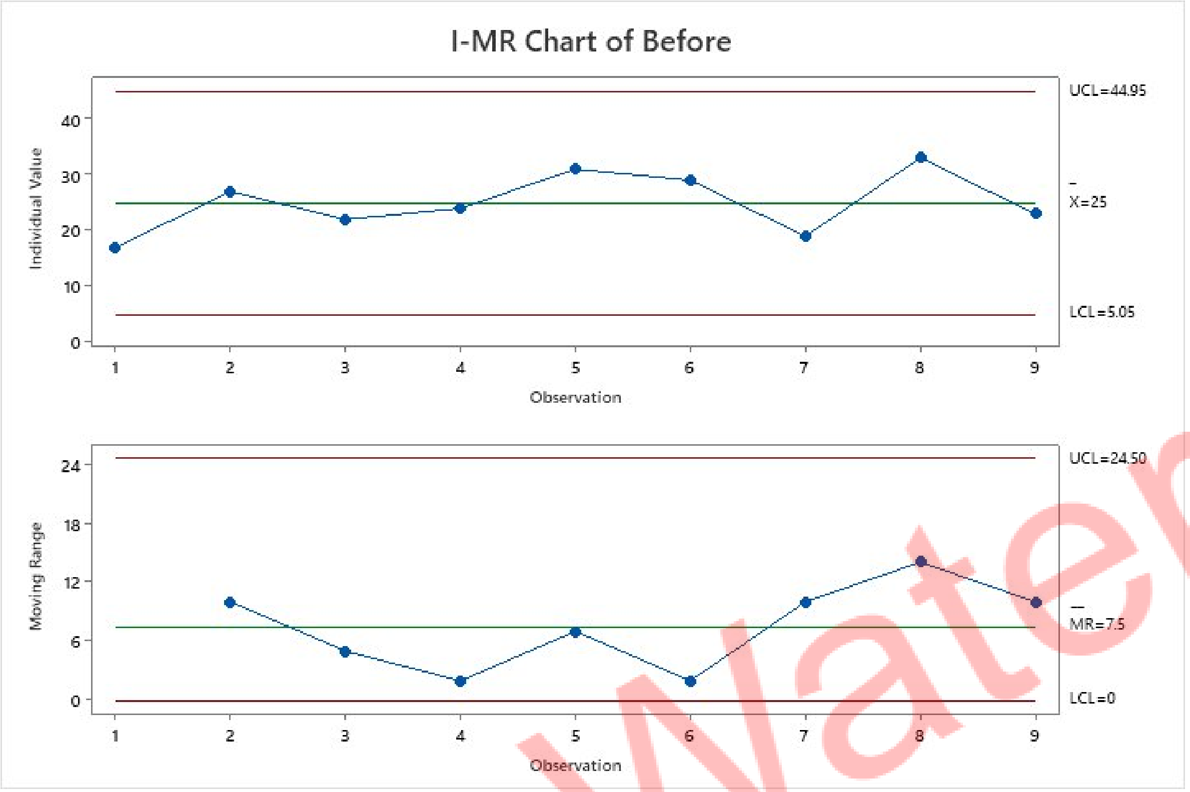
FMEA

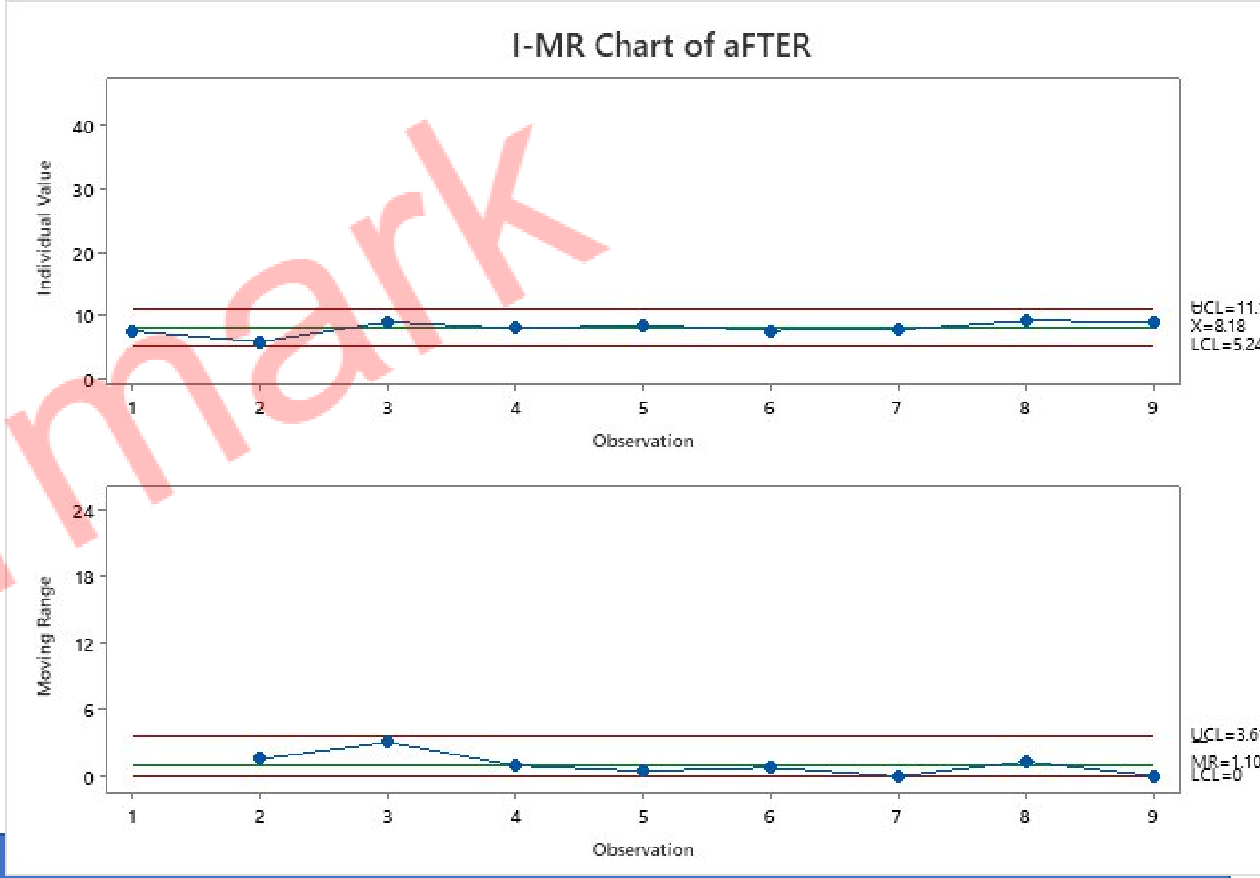
Process Step	Function / Requirement	Potential Failure Mode	Potential Effects	S	Potential Causes / Mechanisms	O	Current Controls (Prev/Det)	D	RPN	Recommended Actions (acceptance criteria)	Owner	Target	Residual S	Residual O
Program load (DNC)	Correct recipe & locked parameters	Wrong program/params loaded or drift from recipe	OOT dims, scrap spike	9	Wrong file, manual edits, legacy offsets	5	Paper signoff; 1st-off check	6	270	DNC checksum & read-only CTQ params; auto-compare to golden; override timer ≤5 min with alarm	Mfg Eng	Week 1	9	2
Tool management	Hold VB below limit	Tool wear limit exceeded (VB)	Finish fail, burrs	8	Extended run, hard material, no early signal	6	Visual checks; periodic VB measure	6	288	PLC interlock at VB 0.10/0.15 mm; life counter tie-off; Andon	Ops / Maint	Week 2	8	2
Tool life control	Replace at/before limit	Tool life overrun	Chatter, OOT dims	7	Counter not reset; takt pressure	5	Manual log; shift review	7	245	Hard stop at +5% life; auto reset; reason code required to extend	Ops	Week 2	7	2
Tooling kitting	Correct insert/holder used	Wrong tool / insert grade	Rapid wear, surface finish fail	8	Kit mix-up, look-alike	3	Traveler check	6	144	Barcode/QR tool ID; presetters; poka-yoke nests	Tool Crib	Week 3	8	1
Machine health	Maintain geometry	Calibration drift after crash	OOT features	7	Crash, thermal drift	3	Monthly ballbar	7	147	Crash event → lock & re-cal; release only after report pass	Maint / QA	Immediate	7	2
Vibration control	Keep RMS ≤ spec	High vibration not acted	SF fail, burrs	6	Unbalance, bearing wear	4	Periodic check	6	144	Online sensor with email/andon at ≥4.5 mm/s; PM ticket auto-create	Maintenance	Week 4	6	2
Coolant control	Maintain concentration /pH	Coolant out of range	Wear ↑, heat, scrap	6	Doser fail, evaporation	5	Manual titration	5	150	Daily refractometer + auto-doser; SPC log; alarm bands	Ops / Chem	Week 2	6	2
CMM program	Verify datum/logic	CMM program mismatch	False scrap / escapes	6	Rev not updated	3	Programmer review	5	90	Simulation + PPAP/FAI signoff; GRR spot check on CTQs	CMM Prog	Week 2	6	1
MSA – VB	Reliable wear reading	High %GRR on VB	Wrong decisions	6	Method variation	4	Ad-hoc checks	6	144	GRR ≤10%, work instruction, refs; re-cal monthly	QA	Week 3	6	2
Skills & SOP	Follow new OCAP	Training gaps / non-adherence	Drifts reappear	7	New limits not learned	5	Toolbox talk	5	175	Cert check-off; job aids at machine; LPA daily	Supervisor / HR	Week 2	7	2

CONTROL PHASE



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





Inference:

- The I-MR charts show high variation and instability before improvement, whereas the after chart is fully stable and in control, confirming a strong reduction in process variability.

Control Plan for sustaining the improvement

Step	Action	Description
Sort	Remove obsolete parameter cards / old recipes	Avoid operator confusion by keeping only latest parameter sheets and software versions.
Set in Order	Color-code control panels & parameter input screens	Use color-coded buttons or software tabs (e.g., Green = Approved Recipes, Red = Manual).
Shine	Daily wipe-down and inspection of control consoles	Prevent dust buildup or accidental knob movement that affects readings.
Standardize	Fix standard parameter labels on each MRF machine	Ensure dwell time, pressure, and wheel speed positions are uniform across machines.
Sustain	Create “Recipe Audit Log”	Weekly checklist to verify that the current recipe matches the standard.

FMEA

Area	Step	Potential Failure Mode (FM)	Potential Effect (FE)	Potential Cause	Current Controls	S	O	D	RPN	Recommended Action	Owner / Target
Polishing Parameters	Create & approve standard recipes	Recipes not correctly defined (wrong target / range)	Parts still fail spec; no yield improvement	Incomplete trials, wrong assumptions, poor cross-functional review	Engineer reviews, informal trials	9	4	6	216	Formal DOE-based recipe confirmation; cross-functional sign-off (Process Engg, QA, Optics expert); document trial results	Process Engineer – 2 weeks
Polishing Parameters	Upload recipes to machine / HMI	Wrong recipe uploaded or overwritten	Wrong parameters used for multiple batches; yield drops	Manual selection error; similar recipe names	Version control in Excel, manual double-check	8	5	5	200	Unique recipe IDs, barcode-based recipe loading, password protection for editing; change control log	Manufacturing Engineer – 3 weeks
Polishing Parameters	Daily operation with locked parameters	Operators bypass parameter limits using manual mode	High variation in parameters; improvement not sustained	Pressure to “adjust” for urgent orders; lack of awareness	Training, supervisor approval for manual mode	8	4	6	192	Disable manual mode for production; only engineering login can enable temporary manual mode with justification form	Production Manager – 4 weeks
Polishing Parameters	Monitoring & reaction plan	Parameter drift not noticed or acted upon (SPC ineffective)	Long runs with off-target settings; hidden yield loss	No reaction plan; no one reviews trends; alarms ignored	SPC charts available, but not reviewed routinely	9	3	7	189	Daily review of critical parameter trends; simple “out-of-control” checklist; Andon signal when limits breached	Quality + Supervisors – Start in 2 weeks

Control Plan

Process Step / Area	Potential Source of Variation (X)	Control Method / Monitoring Activity	Specification / Target / Control Limits	Reaction Plan (if Out of Control)
Polishing Parameter Setup	Polishing parameter deviation (dwell time, wheel speed, spot pressure)	Lock parameter recipes in HMI; Auto load recipe via barcode; Daily SPC check on dwell time & wheel speed	Dwell time ±5%; Wheel speed ±3%; Spot pressure ±2%	Stop batch, notify Process Engineer, investigate reason, correct and resume only after approval
Fixture Setup	Fixture alignment / handling variation	Alignment check using dial gauge; Use of standard fixture verification checklist	Tilt error ≤ 0.5 mrad; Centration error ≤ 5 µm	Re-align fixture; re-verify before resuming
Cleaning Process (Pre & Post MRF)	Inconsistent cleaning method	Visual SOP display; Operator checklist for 5-step cleaning process	100% adherence to cleaning checklist	Retrain operator; record deviation; QA to inspect subsequent parts
Cleaning Material Use	Use of non-approved solvents, wipes	5S visual control; Color-coded bottles and wipes	Only approved cleaning materials in use	Remove non-approved items; re-issue correct materials; audit recurrence
Slurry Preparation	Contamination or incorrect mixing ratio	Batch ID tagging, filtration, batch record with date/time	Mix ratio ±2%; Filtration < 5 µm; Slurry age ≤ 48 hr	Discard contaminated slurry; prepare fresh; root cause analysis
Slurry Storage	Contamination during storage	Color-coded containers; Lids closed; Visual label for expiry	Containers labeled “Fresh / In Use / Expired”	Dispose expired batch; sanitize container; record incident
MRF Operation	Parameter drift during run	Real-time SPC on dwell time, pressure, slurry temperature	Dwell time ±5%; Slurry temperature ±2°C	Stop process if limit exceeded; escalate to Engineer
Operator Skill	Human error or deviation from SOP	OJT certification matrix; skill audit every 6 months	100% of operators trained & certified	Re-train operator; restrict to non-critical jobs until certified
Visual / Final Inspection	Yield variation; optical defects	100% inspection under laser interferometer and scratch-dig standard	Yield ≥ 45%; Surface finish ≤ target RMS	Segregate batch; perform root cause analysis; issue corrective action

CONTROL STRATEGY SUMMARY

Element	Approach
Statistical Control	Use SPC charts for dwell time, wheel speed, and slurry viscosity; monitor Cp/Cpk ≥ 1.33.
Visual Controls	Color-coded cleaning materials, batch tags for slurry, display of parameter trend charts near machine.
Layered Process Audits (LPA)	Weekly supervisor audit covering parameter adherence, cleaning SOP, and slurry tagging compliance.
Standard Work & Training	Maintain updated SOPs (cleaning, polishing, slurry mixing); OJT checklist and re-certification.
Digital Tracking	Use Excel / MES dashboard to log yield, SPC, and audit scores; trend weekly yield vs. baseline (target ≥ 45%).
Preventive Maintenance	Monthly check of fixtures, polishing pads, and sensors to prevent mechanical or calibration-related variation.