

Reduction of Rod Surface Roughness Variation

Tushar

ROADMAP



Overview



Define



Measure



Analyse



Improve



Control

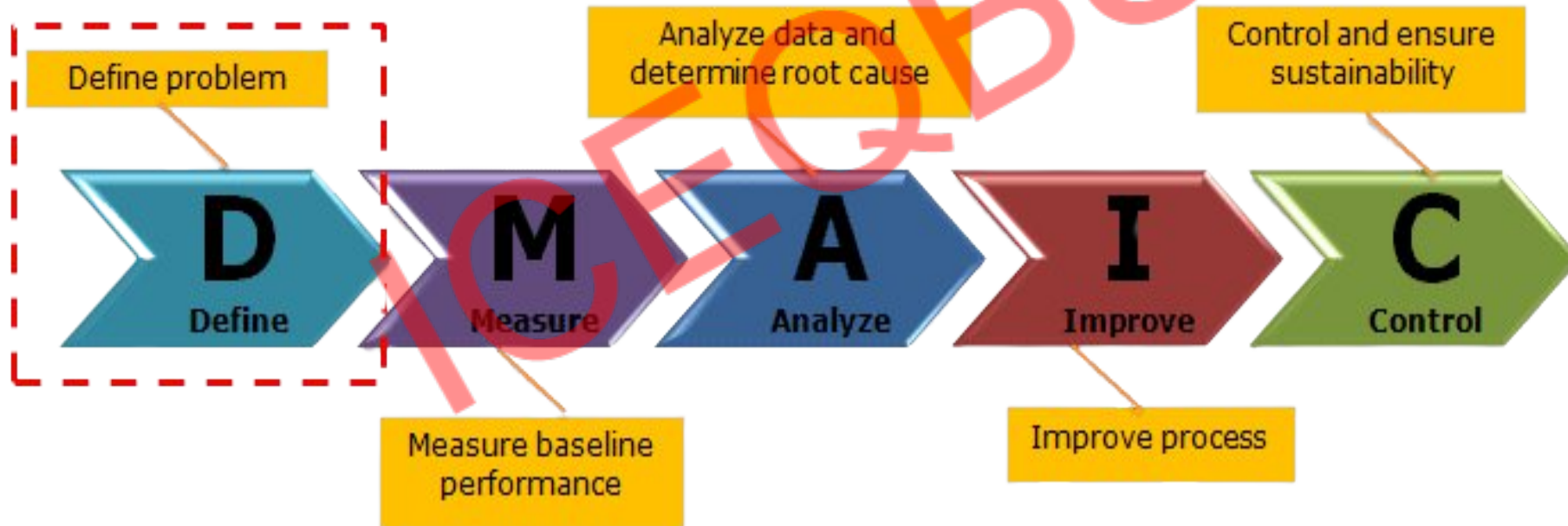
OVERVIEW



Background

Rod grinding surface roughness variation is causing seal wear, hydraulic oil leakage, and premature component failure. These issues are increasing warranty rework, assembly-line rejections, and field service costs, while reducing customer confidence in product reliability. A Six Sigma project is needed to stabilize the grinding process, reduce variation, and prevent leakage-related defects. Consistently achieving the correct surface finish will lower defect rates, improve assembly efficiency, and reduce downtime caused by rework. Stabilizing the process will also enhance performance in the field and strengthen long-term brand trust. Overall, reducing variation will deliver measurable cost savings and improve operational efficiency.

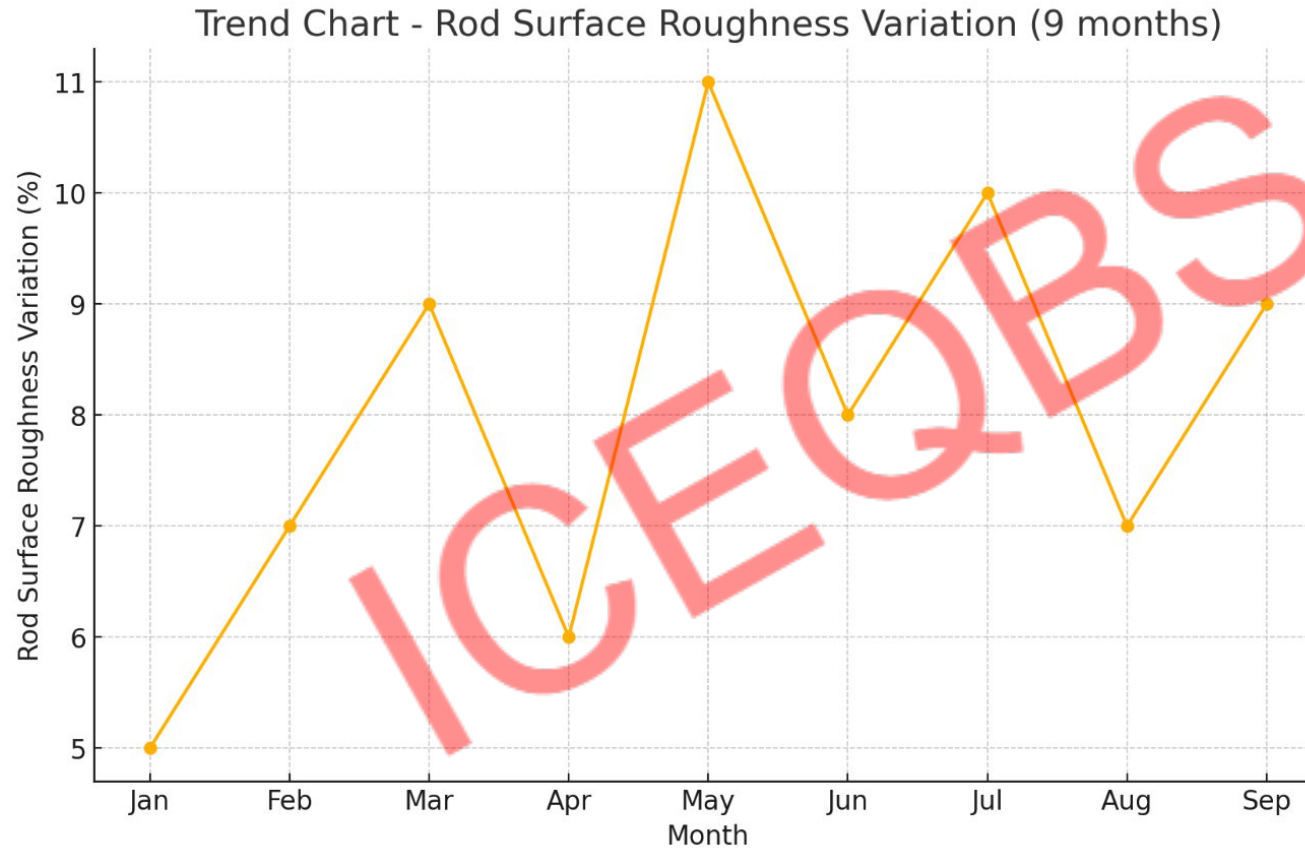
DEFINE PHASE



CTQ Tree :

Voice of customer	Critical to X	Primary Metric for improvement
<i>"my cylinder must NOT leak oil here"</i>	CTQ = Rod Surface Roughness	Primary Metric - Y = % Rod Surface Roughness Variation Secondary Metric - Cylinder Leakage Rate

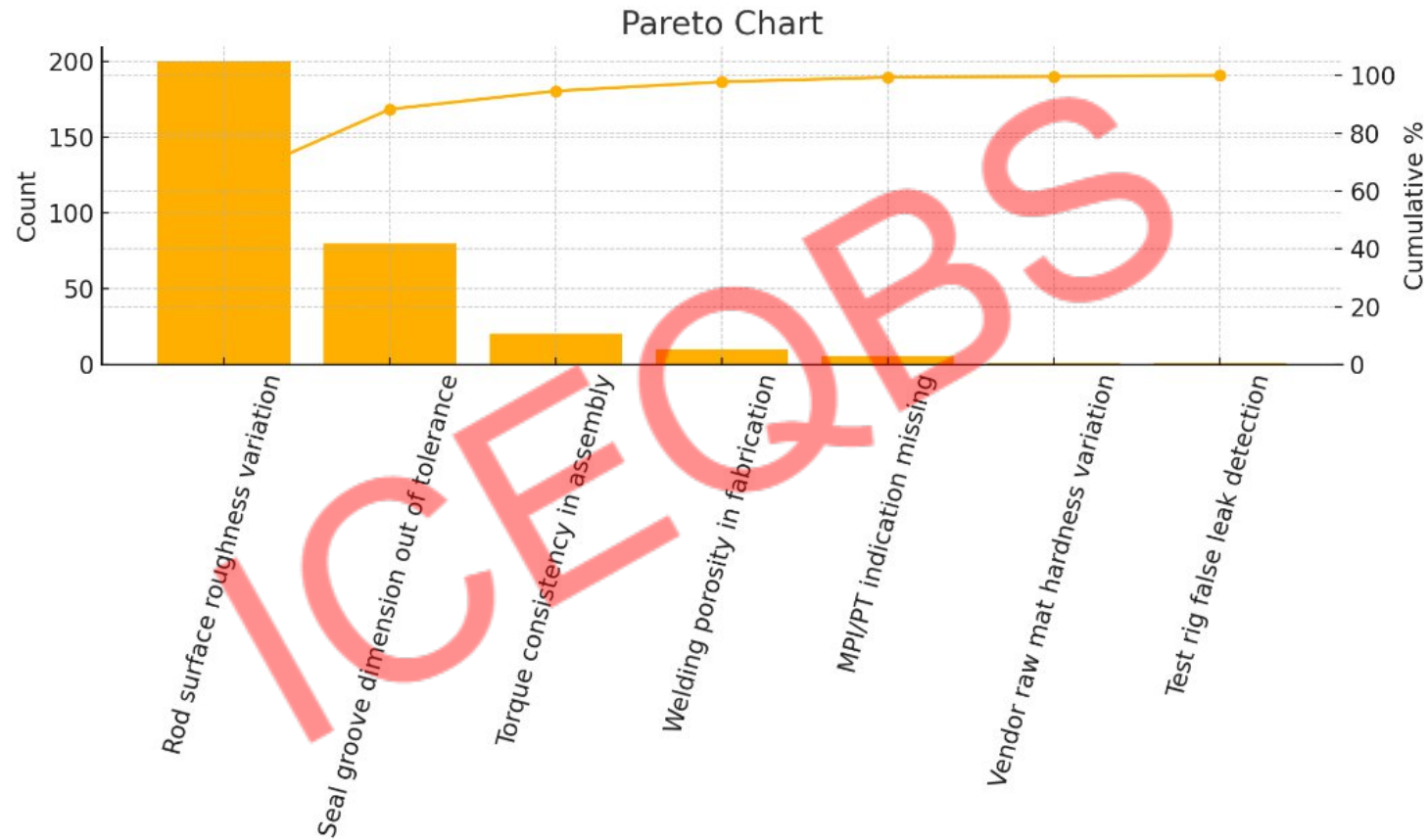
Baseline Performance of Primary Metric (9 months data as Line chart)



Inference :

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

Pareto chart



Inference :

- Rod surface roughness variation contributes substantially and included in the scope of the project

SIPOC

Suppliers (S)	Inputs (I)	Process (P)	Outputs (O)	Customers (C)
Vendor steel supplier	Chrome plated rod bar	Bar cutting	Ground rod	Assembly line
Tool grinding wheel OEM	Coolant additive	Rough grinding	Measured ra result	QA inspection
Maintenance team	Grinder dressing tool	Finish grinding	Stable variation	End customer
QC incoming	MSA calibrated stylus	Surface inspection	Compliant rod finish	Railway machine OEM

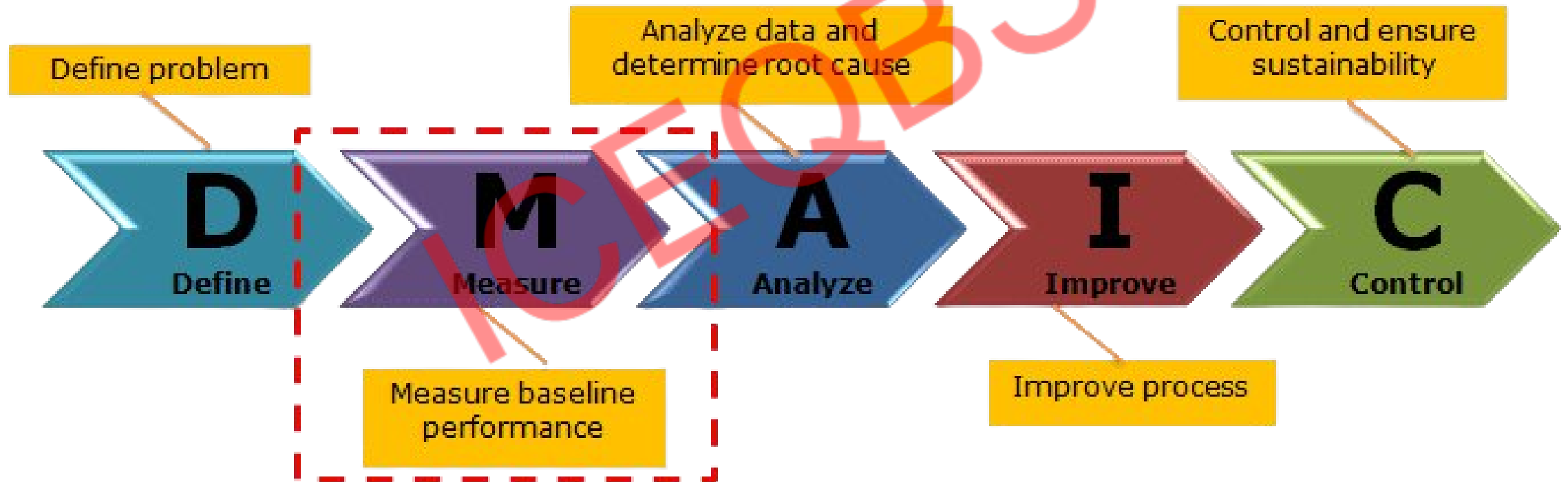
Project Charter

Project Title:		Reduction of Rod Surface Roughness Variation		
Project Leader			Project Team Members:	
Tushar			Vendor SQA, Maintenance, Assembly Supervisor	
Champion/Sponsors:			Key Stake Holders	
Plant Head – QA			Assembly line team Grinding operator crew Planning Team Procurement Team	
Problem Statement:			Goal Statement:	
In last 9 months, Rod Surface Roughness variation ranged from 5% to 11% with average 8%. This high variability leads to increased leakage complaints and rejection at final assembly.			reduce rod surface roughness variation from current 8% → ≤ 3% within 4 months	
Secondary Metric			Assumptions Made:	
Cylinder Leakage Rate			Grinding machine condition, tooling, and coolant supply remain consistent during the study. Operators follow standard operating procedures without major deviations.	

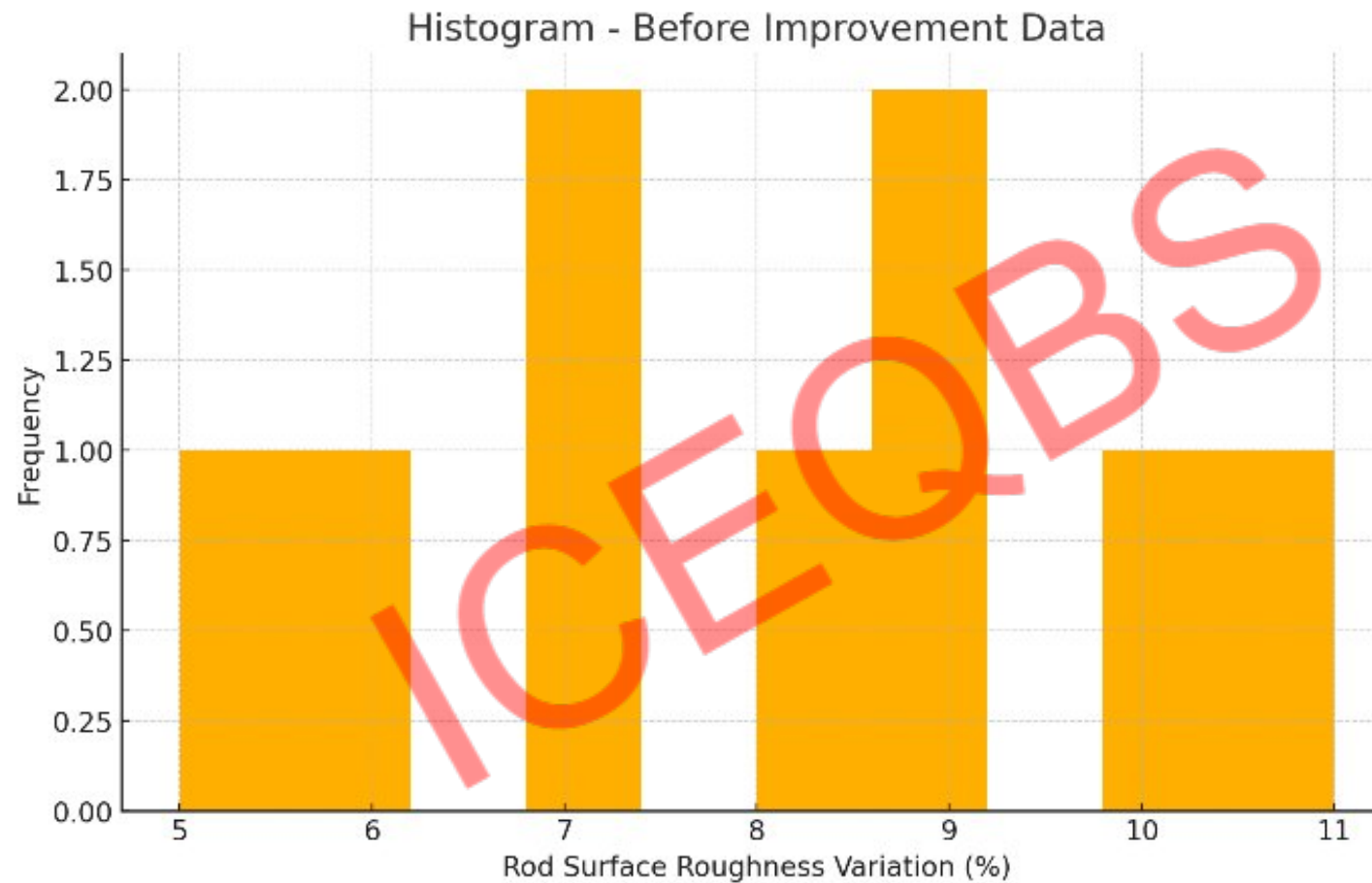
Project Charter

Tangible and Intangible Benefits:		Risk to Success:	
rework reduction = 35% drop leakage NCR reduction = 40% drop cost saving per year = ₹ 22 Lakhs		Variability in incoming rod material affecting grinding performance. Inconsistent operator practices or resistance to new standards. Machine downtime or unplanned maintenance impacting data collection.	
In Scope:		Out of Scope:	
Rod grinding process parameters (feed, speed, coolant flow, wheel dressing). Measurement and analysis of rod surface roughness variation. Operator training and standardization activities.		Changes to rod material specification or supplier. Modifications to seal design or hydraulic system design. Activities related to downstream assembly operations (beyond roughness feedback).	
Signatories:		Project Timeline:	
Project Sponsor, Process Owner, Champion		6 Months	

MEASURE PHASE



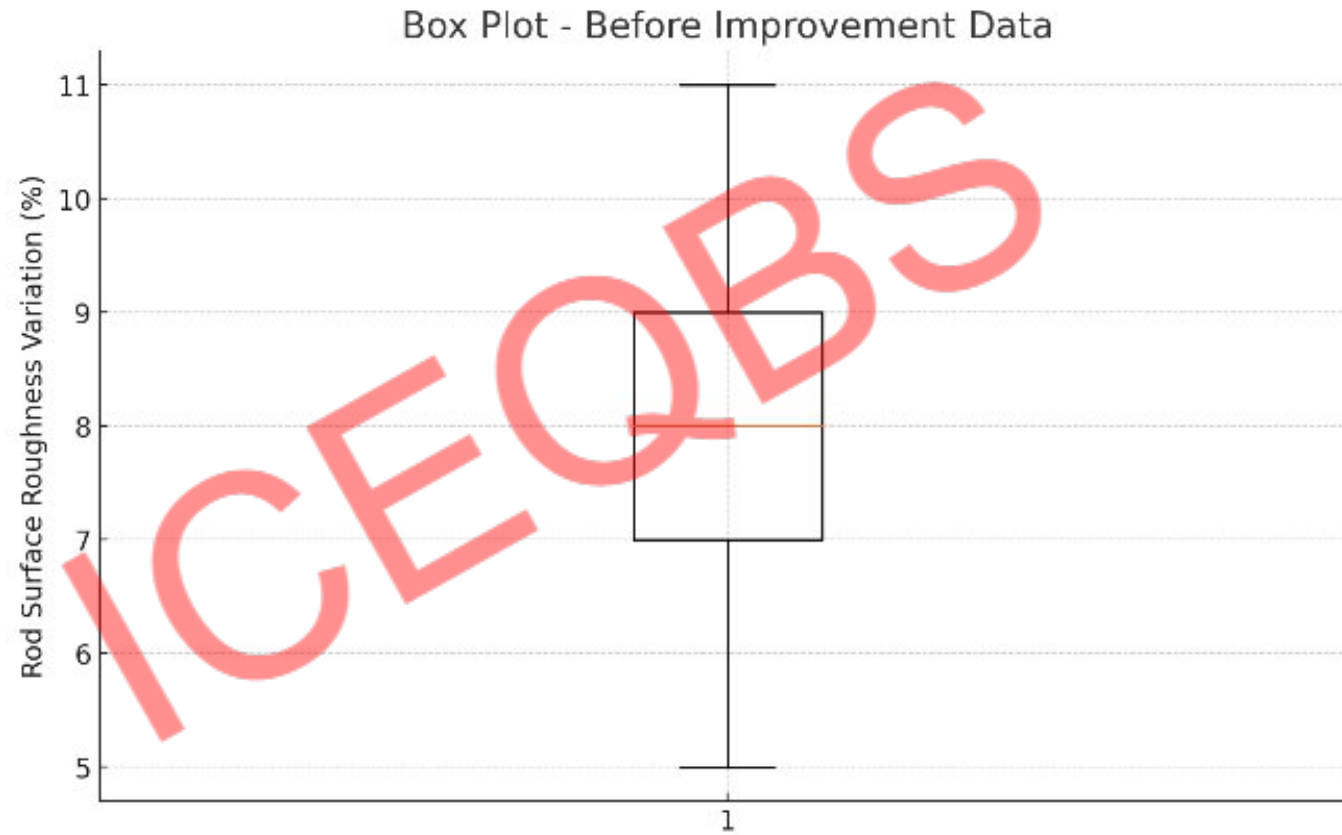
Data collection – Histogram (Before improvement)



Inference :

- Data is normally distributed over the mean

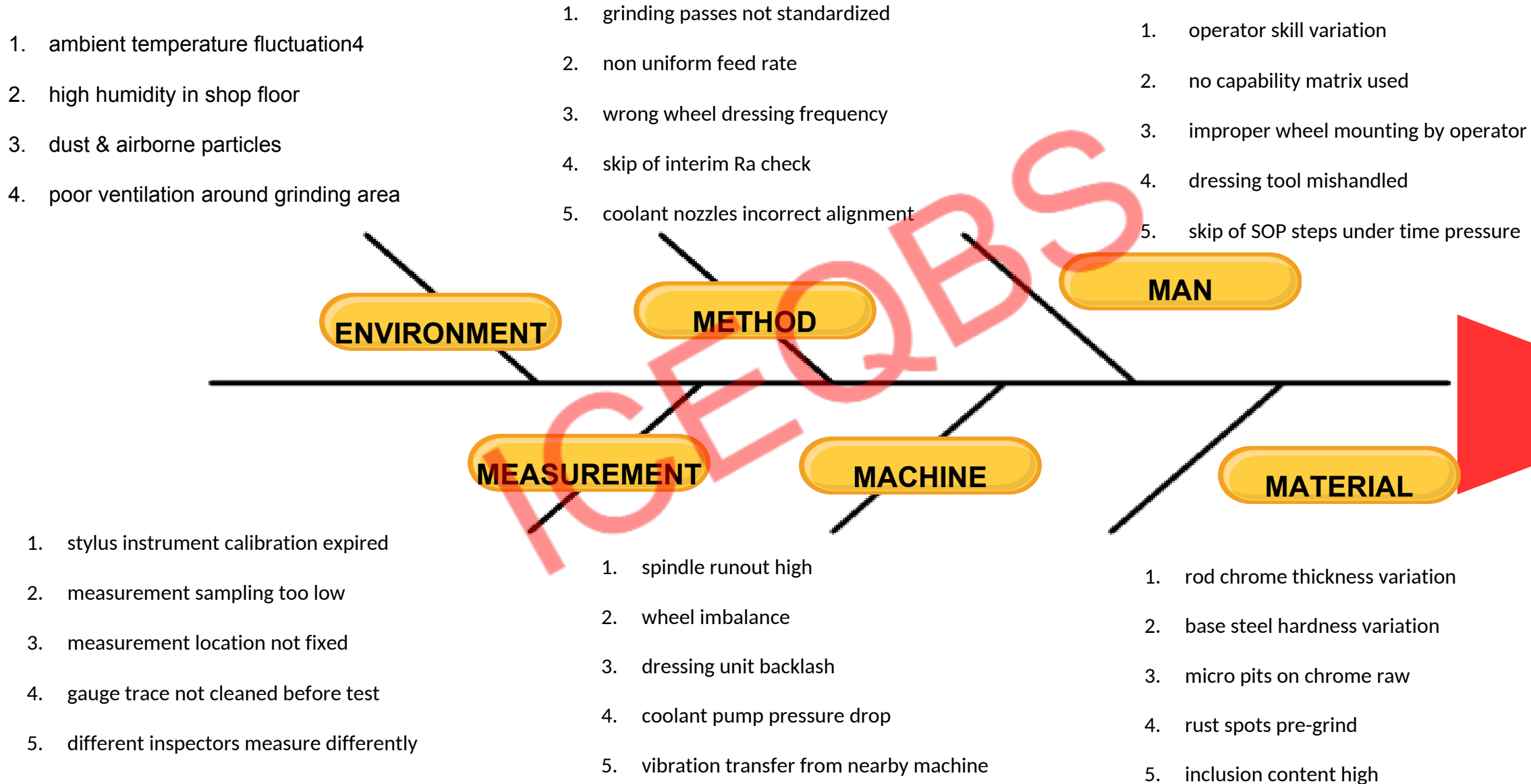
Data collection – Run Chart (Before improvement)



Inference :

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

Fish Bone Diagram



COMMON CAUSES vs SPECIAL CAUSES

COMMON CAUSES

- operator skill variation
- non uniform feed rate
- wrong wheel dressing frequency
- measurement sampling too low
- measurement location not fixed
- coolant nozzles incorrect alignment
- skip interim Ra check
- skip SOP due time pressure
- tool dressing unit backlash (gradual wear)
- spindle runout high (progressive)

SPECIAL CAUSES

- wheel imbalance (one sudden event)
- coolant pump pressure drop (breakdown event)
- vibration transfer from next machine (sporadic)
- rust spots pre-grind (lot specific)
- inclusion content high (lot specific)
- base steel hardness variation (heat treat lot)
- chrome thickness variation (vendor batch)
- stylus calibration expired (event based)
- dirty trace during measure (random miss)
- improper wheel mounting (isolated human error)

3M Analysis for Waste

MUDA

- re-grinding same rod twice because first pass Ra was bad
- inspectors taking multiple repeats because variation is huge
- holding excess WIP rods in buffer because output not stable

Mura

- some rods take 1 finish pass, some rods take 3 – no standard pattern
- Ra value swings from 5% to 11% month to month
- feed rate & cooling are adjusted manually depending on “feel”

Muri

- operator forced to run 2 grinders at same time
- grinding wheel forced to run beyond recommended dressing interval
- QC forced to check 100% because process isn't trusted yet

8 Wastes Analysis

Defects

- rod roughness out of spec → re-grind required
- chrome peel marks → rod rejection

Overproduction

- grinding more rods ahead of assembly demand
- finishing extra rods “just in case” rejection comes

Waiting

- operator waits for maintenance to fix coolant pump
- rods waiting in queue for Ra inspection

Non-Utilized Talent

- skilled grinder only doing basic deburr work
- QC engineer stuck doing clerical data entry

Transportation

- moving rods 50 meters from grinder to QC room
- returning rods back to grinding after fail inspection

Inventory

- high WIP rods stacked near grinding machine
- extra grinding wheels stocked due fear of shortage

Motion

- operator walking to fetch dressing tool every cycle
- inspector walking to collect printout from remote printer

Overprocessing

- performing 3 finish passes when 1 pass was enough
- re-measuring Ra thrice due to poor measurement method

Action Plan for Low Hanging Fruits

Special Causes (sudden failures / abnormalities)

Observed Issue / Cause	Lean Tool / Approach	Action to be Taken	Expected Benefit (Low Hanging Fruit)
wheel imbalance / improper mounting (special cause)	5S + Poka Yoke	create standard wheel mounting torque & color-coded fixture pins	instant reduction of random roughness spikes
coolant nozzle not aimed at cut zone (special cause)	Standard Work Sheet	fix nozzle angle with template jig + label angle	cooler grind zone → lower micro-burn defects
dressing done at random timing (muri)	Visual Kanban	fix “dress every X rods” card system	stable finish passes, reduce variation
rods moving back&forth to QC (transport waste)	Point of Use Quality	move Ra checker near grinder	reduce non value-add movement & waiting
operator handling two grinders (muri)	Line Balancing	assign dedicated grinder operator per shift	focus ↑ variation ↓
re-measuring Ra 3 times (extra processing waste)	Standard Work	lock measurement location + one measurement rule	faster cycle — more trust in measurement
incoming chrome pitting (special cause)	Vendor Containment	introduce lot based chrome pit visual check sheet	reject bad batch in incoming, not after grind

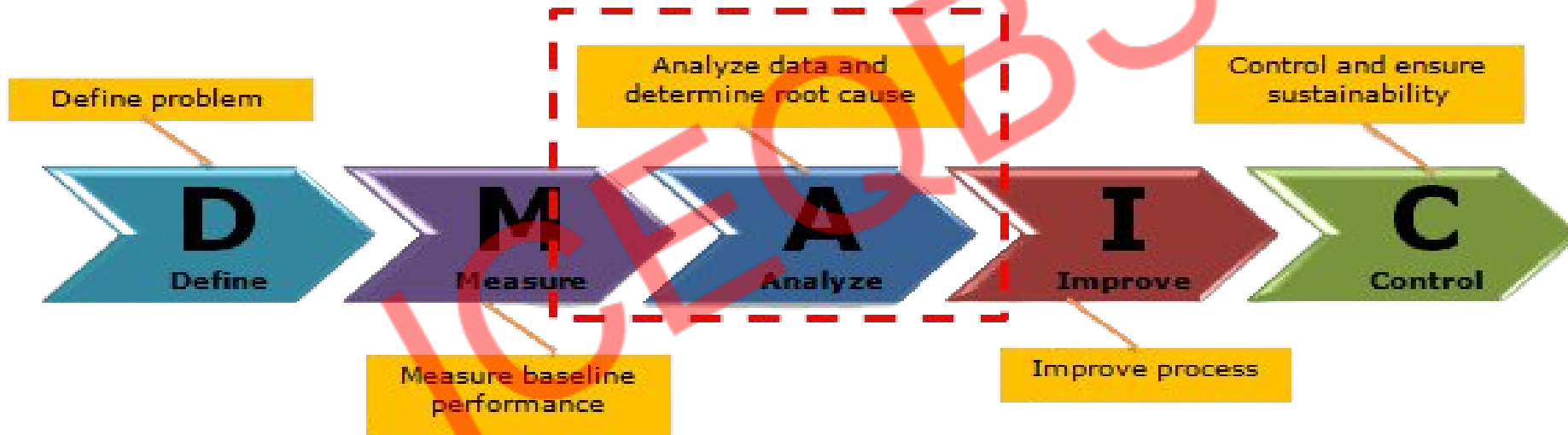
Top 12 Prioritized Root Causes (Based on Net Score)

Root Cause	Score
Wheel imbalance	210
Spindle runout high	210
Uncontrolled feed rate	210
Coolant nozzle misalignment	192
Dressing frequency random	192
Chrome thickness variation (vendor)	190
Raw chrome pits (vendor)	190
Operator skill variation	144
Base steel hardness variation	136
Overloading operator (MURI)	132
Measurement location not fixed	132
Calibration expired	132

Data Collection Plan

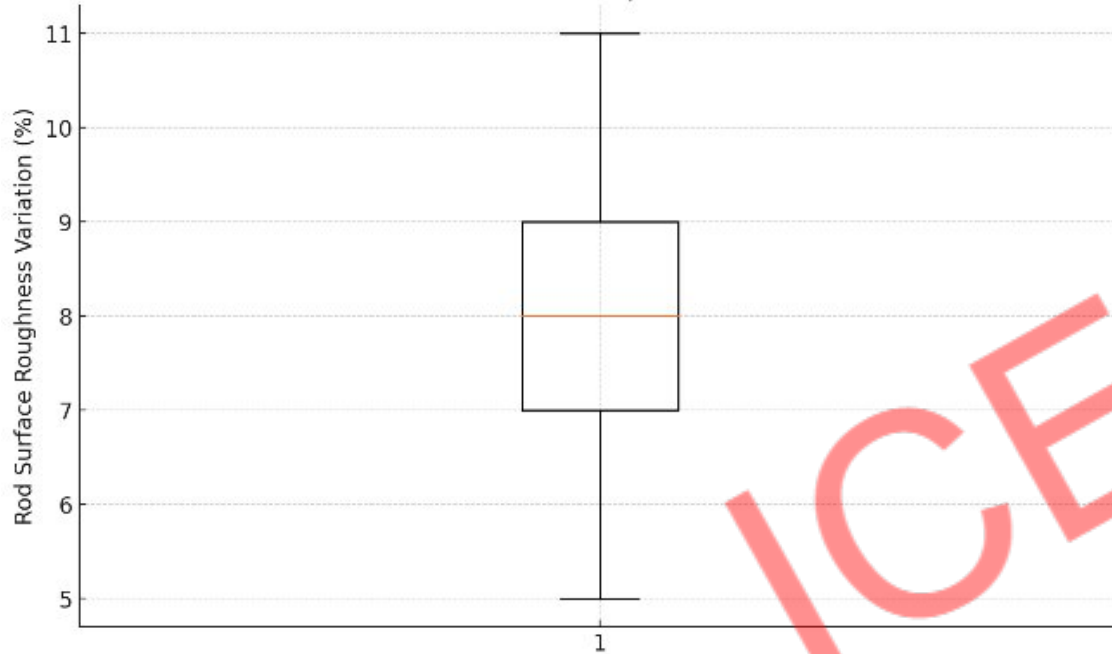
Root Cause / Factor to Measure	Data to be Collected	Measurement Method / Source	Frequency / Sample Size	Responsible Person
wheel imbalance	wheel balancing deviation value (g.mm)	dynamic balancer readout sheet	each new wheel mounting — n=5 wheels per week	Grinding Operator
spindle runout	spindle runout (µm)	dial indicator measurement on spindle nose	once per shift — n=3 readings per shift	Maintenance Fitter
feed rate variation	actual feed speed vs set feed speed (mm/sec)	PLC feed value log download	once daily — 30 rods daily sample	Production Engineer
dressing frequency inconsistency	rods count between dressing cycles	dressing counter tally sheet	every shift — record 100%	Grinder Operator
coolant nozzle misalignment	nozzle angle degree vs standard angle	angle template gauge check	twice per week — n=10 checks each time	Maintenance Technician

ANALYSE PHASE

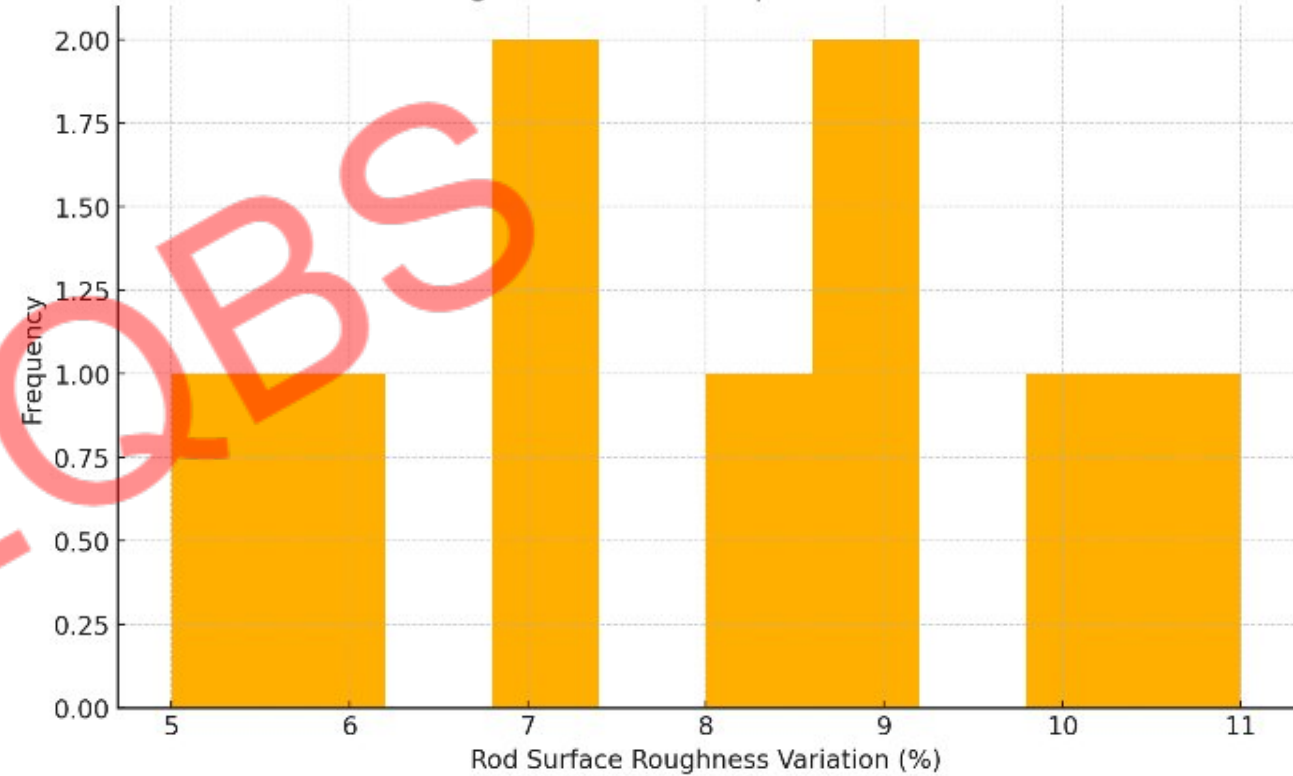


Analyse – Hypothesis testing

Box Plot - Before Improvement Data



Histogram - Before Improvement Data



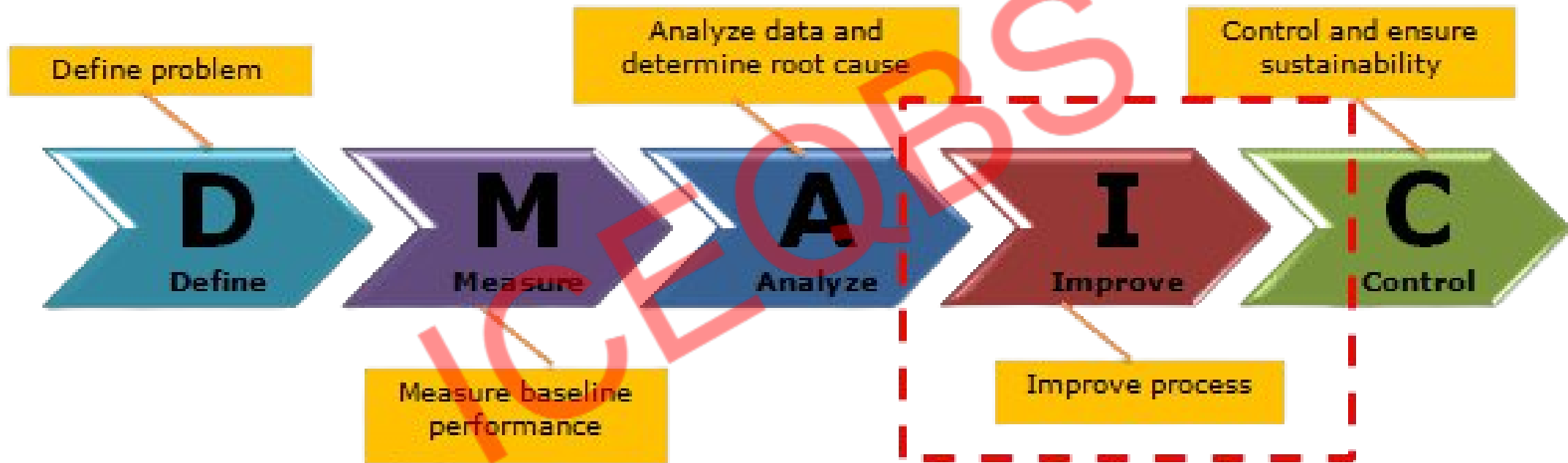
Inference :

- The data shows high and inconsistent roughness variation (5–11%), indicating an unstable process before improvement.

Analyse – Hypothesis testing

Suspected root cause	Hypothesis test used	P-value	Conclusion
Wheel imbalance	2 sample t test (balanced vs unbalanced)	0.000	VALIDATED critical
Spindle runout	Simple linear regression	0.000	VALIDATED critical
Feed rate high	One-way ANOVA (low / nominal / high)	0.000	VALIDATED critical
Dressing interval too long	2 sample t test (≤ 15 rods vs > 15 rods)	0.000	VALIDATED critical
Coolant nozzle alignment wrong	2 sample t test (aligned vs misaligned)	0.000	VALIDATED critical
Chrome pits from vendor	2 sample t test (clean vs pits batch)	0.000	VALIDATED critical

IMPROVE PHASE



Improve ACTION PLAN FOR VALIDATED ROOT CAUSES

Critical Root Cause	Action / Countermeasure	Responsible	Target Date	Expected Improvement
Wheel imbalance	introduce mandatory dynamic wheel balancing before mounting + poka yoke torque fixture	Maintenance + Production ME	15-Dec-2025	remove random spike roughness events
Spindle runout high	scheduled replacement of worn bearings + spindle alignment SOP every 15 days	Maintenance	20-Dec-2025	reduce mechanical chatter pattern
Feed rate too high	lock feed rate window on PLC (no manual override) + standard work sheet display	Production Engineer	18-Dec-2025	stabilise grinding material removal rate
Dressing interval too long	dressing interval Kanban card (dress every 15 rods) + visual counter	Grinding Operator	16-Dec-2025	wheel face remains uniform and sharp
Coolant nozzle misaligned	angle jig template + nozzle fixed bracket + 5S mark	Maintenance	17-Dec-2025	ensure constant cooling at cut zone
Chrome pits from vendor	vendor incoming pit inspection sheet + reject batch containment	SQA	22-Dec-2025	filter defective raw bars before grinding

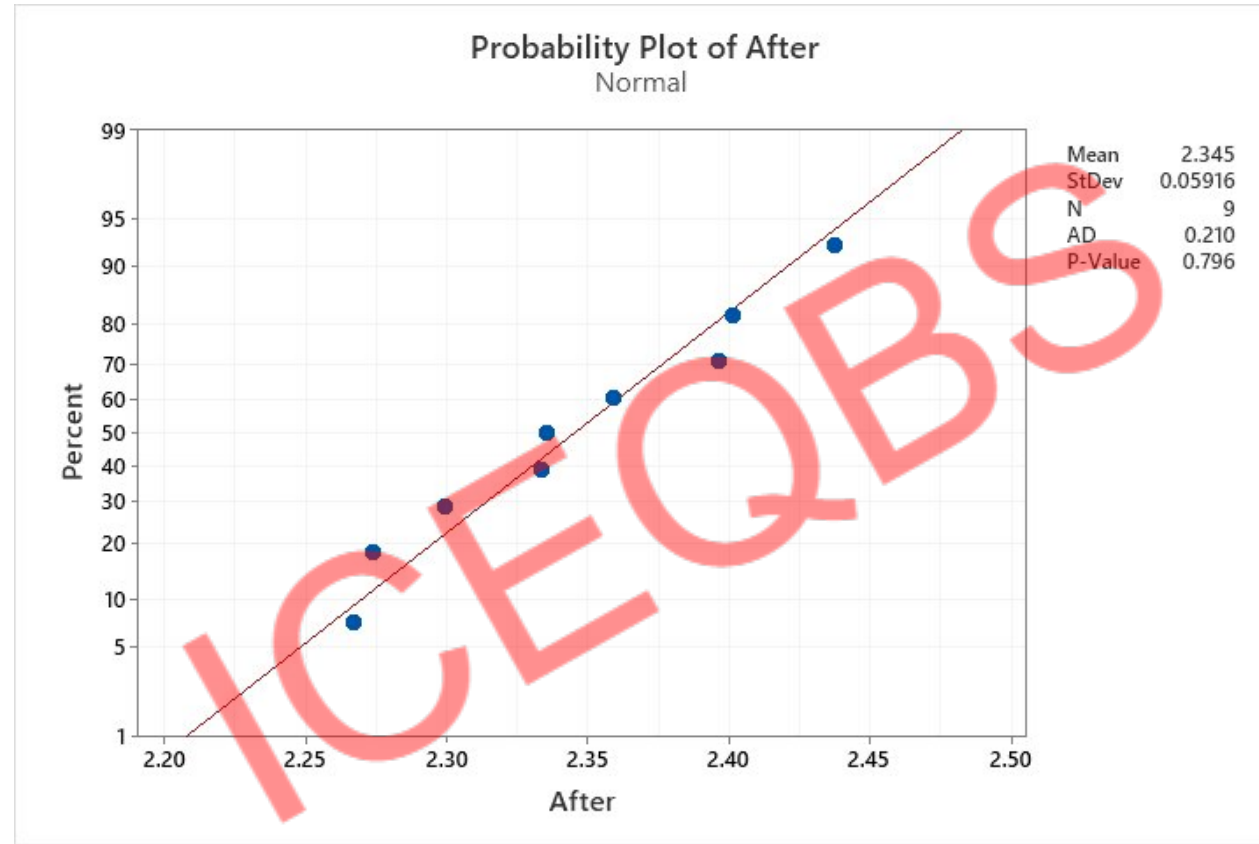
Improve



Inference:

- The run chart shows a stable and random pattern with no special-cause signals, confirming the process is consistent after improvement.

Improve



Inference:

- The probability plot shows the improved process data follows a normal distribution (P-value 0.796), indicating a stable and predictable surface roughness performance 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.

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
8.76	8	0.000

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Before	9	8.00	1.94	0.65
After	9	2.3448	0.0592	0.020

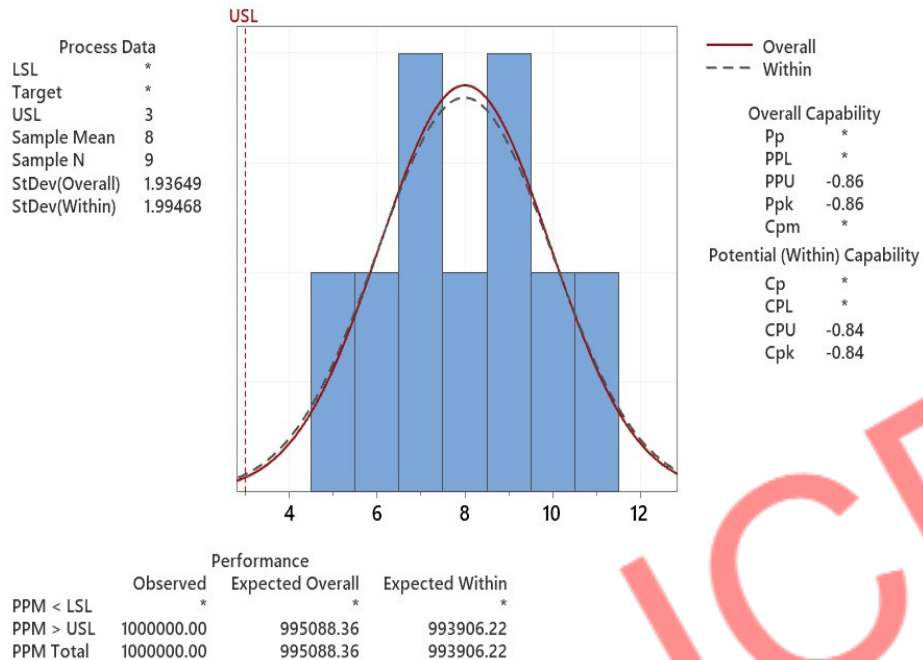
Estimation for Difference

Difference	95% CI for Difference
5.655	(4.166, 7.144)

The two-sample t-test shows a statistically significant reduction in roughness variation after improvement ($p < 0.001$), confirming that the project delivered a real and measurable improvement.

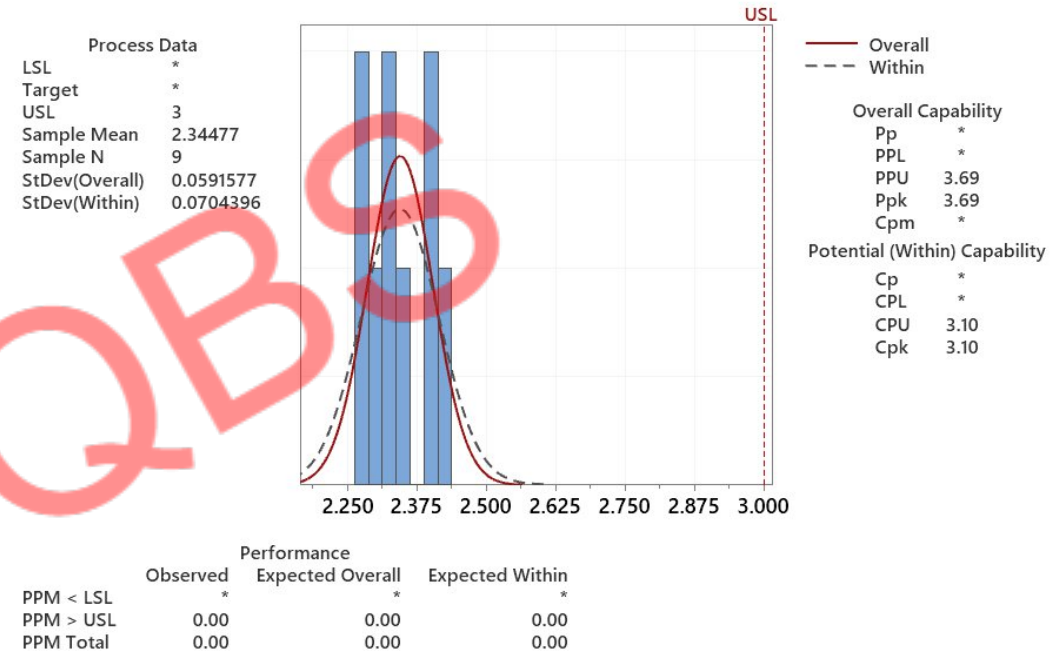
Improve – Process capability – Before & After Improvement

Process Capability Report for Before



The actual process spread is represented by 6 sigma.

Process Capability Report for After

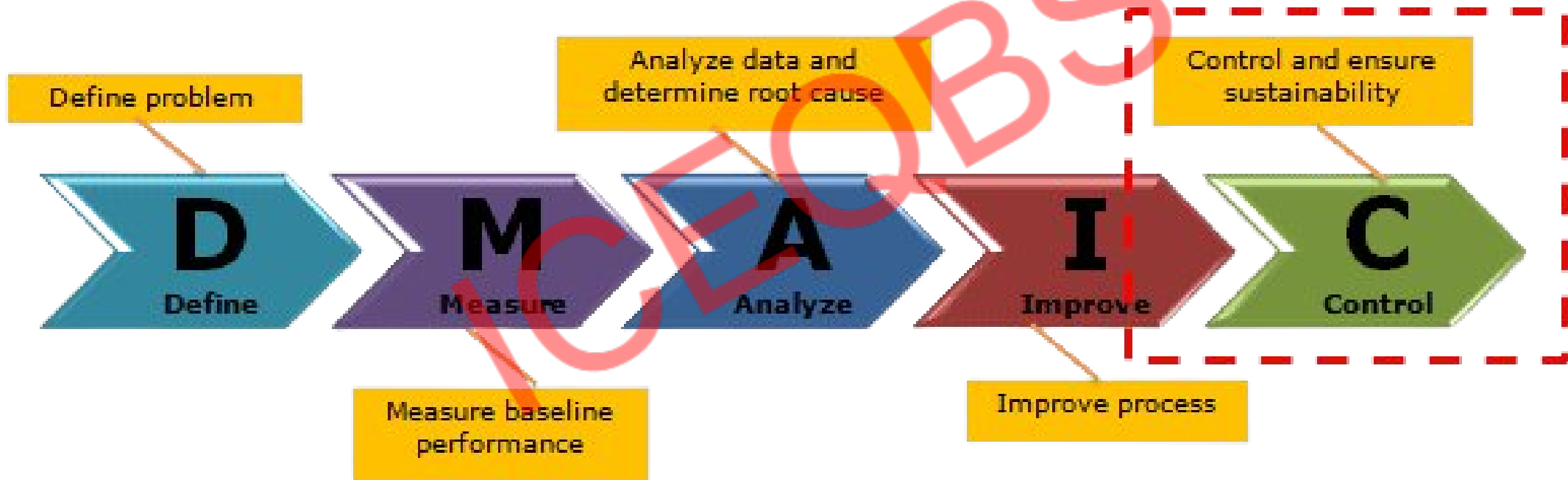


The actual process spread is represented by 6 sigma.

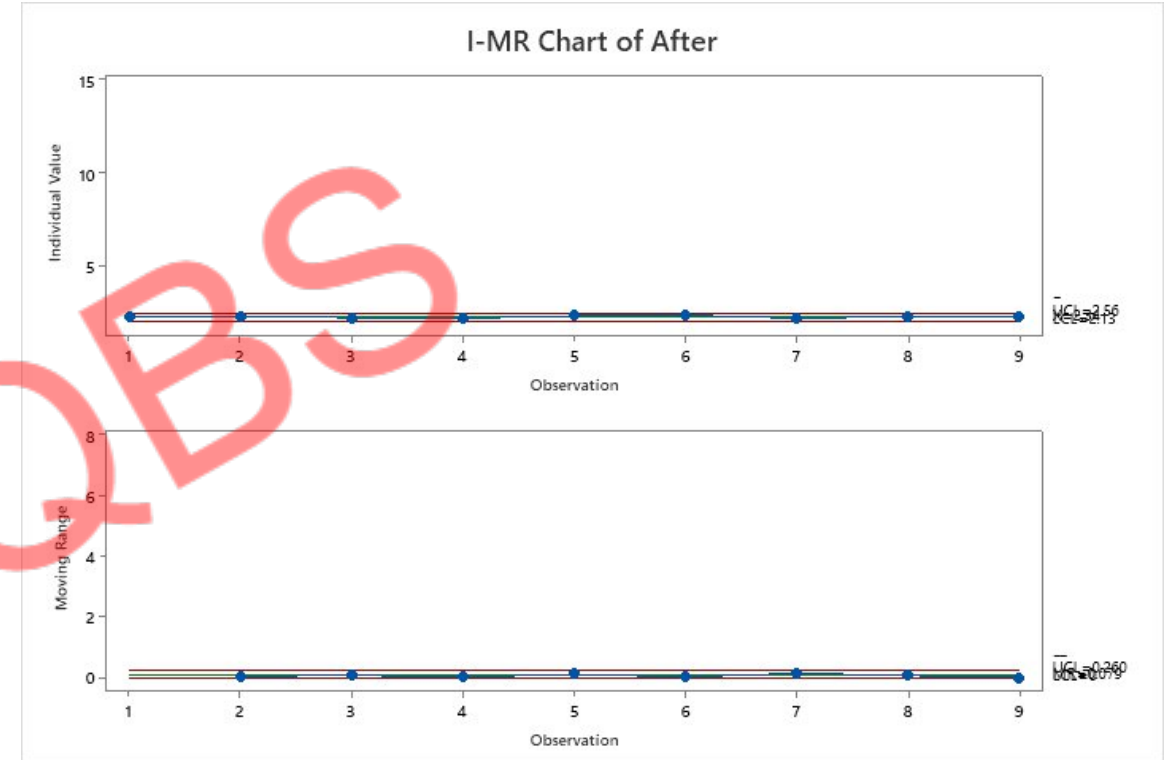
Inference :

- Process capability improved drastically—from a non-capable, highly variable process ($Cpk \approx -0.84$) before, to a highly capable and stable process after improvement ($Cpk \approx 3.0$).

CONTROL PHASE



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



Inference:

- The I-MR charts show the process was unstable with wide variation before improvement, but became fully stable and tightly controlled after improvement, with all points well within limits.

Control Plan – 5S

5S Element	Sustaining action idea for grinding area
Sort	red tag old wheels, damaged dressing diamonds, expired stylus tips — scrap out monthly
Set in Order	mark fixed parking for nozzle angle jig, balancing mandrel, dial indicator stand
Shine	coolant tank clean schedule weekly + transparent level gauge strip so low level seen at eye
Standardize	laminated “15 rods = DRESS” visual card posted on machine front
Sustain	create photo standard of correct tool layout — supervisor audits once per shift

Control Plan - POKA YOKE MECHANISMS

Cause Risk	Poka-Yoke Mechanism
wrong nozzle angle	use a keyed bracket with only ONE fit angle (cannot rotate)
wheel mounting torque variation	torque wrench with clutch that click locks at exact torque — cannot over/under
skipping dressing	counting clicker counter linked to cycle start push button — turns RED LED at 15 rods
wrong feed override	put locking pin cover on override knob — only supervisor has key
wrong measurement location	simple “V” block fixture that clamps rod in ONE location — stylus can only touch one band

FMEA

#	Process/Step	Potential Failure Mode	Effect on Y (Ra) / Customer	S	Potential Cause	O	Current Controls	D	RPN	Recommended Action	Owner	Target
1	Wheel mounting & balance	Wheel not dynamically balanced or torque wrong	Roughness spikes, regrind/reject	8	Skipped balancing; wrong torque	6	Balance sheet, visual torque note	6	288	Poka-yoke flange + color-coded studs; mandatory dynamic balance ticket; torque wrench with clutch	Maint + Prod ME	15-Dec
2	Spindle health check	Excess runout after bearing wear	Chatter bands, high Ra	9	Bearing wear; no weekly check	5	Monthly PM	6	270	Weekly TIR check SOP; max 10 µm limit; trigger spare set & swap plan	Maintenance	20-Dec
#	Process/Step	Potential Failure Mode	Effect on Y (Ra) / Customer	S	Potential Cause	O	Current Controls	D	RPN	Recommended Action	Owner	Target
3	Feed rate control	Override used outside window	Burn/tear → high Ra	8	Manual knob access	5	Posted nominal	6	240	Lock override by key; PLC limits 90–110%; alarm & interlock	Prod Eng	18-Dec
4	Dressing interval	Late/irregular dressing	Loaded wheel → rough finish	7	No counter; rush	6	Operator memory	5	210	Cycle counter + red light at 15 rods; check-sheet signoff	Operator + QA	16-Dec
5	Coolant nozzle setting	Angle shifted / low flow	Local burn marks	7	Loose bracket; no gauge	5	Visual check	6	210	Keyed bracket (single angle); angle template jig; weekly tighten	Maintenance	17-Dec
6	Incoming chrome rod	Pits/variable hardness	Surface defects post-grind	8	Vendor batch issue	4	COA only	6	192	IQC pit checklist + microhardness spot check; vendor NCR & lot hold	SQA	22-Dec
7	Measurement system	Stylus out of cal / location variation	Wrong decision; false pass/fail	7	Overdue cal; no fixture	4	Annual cal	6	168	Gage R&R; location fixture; 6-month cal; clean-trace SOP	QA	19-Dec
8	Operator workload	Running two grinders	Skipped dressing/adjustment	6	Staffing gap	5	Supervisor oversight	5	150	Line balance; one-machine-per-operator; relief plan	Production	18-Dec
9	Point-of-Use Quality	Ra check stationed far	Delay → rework pile	5	QC room distant	5	Batch testing	5	125	Move Ra tester to machine; 100% first off +	QA	18-Dec

Control plan to sustain improvements

Control Item (Critical X / Y)	Measurement Method / Tool	Frequency	Control Limits / Target	Reaction Plan if Out-of-Control	Responsibility
Rod Surface Roughness Ra value (Y)	I-MR Chart + Point-of-Use Ra measurement at grinder	Daily (30 rods/day sample)	Target Mean 2.0 μm (Spec: 0.8–3.2 μm)	Stop machine, isolate last 20 rods, re-measure, investigate dominant X	QA Engineer
Wheel balancing	Dynamic Wheel Balancer Ticket + torque click wrench	Every wheel change	g.mm < 50 (balanced)	Reject wheel / re-balance → do not start production run	Maintenance
Spindle Runout	Dial Indicator TIR Check on spindle nose	Weekly	TIR < 0.010 mm	Replace bearing / correct alignment before restart	Maintenance
Feed Rate	PLC Monitoring (override lock)	Daily	90–110% nominal feed zone	Supervisor unlock required + operator retraining	Production Eng
Dressing Interval	Visual Kanban counter (dress every 15 rods)	Every shift	Dress at 15 rods (max limit)	Immediate dress + root cause why counter was bypassed	Grinding Operator
Coolant Nozzle Angle	Angle jig + bracket check	Twice per week	$\pm 3^\circ$ tolerance	Re-align bracket and tighten clamp	Maintenance
Incoming Chrome Surface	Pit check sheet + visual standard	Every batch	ZERO pits	Reject batch, NCR vendor, block lot	SQA
Gage Health (Ra equipment)	Calibration label + fixture measurement point	Monthly + 6 months	MSA GRR $\leq 10\%$	Remove gage / re-calibrate / root cause	QA Metrology



Results after improvement

- Project has achieved its intended results after reducing the variation of Rod Surface