STAGE 1

1. DEFINE

Stage 1 comprises of 3 sub-processes - raw material collection, mixing of the clay, transfer by conveyor. Detailed description of this stage is given below:

Raw material collection: Black soil, yellow soil and sand is collected from selected suppliers. Black soil is for strength and yellow soil gives the colour to the product. Sand is mixed to give strength and for heating purposes. These are collected from the suppliers mostly during winter and summer seasons. During heavy summer, water is collected from the nearby company wells for mixing stage.

Mixing of the clay: The soil is let outside for decomposing for some time. Yellow soil is taken 60%, black soil around 40% and about 10-15% of sand is mixed thoroughly using Hitachi-Zeus 200.

Transfer by conveyor: The mixed clay is made into small lump sum amounts. Then it is transferred on to conveyor. Conveyor take it to the de-airing machine then to pug mill. The finely mixed clay is the final product of this stage.

SIPOC

The SIPOC diagram maps process flows, enumerating the supplier, inputs process, output and customers of the process that helps further investigation of the problem

Defects in the various processes of Stage 1 which are identified by the company are:

1. Huge stones

Huge stones are found in the mixed clay, which often got stuck in the roller and high-speed roller interrupting the smooth functioning.

2. Metal particles

Metal particles often go till moulding phase, since there is no separation technique for metal particles. This may hurt workers too.

3. Sticky clay

Excess water during mixing or environmental exposure leads to sticky clay which is unsuitable.

4. Roots

Non-decomposed roots appear on the mixed clay which is not ideal for making roof clay tiles.

5. Loss at conveyor

Conveyor is not a closed container so that due to improper placement of mixed clay leads to loss while transferring to de-airing machine.

2. MEASURE

In the measure phase of DMAIC methodology, the current level of the process performance (in terms of sigma level) based on the five defects identified in the define stage is established, followed by defect prioritization with the help of pareto chart.

The company collects data on the number of defective units observed through a continuous quality check process. Defectives are visually inspected. A unit is classified as defective if any defect is observed, and such units are removed from the manufacturing line. The company operates its manufacturing process in three shifts per day, typically for all seven days of the week. For this study, defect data was collected over a period of ten days, with data recorded for each of the three shifts per day.

The table below presents the number of defectives observed at the end of stage 1 for each shift. In this context, shift 1, shift 2, shift 3 represents 3 shifts of a day. Thereby there are 30 data in total. The frequency of defects that caused the parts to be classified as defective is recorded for each shift. The sample size of each shift is also noted. The table contains 5 defects types and frequency of each in the table.

i. Check sheet for pre-analysis

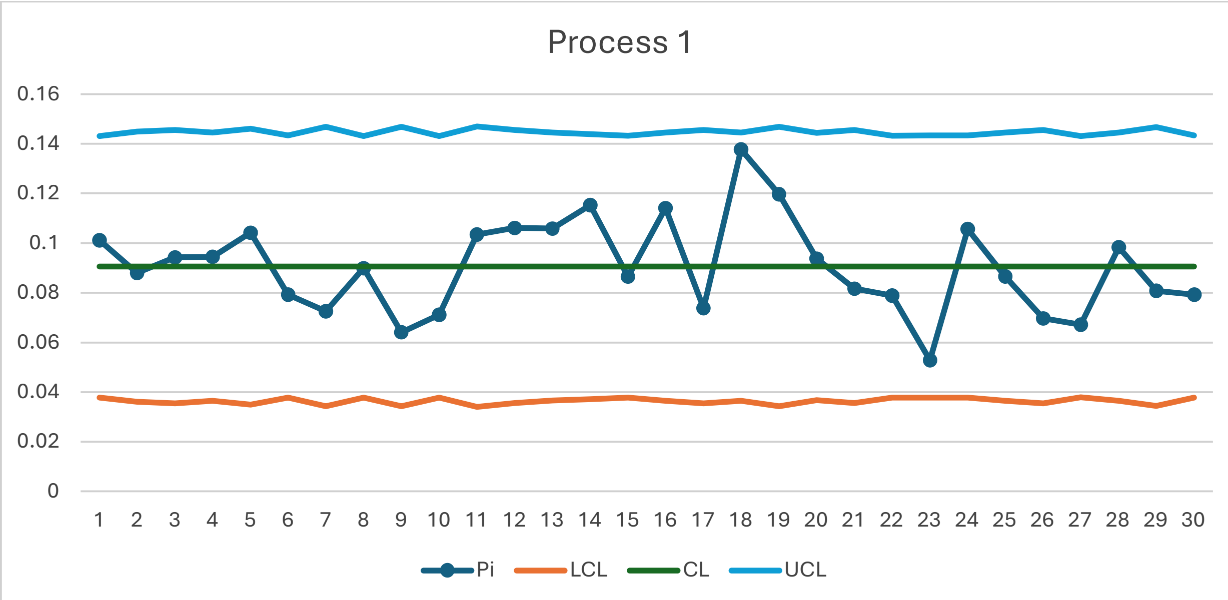
		Huge stones	Metal Particles	Excess Liquidity	Loss at Conveyor	Roots	Total defectives	Sample inspected
1	Shift 1	15	3	1	1	7	27	267
2	Shift 2	13	2	2	0	5	22	250
3	Shift 3	15	5	0	1	2	23	244
4	Shift 1	10	1	3	2	8	24	254
5	Shift 2	17	2	1	0	5	25	240
6	Shift 3	13	4	0	0	4	21	265
7	Shift 1	10	0	1	0	6	17	234
8	Shift 2	17	1	2	0	4	24	267
9	Shift 3	10	0	0	0	5	15	234
10	Shift 1	14	0	0	0	5	19	267
11	Shift 2	15	0	2	0	7	24	232
12	Shift 3	16	1	1	0	8	26	245
13	Shift 1	19	1	2	1	4	27	255
14	Shift 2	14	1	3	3	9	30	260
15	Shift 3	12	0	3	0	8	23	266
16	Shift 1	16	2	1	2	8	29	254
17	Shift 2	12	1	0	1	4	18	244
18	Shift 3	18	4	2	2	9	35	254
19	Shift 1	19	0	3	0	6	28	234
20	Shift 2	17	1	0	0	6	24	256
21	Shift 3	14	2	0	0	4	20	245
22	Shift 1	15	2	1	0	3	21	266
23	Shift 2	12	0	0	2	0	14	265
24	Shift 3	18	1	2	1	6	28	265
25	Shift 1	17	2	0	0	3	22	254
26	Shift 2	13	0	0	0	4	17	244
27	Shift 3	10	1	1	0	6	18	268
28	Shift 1	13	2	3	1	6	25	254
29	Shift 2	12	0	1	2	4	19	235
30	Shift 3	10	1	1	0	9	21	265
	COUNT	426	40	36	19	165	686	7583

ii. Statistical Quality Control using control chart (Here, p chart)

In this project, a P control chart is used, because the P control chart is used if the defect size is the proportion of defective products in each sample taken.

Sl NO.	Total defectives	Total Checked	Pi	LCL	CL	UCL
1	27	267	0.101123596	0.037865489	0.090552681	0.14324
2	22	250	0.088	0.036103584	0.090552681	0.145002
3	23	244	0.094262295	0.035438194	0.090552681	0.145667
4	24	254	0.094488189	0.036534019	0.090552681	0.144571
5	25	240	0.104166667	0.034980805	0.090552681	0.146125
6	21	265	0.079245283	0.037667043	0.090552681	0.143438
7	17	234	0.072649573	0.034272854	0.090552681	0.146833
8	24	267	0.08988764	0.037865489	0.090552681	0.14324
9	15	234	0.064102564	0.034272854	0.090552681	0.146833
10	19	267	0.071161049	0.037865489	0.090552681	0.14324
11	24	232	0.103448276	0.034030789	0.090552681	0.147075
12	26	245	0.106122449	0.035550788	0.090552681	0.145555
13	27	255	0.105882353	0.036640042	0.090552681	0.144465
14	30	260	0.115384615	0.037160949	0.090552681	0.143944
15	23	266	0.086466165	0.037766546	0.090552681	0.143339
16	29	254	0.114173228	0.036534019	0.090552681	0.144571
17	18	244	0.073770492	0.035438194	0.090552681	0.145667
18	35	254	0.137795276	0.036534019	0.090552681	0.144571
19	28	234	0.11965812	0.034272854	0.090552681	0.146833
20	24	256	0.09375	0.036745443	0.090552681	0.14436
21	20	245	0.081632653	0.035550788	0.090552681	0.145555
22	21	266	0.078947368	0.037766546	0.090552681	0.143339
23	14	265	0.052830189	0.037667043	0.090552681	0.143438
24	28	265	0.105660377	0.037667043	0.090552681	0.143438
25	22	254	0.086614173	0.036534019	0.090552681	0.144571
26	17	244	0.069672131	0.035438194	0.090552681	0.145667
27	18	268	0.067164179	0.037963878	0.090552681	0.143141
28	25	254	0.098425197	0.036534019	0.090552681	0.144571
29	19	235	0.080851064	0.034392726	0.090552681	0.146713
30	21	265	0.079245283	0.037667043	0.090552681	0.143438
			2.716580444			
		P-BAR	0.090552681			

iii. After the control limit calculations are obtained, the next step is to create a control chart graphic which functions to map the data limits. The purpose of making this control chart graph is to find out whether the data is within control limits or not.



The graph clearly depicts that the process is in control as all the points lie within the control limits.

Now, let us check how well the process's performance is depicted using Yield and sigma level.

iv. Yield is the percentage of non-defective items and thus it is given by the formula as:

Yield = (1-(total number of defectives/total number of items inspected)) *100

v. Sigma level can then be calculated as the two tailed z-value treating Yield as the area under the curve with a shift of +1.5 which is the industry standard. The formula used is given as:

Sigma Level = NORM.S.INV(0.5+(Yield/100/2)) + 1.5

Using these formulas, the results obtained are:

DPMO	18093.10299	0.018093103
SIGMA	3.59482889	

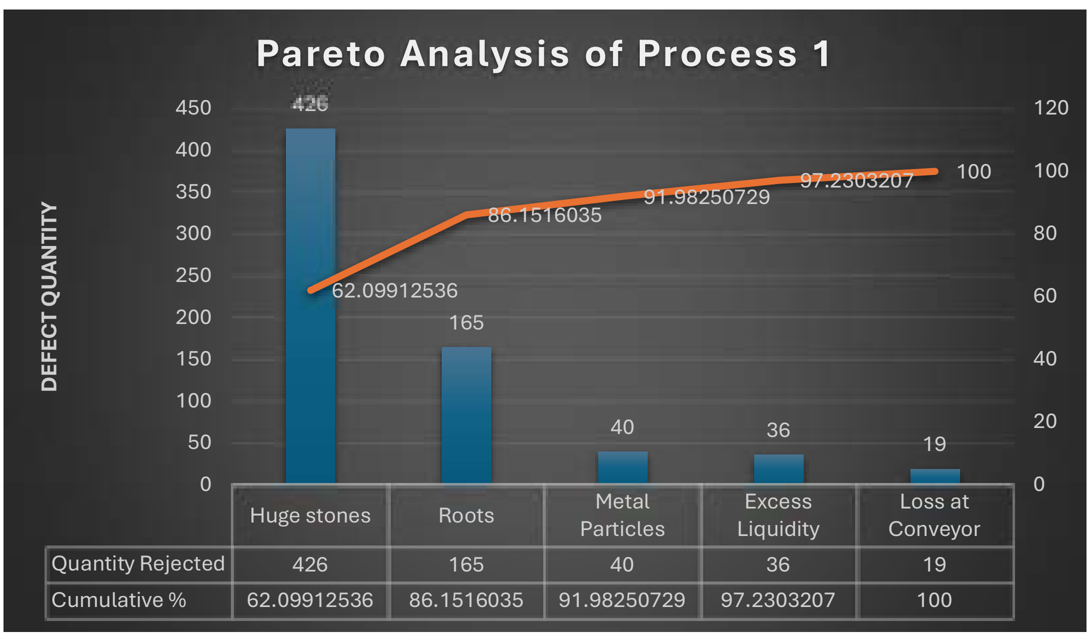
As we can see, the Sigma Level is just 3.59482889, which is quite low as compared to the other products manufactured by the company. Thus, there is scope of improvement so we will start the defect analysis here. So, we move onto the next stage of our methodology, i.e. Analyse.

3. ANALYSE

After going through the measurement stage, the next step is the stage of identification and analysis. Basically, this stage is the stage of identification and analysis regarding the main problems and in the end, we will find out how to anticipate the causes of the main defects.

i. Pareto Chart: Firstly, we will plot Pareto Chart to identify the defects which are the ―Vital Few. For that, let us calculate the cumulative percentage of defects.

SI.NO.	Defects	Quantity Rejected	Rejection %	Cumulative %
1	*Huge stones*	426	62.09912536	62.09912536
2	*Roots*	165	24.05247813	86.1516035
3	*Metal Particles*	40	5.83090379	91.98250729
4	*Excess Liquidity*	36	5.247813411	97.2303207
5	*Loss at Conveyor*	19	2.7696793	100
	Total Sum	686		

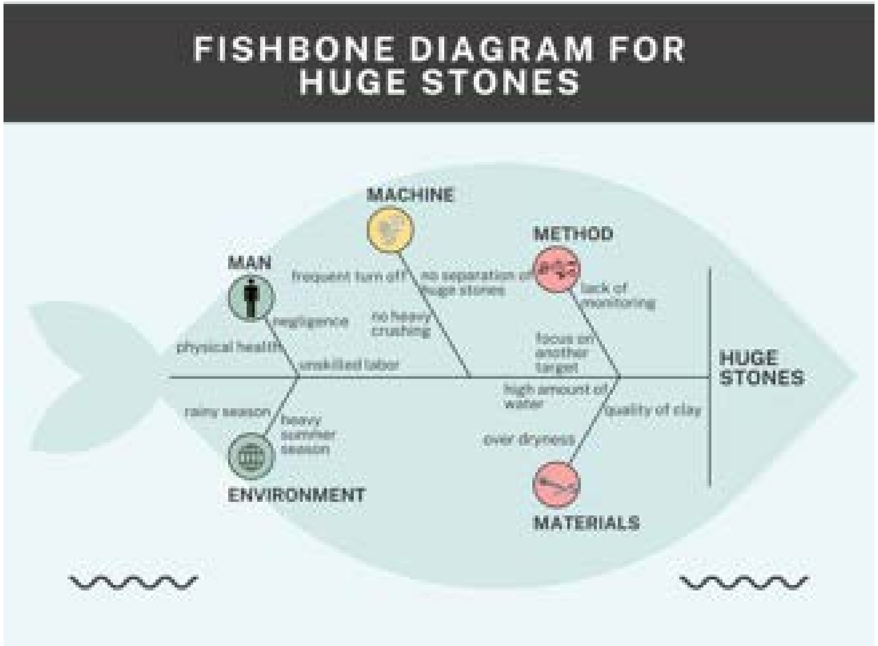


We can see from the pareto chart that elbow is forming at the defect 'Roots.' Therefore, we need to work upon two defects which are huge stones and roots.

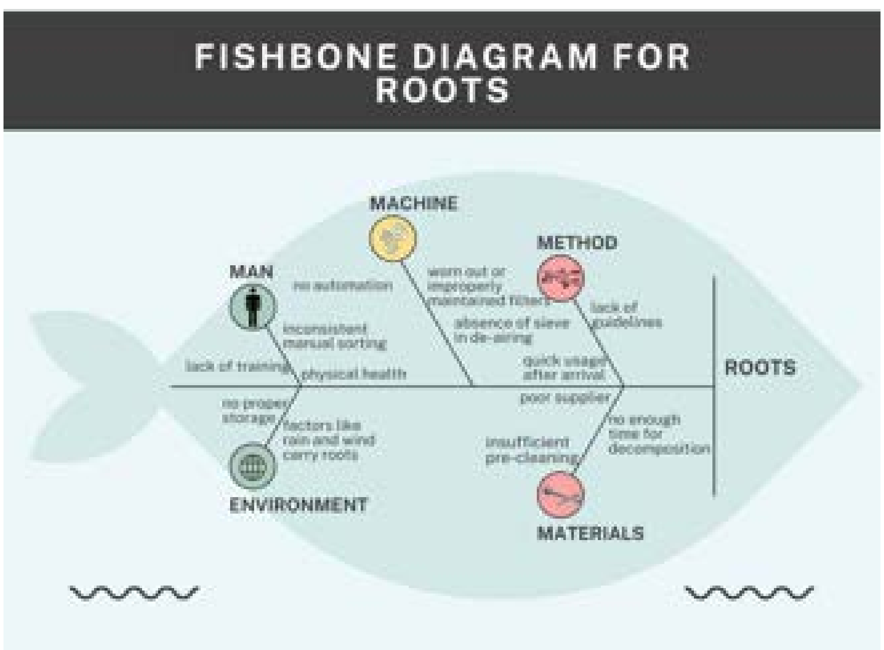
So, now we will work on these two defects to improve the sigma level.

ii. Cause & Effect analysis or Ishikawa Diagram or Fishbone diagram: Cause &Effect analysis was conducted and a Cause & Effect diagram categorizing the causes in 5 generic categories were prepared as shown:

Huge stones



Roots



Since there are a lot of possible reasons for both the defects, exact reason behind the occurrences is still unknown.

iii. 5- why analysis: to find the root cause of the top 2 defects.

DEFECT TYPE		HUGE STONES	ROOTS
WHY 1	QUESTION	Why Huge stones are the most dominant and cause defects?	Why roots are the most dominant and cause defects?
	ANSWER	Because there is no separation mechanism for huge stones before processing.	Because manual sorting is inconsistent and filters are worn out or absent.
WHY 2	QUESTION	Why is there no separation mechanism for huge stones?	Why is manual sorting inconsistent and filters worn out?
	ANSWER	Because the machine lacks heavy crushing capability and a sieve and is not maintained regularly.	Because the initial cleaning step is insufficient and no proper automation and improper machine maintenance.
WHY 3	QUESTION	Why are the machine lacks heavy crushing and sieve?	Why is there lack of cleaning and improper machine maintenance?
	ANSWER	Because of poor maintenance and SOPs for machine setup and operation are not followed for current material types.	Because of time constraints and the system depends heavily on manual processes.
WHY 4	QUESTION	Why is the machine poorly maintained and not suited?	Why is there time pressure and dependency on manual work?
	ANSWER	Because supervisors do not consistently monitor operations plus a focus on other production targets and not upgraded to the latest machineries.	Because of poor scheduling and quick usage without inspection, and no structured SOPs.
WHY 5	QUESTION	Why are supervisors not consistently monitoring operations?	Why is the production schedule poorly planned?
	ANSWER	Because they are focusing on other production targets like output quantity and efficiency.	Because of inaccurate forecasting and production focus is on output quantity over quality control.
	Corrective measure	**Better forecasting, and investment in machinery upgrades.**	

iv. Analytical Hierarchy Process (AHP): We will implement AHP to classify defects based on their pairwise comparisons, taking into consideration various criteria that influence the criticality of the defects.

The criteria that are to be considered here are:

	CRITERIA
1	Frequency of Occurrence (FREQ)
2	Severity of Impact (SEV)
3	Cost of Repair/Rework (COST)
4	Customer Impact (CUST)

And the list of defects (top 3) under consideration are:

Huge stones
Roots
Metal Particles

Now let us create pairwise comparison matrices and find weight vectors.

Pairwise comparison of criteria:

	FREQ	SEV	COST	CUST
FREQ	1.00	0.33	3.00	0.50
SEV	3.00	1.00	5.00	3.00
COST	0.33	0.20	1.00	0.33
CUST	2.00	0.30	3.00	1.00
	6.33	1.83	12.00	4.83

					Normalised weight	
0.157978	0.180327869	0.25	0.10352	0.691825	**0.172956**	
0.473934	0.546448087	0.416666667	0.621118	2.058166	**0.514542**	
0.052133	0.109289617	0.083333333	0.068323	0.313079	**0.07827**	
0.315956	0.163934426	0.25	0.207039	0.93693	**0.234232**	

Weight Sum Vector	**Consistency Vector**
0.69468	4.016506
2.127456	4.134663
0.31555	4.031578
0.969317	4.138269

lambda	4.080254
CI	0.026751
CR	0.029724

Pairwise comparisons for Alternatives - Defect types

FREQUENCY

	Huge stones	Roots	Metal Particles
Huge stones	1.00	7.00	9.00
Roots	0.14	1.00	3.00
Metal Particles	0.11	0.333333333	1
	1.25	8.33	13.00

				Normalised weight
0.797468354	0.84	0.69	2.33	0.78
0.113924051	0.12	0.23	0.46	0.15
0.088607595	0.04	0.08	0.21	0.07

Weight Sum Vector	Consistency Vector
2.477468	3.19018
0.47137	3.043105
0.206431	3.013139

lambda	3.082141
CI	0.041071
CR	0.070811

SEVERITY

	Huge stones	Roots	Metal Particles
Huge stones	1	0.333333333	3
Roots	3	1	5
Metal Particles	0.333333333	0.2	1
	4.333333333	1.533333333	9

				Normalised weight
0.230769231	0.217391304	0.333333	0.781494	0.260498
0.692307692	0.652173913	0.555556	1.900037	0.633346
0.076923077	0.130434783	0.111111	0.318469	0.106156

Weight Sum Vector	Consistency Vector
0.790082	3.032969
1.945621	3.071973
0.319658	3.011202

lambda	3.038715
CI	0.019357
CR	0.033375

COST

	Huge stones	Roots	Metal Particles
Huge stones	1	0.5	4
Roots	2	1	6
Metal Particles	0.25	0.166666667	1
	3.25	1.666666667	11

				Normalised weight
0.307692308	0.3	0.363636	0.971329	0.323776
0.615384615	0.6	0.545455	1.760839	0.586946
0.076923077	0.1	0.090909	0.267832	0.089277

Weight Sum Vector	Consistency Vector
0.974359	3.009359
1.770163	3.015886
0.268046	3.002393

lambda	3.009213
CI	0.004606
CR	0.007942

CUSTOMER

	Huge stones	Roots	Metal Particles
Huge stones	1	3	5
Roots	0.333333333	1	2
Metal Particles	0.2	0.5	1
	1.533333333	4.5	8

				Normalised weight
0.652173913	0.666666667	0.625	1.943841	0.647947
0.217391304	0.222222222	0.25	0.689614	0.229871
0.130434783	0.111111111	0.125	0.366546	0.122182

Weight Sum Vector	Consistency Vector
1.94847	3.007145
0.690217	3.002627
0.366707	3.001318

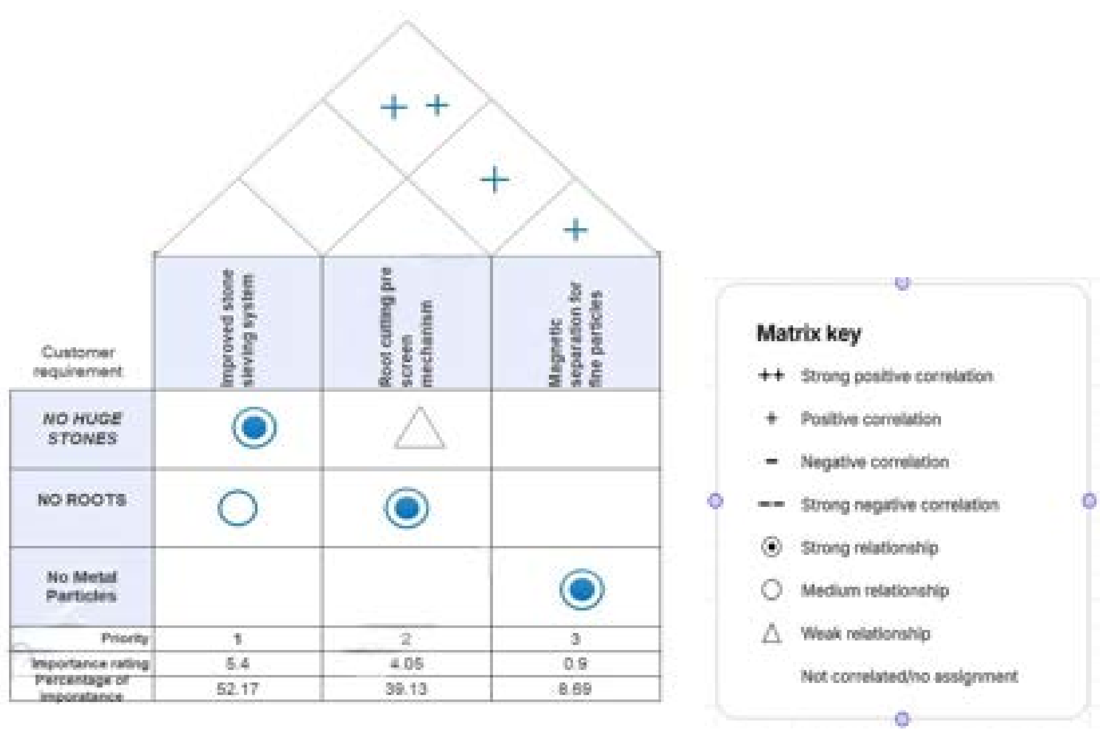
lambda	3.003697
CI	0.001848
CR	0.003187

Comparison matrix of defects vs criteria and finding the priority:

	FREQ	SEV	COST	CUST	PRIORITY
Huge stones	0.78	0.26	0.32	0.65	0.45
Roots	0.15	0.63	0.59	0.23	0.45
Metal Particles	0.07	0.11	0.09	0.12	0.10

Both huge stones and roots are having equal priorities hence, these two defects must be given extra care and should be given suggestions to improve.

v. QFD- Hoq: The "Voice of Customer" (VOC) symmetrically translated into measurable requirements by using the QFD technique. There are 2 variables involved in the QFD analysis- Customer requirements and Engineering characteristics.



After QFD analysis, it is understood that stone sieving system should be improved. Therefore, after all these analyses primary concern are given to huge stones, roots, and metal particles which after resolving is beneficial for both customer and company.

SUGGESTED ACTIONS

	Defect	Suggestive Action Plan
1	Huge stones	• Use a jaw crusher or roller crusher to crush huge stones. • Apply sieves at all valves to ensure small stones get removed • Ensure raw clay providers are instructed to avoid heavily stony deposits. • Train workers to manually remove huge stones while mixing the soil.
2	Roots	• Extract clay from below the organic layer in the soil. • Soak clay in water, allowing roots to float and be separated. • Install sieves to remove large roots. • Leave clay for some time so that roots get decomposed naturally.
3	Metal Particles	• Install magnets (over belt or inline) in clay conveyor or mixing lines to attract ferrous particles. • Use high-pressure water separation systems to remove metallic impurities.

4. CONTROL AND IMPROVE

The above suggestions were provided to the company and they further implemented these changes according to their company terms and standards. Sufficient time and resources were dedicated to this procedure aiming to improve the sigma level, i.e. the performance of the process. After this, new data was recorded to monitor the improvements (if any) that were achieved by following the mentioned procedure. This data was recorded in a span of 4 days, resulting into 12 shifts i.e. 12 timestamps. The number of defectives arising through each defect were counted for each lot being produced in a continuous process.

i. Defects Check Sheet Post Analysis:

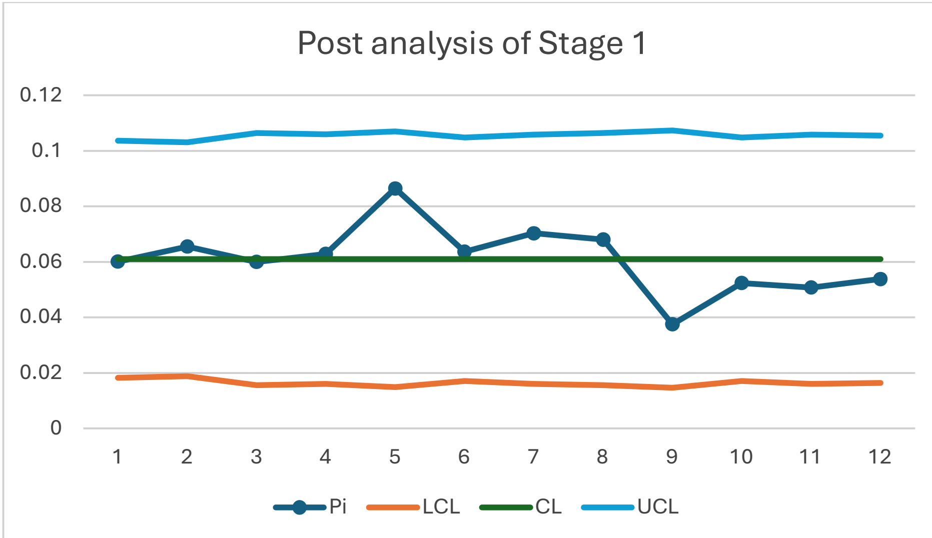
	Huge stones	Metal Particles	Excess Liquidity	Loss at Conveyor	Roots	Total defectives	Sample inspected
Shift 1	10	0	1	1	5	17	283
Shift 2	9	2	2	0	6	19	290
Shift 3	8	4	0	1	2	15	250
Shift 1	11	1	2	1	1	16	255
Shift 2	12	2	1	0	6	21	243
Shift 3	7	3	0	0	7	17	267
Shift 1	9	0	1	0	8	18	256
Shift 2	13	1	1	0	2	17	250
Shift 3	7	0	0	0	2	9	240
Shift 1	10	2	0	1	1	14	267
Shift 2	10	0	0	0	3	13	256
Shift 3	9	0	1	0	4	14	260
COUNT	115	15	9	4	47	190	3117

Here, we can see that the frequencies of the defects “Huge stones”, “Roots” and “metal particles” has reduced significantly.

ii. Construction of p Chart:

SI NO.	Total defectives	Total Checked	Pi	LCL	CL	UCL
1	17	283	0.060070671	0.018280484	0.060941461	0.103602
2	19	290	0.065517241	0.018798503	0.060941461	0.103084
3	15	250	0.06	0.015552106	0.060941461	0.106331
4	16	255	0.062745098	0.015999303	0.060941461	0.105884
5	21	243	0.086419753	0.014902991	0.060941461	0.10698
6	17	267	0.063670412	0.017020849	0.060941461	0.104862
7	18	256	0.0703125	0.016087166	0.060941461	0.105796
8	17	250	0.068	0.015552106	0.060941461	0.106331
9	9	240	0.0375	0.014616144	0.060941461	0.107267
10	14	267	0.052434457	0.017020849	0.060941461	0.104862
11	13	256	0.05078125	0.016087166	0.060941461	0.105796
12	14	260	0.053846154	0.016433537	0.060941461	0.105449
			0.731297537			
		P-BAR	0.060941461			

iii. p-chart:



As we can clearly see, no points lie outside the calculated control limits, thus the process is in statistical control. We can now measure the performance of the process after improving on the defect identified.

DPMO	**12191.2095**	**0.012191209**
SIGMA	3.751049238	

Thus, we can observe that the sigma level has increased from 3.5 to 3.8, which is significant improvement considering the shorter time-period. Standardizing the process and then observing through a longer period, the results might increase even further.

STAGE 2

1. DEFINE

This stage has 3 main important sub-processes- high speed roller, pug mill and de-airing machine, revolving process. After the end of this stage, moulded clay floor tile will be produced. The subprocesses are explained in detail:

High speed roller: The mixed clay is made to pass through a roller, then a high-speed roller where clay is mixed thoroughly and some of the stones gets crush here. There is a control attached to this roller so that when a stone gets stuck, it helps to turn off the roller.

Pug-mill & De-airing machine: Then clay is transferred in to de-airing machine where vaccum is created and most of the water gets dried out. The pressure valve controls the pressure inside de-airing machine. Then it gets inside pug-mill where the clay is made into a set of 5 sheets of clay. Then it is passed by conveyor to the revolving machine.

Revolving press: Revolving press is also known as moulding press. The sheets of clay is transferred into the revolving press manually. The moulded clay is received from the other side and then transferred into the conveyer for air-drying.

SIPOC

The SIPOC diagram maps process flows, enumerating the supplier, inputs process, output and customers of the process that helps further investigation of the problem

Defects in the various processes of Stage 2 which are identified by the company are:

1. Sticky Clay

When the application of pressure is not enough causes sticky clay. And sometimes inside the pugmill, the clay is not properly cut into 5 sheets.

2. Dent

Caused by dimensional in accuracy of wooden tray or mould.

3. Bending

Over-liquidity or lack of care of labours results in bending.

4. Dimensioanl Inaccuracy

When oiling (greasing) is not uniform and when mould is not fitted properly.

5. Chipping & Edge Damage

Chop corners are mainly due to lack of greasing and by mishandling.

6. Mishandling

Lack of care or fatigue nature of workers often results in breakage of products.

7. Surface Crack

Lack of moisture results in surface crack or also the environmental dryness.

2. MEASURE

In the measure phase of DMAIC methodology, the current level of the process performance (in terms of sigma level) based on the seven defects identified in the define stage is established, followed by defect prioritization with the help of pareto chart.

The company collects data on the number of defective units observed through a continuous quality check process. Defectives are visually inspected. A unit is classified as defective if any defect is observed, and such units are removed from the manufacturing line. The company operates its manufacturing process in three shifts per day, typically for all seven days of the week. For this study, defect data was collected over a period of ten days, with data recorded for each of the three shifts per day.

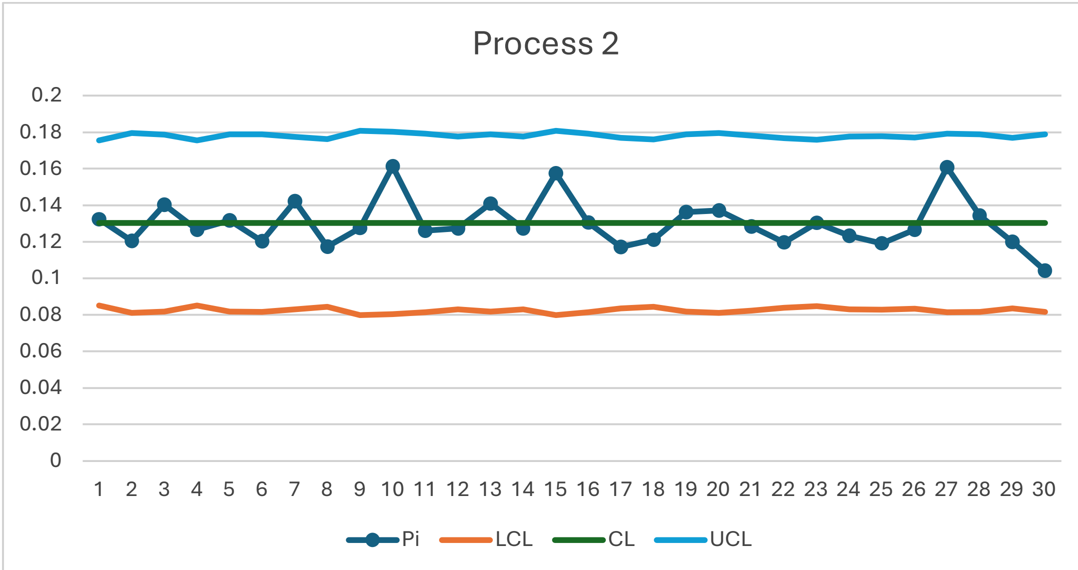
i. Check sheet for pre-analysis

		Sticky Clay	Chipping & Edge Damage	Bending	Dent	Mishandling	Surface crack	Dimensional Inaccuracy	Total defectives	Sample inspected
1	Shift 1	30	1	22	4	0	0	9	66	499
2	Shift 2	22	0	25	3	0	0	1	51	423
3	Shift 3	38	3	12	4	1	0	3	61	435
4	Shift 1	27	2	25	8	1	0	0	63	498
5	Shift 2	26	0	26	5	0	0	0	57	433
6	Shift 3	23	0	22	4	0	1	2	52	432
7	Shift 1	29	1	24	7	2	1	1	65	457
8	Shift 2	22	2	23	5	0	2	3	57	486
9	Shift 3	20	1	21	6	0	1	2	51	400
10	Shift 1	29	1	24	6	0	3	3	66	409
11	Shift 2	21	0	22	3	0	2	6	54	428
12	Shift 3	22	2	24	5	1	1	3	58	456
13	Shift 1	28	0	21	9	1	1	1	61	433
14	Shift 2	28	0	23	2	2	1	2	58	456
15	Shift 3	25	3	25	1	2	2	5	63	400
16	Shift 1	20	2	23	5	2	2	2	56	429
17	Shift 2	21	1	22	3	1	1	6	55	469
18	Shift 3	21	1	21	4	3	1	8	59	487
19	Shift 1	27	0	20	3	0	1	8	59	433
20	Shift 2	27	0	20	6	0	2	3	58	423
21	Shift 3	26	1	19	3	0	1	7	57	444
22	Shift 1	25	2	21	5	0	3	1	57	476
23	Shift 2	22	0	25	5	0	3	9	64	491
24	Shift 3	27	0	22	3	0	1	3	56	454
25	Shift 1	25	0	23	4	1	0	1	54	453
26	Shift 2	28	1	21	7	2	0	0	59	466
27	Shift 3	27	2	25	3	1	0	11	69	429
28	Shift 1	21	5	22	4	0	0	6	58	432
29	Shift 2	31	1	20	3	0	0	1	56	467
30	Shift 3	29	1	11	2	0	0	2	45	432
	COUNT	767	33	654	132	20	30	109	1745	13430

ii. In this project, a P control chart is used, because the P control chart is used if the defect size is the proportion of defective products in each sample taken.

SI NO.	Total defectives	Total Checked	Pi	LCL	CL	UCL
1	66	499	0.132264529	0.085063428	0.130268	0.175472625
2	51	423	0.120567376	0.081170151	0.130268	0.179365903
3	61	435	0.140229885	0.081852099	0.130268	0.178683955
4	63	498	0.126506024	0.085018065	0.130268	0.175517989
5	57	433	0.131639723	0.081740412	0.130268	0.178795641
6	52	432	0.12037037	0.081684279	0.130268	0.178851775
7	65	457	0.142231947	0.083031844	0.130268	0.177504209
8	57	486	0.117283951	0.08446283	0.130268	0.176073224
9	51	400	0.1275	0.079778315	0.130268	0.180757739
10	66	409	0.161369193	0.080336915	0.130268	0.180199139
11	54	428	0.126168224	0.08145778	0.130268	0.179078274
12	58	456	0.127192982	0.082980079	0.130268	0.177555975
13	61	433	0.140877598	0.081740412	0.130268	0.178795641
14	58	456	0.127192982	0.082980079	0.130268	0.177555975
15	63	400	0.1575	0.079778315	0.130268	0.180757739
16	56	429	0.130536131	0.081514701	0.130268	0.179021352
17	55	469	0.117270789	0.083640061	0.130268	0.176895993
18	59	487	0.121149897	0.084509882	0.130268	0.176026172
19	59	433	0.136258661	0.081740412	0.130268	0.178795641
20	58	423	0.137115839	0.081170151	0.130268	0.179365903
21	57	444	0.128378378	0.082345313	0.130268	0.178190741
22	57	476	0.119747899	0.083984184	0.130268	0.17655187
23	64	491	0.130346232	0.084696651	0.130268	0.175839403
24	56	454	0.123348018	0.082876035	0.130268	0.177660019
25	54	453	0.119205298	0.082823755	0.130268	0.177712299
26	59	466	0.126609442	0.083490212	0.130268	0.177045842
27	69	429	0.160839161	0.081514701	0.130268	0.179021352
28	58	432	0.134259259	0.081684279	0.130268	0.178851775
29	56	467	0.119914347	0.083540322	0.130268	0.176995732
30	45	432	0.104166667	0.081684279	0.130268	0.178851775
			3.908040804			
		P-BAR	0.130268027			

iii. After the control limit calculations are obtained, the next step is to create a control chart graphic which functions to map the data limits. The purpose of making this control chart graph is to find out whether the data is within control limits or not.



The graph clearly depicts that the process is in control as all the points lie within the control limits.

Now, let us check how well the process's performance is depicted using Yield and sigma level.

iv. Yield is the percentage of non-defective items and thus it is given by the formula as:

Yield = (1-(total number of defectives/total number of items inspected)) *100

v. Sigma level can then be calculated as the two tailed z-value treating Yield as the area under the curve with a shift of +1.5 which is the industry standard. The formula used is given as:

Sigma Level = NORM.S.INV(0.5+(Yield/100/2)) + 1.5

Using these formulas, the results obtained are:

DPMO	18561.85512	0.018561855
SIGMA	3.584400964	

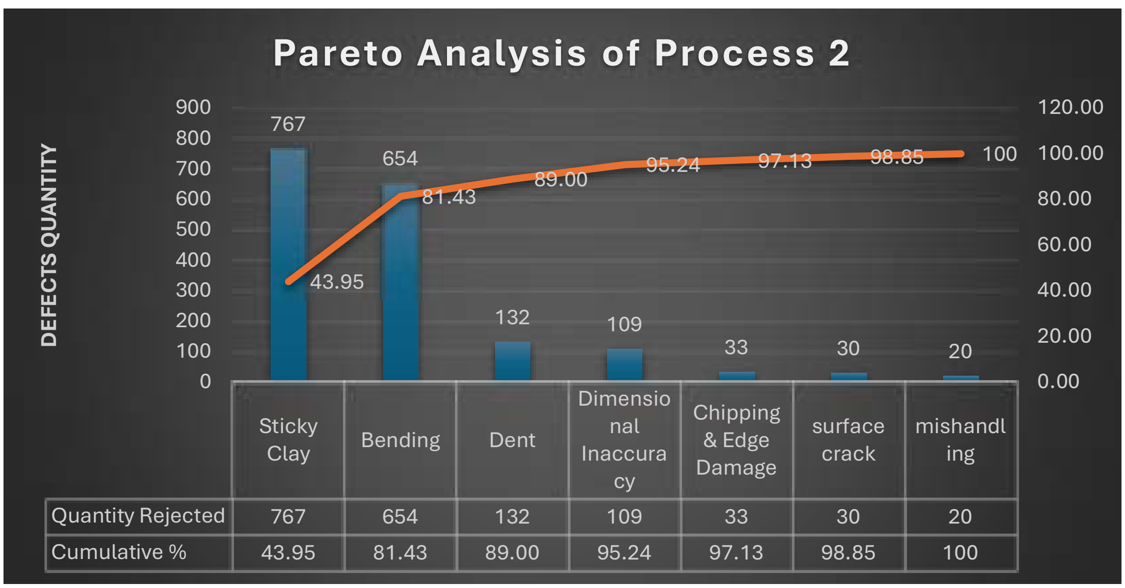
As we can see, the Sigma Level is just 3.584400964, which is quite low as compared to the other products manufactured by the company. Thus, there is scope of improvement so we will start the defect analysis here. So, we move onto the next stage of our methodology, i.e. Analyse.

3. ANALYSE

After going through the measurement stage, the next step is the stage of identification and analysis. Basically, this stage is the stage of identification and analysis regarding the main problems and in the end, we will find out how to anticipate the causes of the main defects.

i. Pareto Chart: Firstly, we will plot Pareto Chart to identify the defects which are the ―Vital Few. For that, let us calculate the cumulative percentage of defects.

SI NO.	Defects	Quantity Rejected	Rejection %	Cumulative %
1	*Sticky Clay*	767	43.95	43.95
2	*Bending*	654	37.48	81.43
3	*Dent*	132	7.56	89.00
4	*Dimensional Inaccuracy*	109	6.25	95.24
5	*Chipping & Edge Damage*	33	1.89	97.13
6	*surface crack*	30	1.72	98.85
7	*mishandling*	20	1.15	100
	Total Sum	1745		

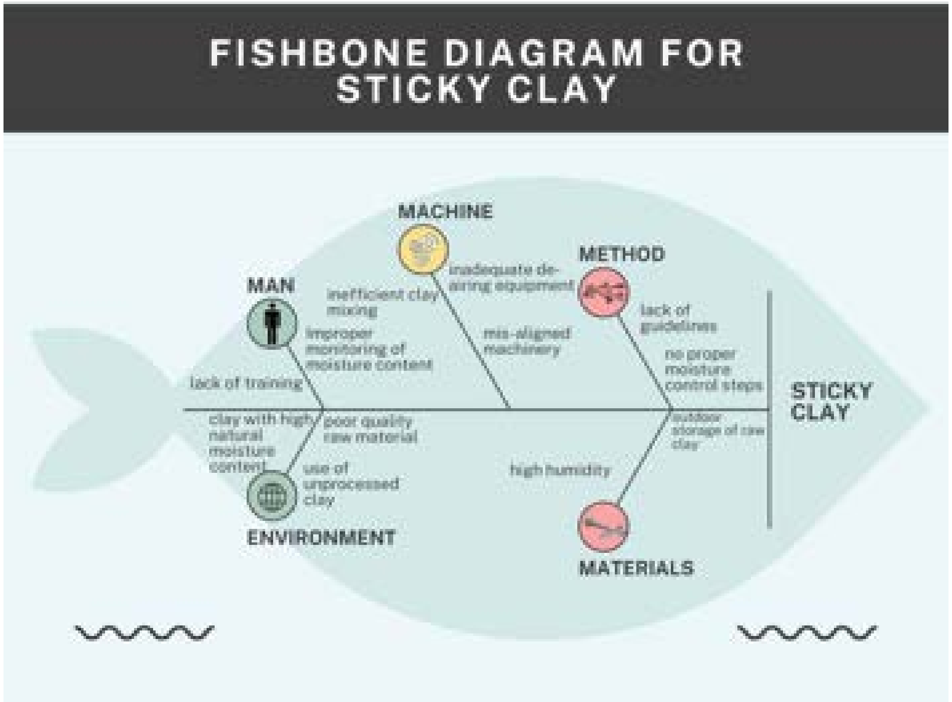


We can see from the pareto chart that elbow is forming at the defect 'Bending.' Therefore, we need to work upon two defects which are sticky clay and bending.

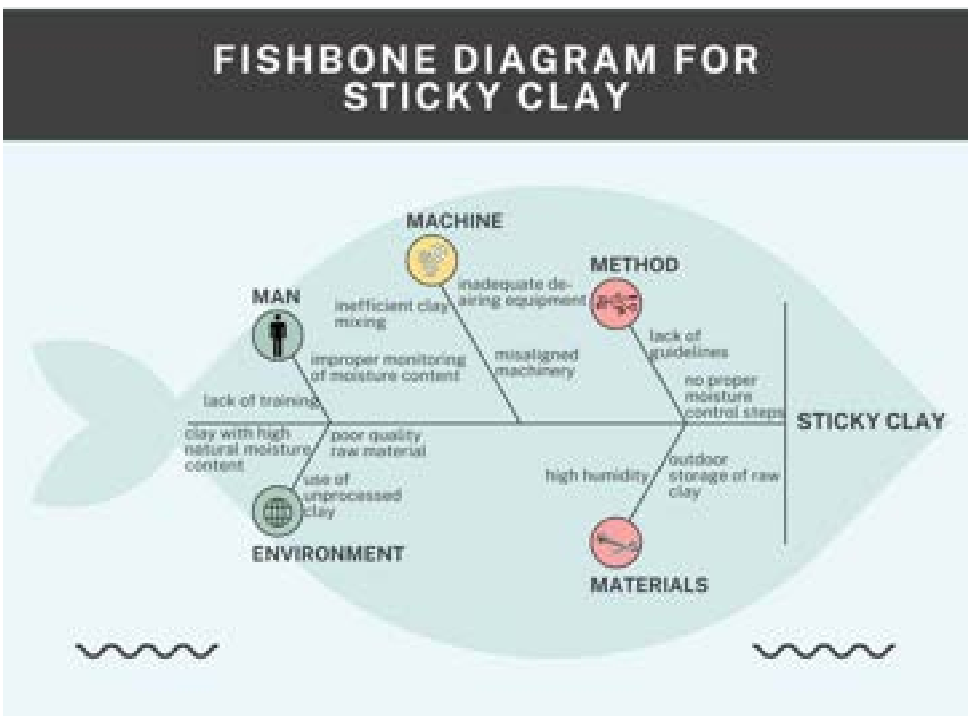
So, now we will work on these two defects to improve the sigma level.

ii. Cause & Effect analysis or Ishikawa Diagram or Fishbone diagram: Cause &Effect analysis was conducted and a Cause & Effect diagram categorizing the causes in 5 generic categories were prepared as shown:

Sticky clay



Bending



Since there are a lot of possible reasons for both the defects, exact reason behind the occurrences is still unknown.

iii. 5- why analysis: to find the root cause of the top 2 defects.

DEFECT TYPE		STICKY CLAY	BENDING
WHY 1	QUESTION	Why is the clay sticky?	Why does the product bend?
	ANSWER	Because it contains high natural moisture and lack of proper de-airing process in pug mill.	Because of uneven pressure in moulding and inconsistent moisture content in clay.
WHY 2	QUESTION	Why clay contains high natural moisture and lack of proper de-airing?	Why is the pressure uneven and moisture inconsistent?
	ANSWER	Because it is stored outdoors and lack of pug mill maintenance.	Because of worn-out or misaligned moulds, improper stacking, and use of unprocessed clay.
WHY 3	QUESTION	Why clay is stored outdoors and lack of pug mill maintenance?	Why are moulds worn out and clay unprocessed?
	ANSWER	Because of lack of enough space, method lacks moisture control guidelines, and lack of monitoring.	Because of lack of lubricant, maintenance, and negligence in pre-processing clay.
WHY 4	QUESTION	Why are there no monitoring of moisture and machine?	Why is there no maintenance or clay preprocessing?
	ANSWER	Because open storage for raw materials and no periodic service of pug mill.	Because negligence of workers.
WHY 5	QUESTION	Why is open storage for raw material and no periodic service of pug mill?	Why are workers negligent?
	ANSWER	Because the organization has not implemented structured SOPs for raw clay handling and pug mill maintenance.	Because of high speed of Revolver and lack of training for checking preprocess quality of clay.
	Corrective measure	Implement a standard SOP so that raw material is handled proper and training to workers on revolving press mechanism.	

iv. Analytical Hierarchy Process (AHP): We will implement AHP to classify defects based on their pairwise comparisons, taking into consideration various criteria that influence the criticality of the defects.

The criteria that are to be considered here are:

	CRITERIA	
1	Frequency of Occurrence (FREQ)	
2	Severity of Impact (SEV)	
3	Cost of Repair/Rework (COST)	

Pairwise comparison of criteria

	FREQ	SEV	COST
FREQ	1.00	0.13	0.33
SEV	8.00	1.00	3.00
COST	3.00	0.33	1.00
	12.00	1.46	4.33

				Normalised weight	
0.08	0.09	0.08	0.25	0.08	
0.67	0.69	0.69	2.04	0.68	
0.25	0.23	0.23	0.71	0.24	

Weight Sum Vector	Consistency Vector
0.25	3.00
2.05	3.00
0.71	3.00

lambda	3.002
CI	0.001
CR	0.002

Pairwise comparisons for Alternatives - Defect types

FREQUENCY

	Sticky Clay	Bending	Dent
Sticky Clay	1.00	3.00	9.00
Bending	0.33	1.00	6.00
Dent	0.11	0.17	1.00
	1.44	4.17	16.00

				Normalised weight
0.69	0.72	0.56	1.98	0.66
0.23	0.24	0.38	0.84	0.28
0.08	0.04	0.06	0.18	0.06

Weight Sum Vector	Consistency Vector
2.04	3.10
0.86	3.05
0.18	3.01

lambda	3.05
CI	0.03
CR	0.05

SEVERITY

	Sticky Clay	Bending	Dent
Sticky Clay	1.00	0.50	0.13
Bending	2.00	1.00	0.20
Dent	8.00	5.00	1.00
	11.00	6.50	1.33

				Normalised weight
0.09	0.08	0.10	0.27	0.09
0.18	0.15	0.15	0.49	0.16
0.73	0.77	0.75	2.25	0.75

Weight Sum Vector	Consistency Vector
0.27	3.02
0.49	3.02
2.27	3.03

lambda	3.02
CI	0.01
CR	0.02

COST

	Sticky Clay	Bending	Dent
Sticky Clay	1.00	1.00	6.00
Bending	1.00	1.00	3.00
Dent	0.17	0.33	1.00
	2.17	2.33	10.00

				Normalised weight	
0.46	0.43	0.60	1.49	0.50	
0.46	0.43	0.30	1.19	0.40	
0.08	0.14	0.10	0.32	0.11	

Weight Sum Vector	Consistency Vector
1.53	3.09
1.21	3.06
0.32	3.02

lambda	3.05
CI	0.03
CR	0.05

Comparison matrix of defects vs criteria and finding the priority:

	FREQ	SEV	COST	PRIORITY
Sticky Clay	0.66	0.09	0.50	0.23
Bending	0.28	0.16	0.40	0.23
Dent	0.06	0.75	0.11	0.54

Based on the comparison matrix, the **Dent** defect has the highest priority (0.54) compared to Sticky Clay (0.23) and Bending (0.23). This suggests that addressing the "Dent" defect should be the primary focus for improvement efforts.

v. QFD- Hoq: The “Voice of Customer” (VOC) symmetrically translated into measurable requirements by using the QFD technique. There are 2 variables involved in the QFD analysis- Customer requirements and Engineering characteristics.

After QFD analysis, primary focus should be on implementing a "Rubberized Mold" as a key technical solution. This is the highest priority from the customer's perspective and likely addresses the most critical defect ("Dent") identified by your internal analysis.

SUGGESTED ACTIONS

	Defect	Suggestive Action Plan
1	Dents	• Apply an even coat of release agent. E.g., oil or kerosene • Regularly maintain moulds; replace damaged ones to new ones. • Train operators to carefully remove tiles. • Ensure moulds have proper draft angles and smooth contours. • Regularly ensure proper dimensions of the wooden tray.

2	Sticky Clay	• Ensure thorough mixing of soil • Store mixed clay away from water (rain). • Introduce a controlled amount of coarse material to reduce stickiness and improve handling. • Maintain a stable ambient temperature in the pressing room. • When clay is found to have high moisture content, increase pressure in the pug mill.
3	Bending	• Train workers to carefully receive raw clay after moulding. • Train workers for properly placing clay in the pressing machine. • Ensure press settings to apply even pressure. • Place moulded clay on flat, non-stick trays to rest before drying.

4. CONTROL AND IMPROVE

The above suggestions were provided to the company and they further implemented these changes according to their company terms and standards. Sufficient time and resources were dedicated to this procedure aiming to improve the sigma level, i.e. the performance of the process. After this, new data was recorded to monitor the improvements (if any) that were achieved by following the mentioned procedure. This data was recorded in a span of 4 days, resulting into 12 shifts i.e. 12 timestamps. The number of defectives arising through each defect were counted for each lot being produced in a continuous process.

i. Defects Check Sheet Post Analysis:

		Sticky Clay	*Chipping & Edge Damage*	*Bending*	*Dent*	*mishandling*	*surface crack*	*Dimensional Inaccuracy*	*Total defectives*	*Sample inspected*
1	Shift 1	25	1	15	2	0	1	5	49	500
2	Shift 2	20	0	18	4	2	1	2	47	480
3	Shift 3	22	0	11	0	1	0	4	38	444
4	Shift 1	24	1	20	2	0	0	8	55	480
5	Shift 2	12	0	22	3	1	0	7	45	433
6	Shift 3	13	0	20	1	1	1	1	37	432
7	Shift 1	17	1	12	2	0	0	1	33	457
8	Shift 2	20	3	23	2	0	0	6	54	486
9	Shift 3	22	1	11	4	3	1	8	36	400

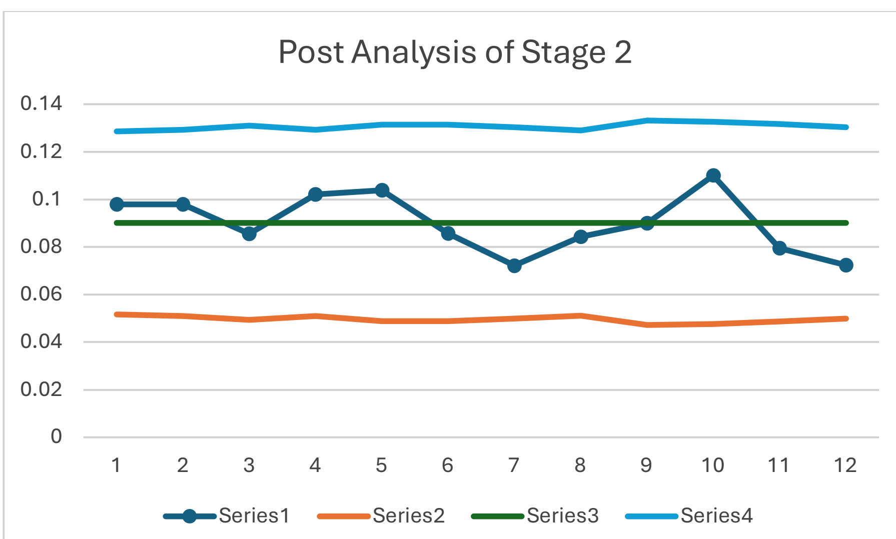
10	Shift 1	23	1	19	1	1	2	2	45	409
11	Shift 2	15	0	11	0	1	2	5	34	428
12	Shift 3	11	0	12	3	0	0	7	33	456
	COUNT	224	8	194	24	10	8	56	506	5405

Here, we can see that the frequencies of the defects “Sticky clay,” “Dents” and “Bending” has reduced significantly.

ii. Construction of p Chart:

SI NO.	Total defectives	Total Checked	Pi	LCL	CL	UCL
1	49	500	0.098	0.051709993	0.09013	0.128550701
2	47	480	0.097916667	0.050917737	0.09013	0.129342956
3	38	444	0.085585586	0.049359016	0.09013	0.130901677
4	49	480	0.102083333	0.050917737	0.09013	0.129342956
5	45	433	0.103926097	0.048844384	0.09013	0.131416309
6	37	432	0.085648148	0.048796627	0.09013	0.131464067
7	33	457	0.072210066	0.049943099	0.09013	0.130317594
8	41	486	0.08436214	0.051160542	0.09013	0.129100151
9	36	400	0.09	0.047175085	0.09013	0.133085608
10	45	409	0.11002445	0.047650327	0.09013	0.132610367
11	34	428	0.079439252	0.048603928	0.09013	0.131656766
12	33	456	0.072368421	0.049899058	0.09013	0.130361635
			1.08156416			
		P-BAR	0.090130347			

iii. P-chart



As we can clearly see, no points lie outside the calculated control limits, thus the process is in statistical control. We can now measure the performance of the process after improving on the defect identified.

DPMO	13373.86	0.01337386
SIGMA	3.71518	

Thus, we can observe that the sigma level has increased from 3.5 to 3.7, which is significant improvement considering the shorter time-period. Standardizing the process and then observing through a longer period, the results might increase even further.

STAGE 3

1. DEFINE

The two most crucial steps are happening in this stage: air drying and kiln baking. The moulded clay from revolving press is transferred to the conveyor. From here it is taken for air drying. The detailed description is given below:

Air-drying: The moulded clay is placed on wooden trays. It is the carried to the racks where they are stacked. It is then left for 7-9 days for air-drying (under sun light). During monsoon, smoke is given between the racks for increased drying.

Kiln baking: Once air dried, the tiles are taken to the kiln and left for 7 days for extreme drying. In this stage the roof clay tiles gain the deep red colour. The fire wood is introduced periodically to maintain the temperature inside the kiln.

SIPOC

The SIPOC diagram maps process flows, enumerating the supplier, inputs process, output and customers of the process that helps further investigation of the problem

Defects in the various processes of Stage 3 which are identified by the company are:

1. Blistering

The water trapped inside the clay causes bubbles which after kiln baking leave a depression on the tile surface.

2. Damage by rodents

While leaving the moulded clay for air drying, rodents like mouse damages the clay surface.

3. Cracking

Lack of care by the workers causes huge amount of cracking. Even rodents' movements results cracking which will be unfit for baking.

2. MEASURE

In the measure phase of DMAIC methodology, the current level of the process performance (in terms of sigma level) based on the seven defects identified in the define stage is established, followed by defect prioritization with the help of pareto chart.

The company collects data on the number of defective units observed through a continuous quality check process. Defectives are visually inspected. A unit is classified as defective if any defect is observed, and such units are removed from the manufacturing line. The company operates its manufacturing process in three shifts per day, typically for all seven days of the week. For this study, defect data was collected over a period of ten days, with data recorded for each of the three shifts per day.

i. Check sheet for pre-analysis

	Cracking	*Damage by Rodents*	*Blistering*	*Total Defectives*	*Sample Inspected*
Shift 1	16	1	2	19	417
Shift 2	17	0	0	17	440
Shift 3	23	2	1	26	426
Shift 1	15	2	2	19	422
Shift 2	18	0	0	18	445
Shift 3	13	0	3	16	412
Shift 1	18	3	3	24	422
Shift 2	16	1	2	19	432
Shift 3	17	2	1	20	422
Shift 1	13	8	0	21	410
Shift 2	19	2	0	21	405
Shift 3	22	0	0	22	421

Shift 1	23	3	2	28	432
Shift 2	11	5	1	17	432
Shift 3	21	2	3	26	413
Shift 1	22	0	1	23	421
Shift 2	21	1	1	23	412
Shift 3	21	2	0	23	419
Shift 1	20	0	0	20	417
Shift 2	19	5	0	24	418
Shift 3	17	3	0	20	433
Shift 1	19	2	1	22	427
Shift 2	12	8	2	22	427
Shift 3	14	1	3	18	438
Shift 1	16	1	1	18	412
Shift 2	11	9	1	21	432
Shift 3	10	4	0	14	400
Shift 1	17	3	2	22	412
Shift 2	12	2	1	15	413
Shift 3	21	3	1	25	426
COUNT	514	75	34	623	12658

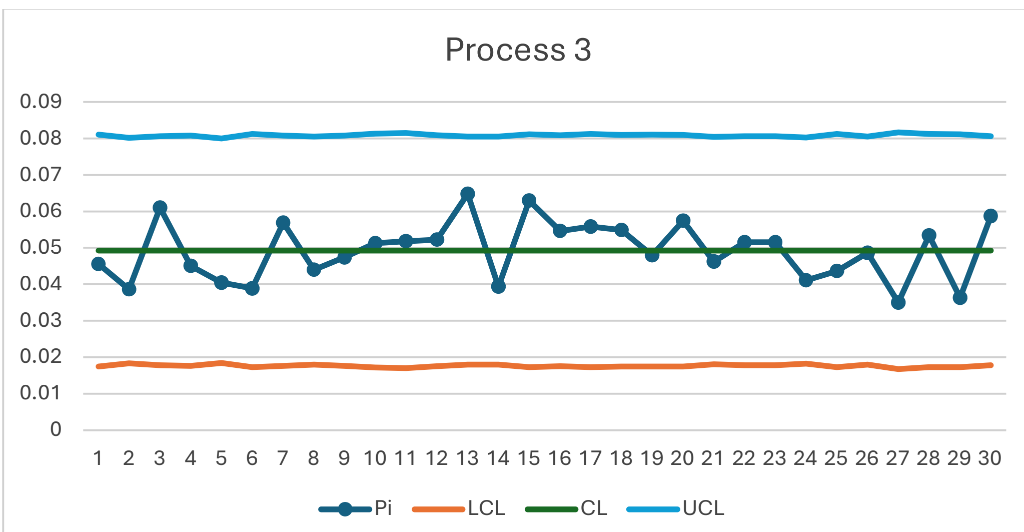
ii. Statistical Quality Control using control chart (Here, p chart)

In this project, a P control chart is used, because the P control chart is used if the defect size is the proportion of defective products in each sample taken.

Total defectives	Total Checked	Pi	LCL	CL	UCL
19	417	0.045563549	0.017448444	0.04923324	0.081018036
17	440	0.038636364	0.018290332	0.04923324	0.080176147
26	426	0.061032864	0.017785991	0.04923324	0.080680488
19	422	0.045023697	0.017637303	0.04923324	0.080829176
18	445	0.040449438	0.01846466	0.04923324	0.080001819
16	412	0.038834951	0.017256156	0.04923324	0.081210323
24	422	0.056872038	0.017637303	0.04923324	0.080829176
19	432	0.043981481	0.018005138	0.04923324	0.080461341
20	422	0.047393365	0.017637303	0.04923324	0.080829176
21	410	0.051219512	0.017178258	0.04923324	0.081288221
21	405	0.051851852	0.016980995	0.04923324	0.081485484
22	421	0.052256532	0.017599801	0.04923324	0.080866679
28	432	0.064814815	0.018005138	0.04923324	0.080461341
17	432	0.039351852	0.018005138	0.04923324	0.080461341
26	413	0.062953995	0.017294893	0.04923324	0.081171586
23	421	0.054631829	0.017599801	0.04923324	0.080866679
23	412	0.055825243	0.017256156	0.04923324	0.081210323
23	419	0.054892601	0.017524393	0.04923324	0.080942086
20	417	0.047961631	0.017448444	0.04923324	0.081018036

24	418	0.057416268	0.017486486	0.04923324	0.080979993
20	433	0.046189376	0.018041219	0.04923324	0.08042526
22	427	0.051522248	0.017822836	0.04923324	0.080643643
22	427	0.051522248	0.017822836	0.04923324	0.080643643
18	438	0.04109589	0.018219767	0.04923324	0.080246713
18	412	0.04368932	0.017256156	0.04923324	0.081210323
21	432	0.048611111	0.018005138	0.04923324	0.080461341
14	400	0.035	0.016780044	0.04923324	0.081686435
22	412	0.053398058	0.017256156	0.04923324	0.081210323
15	413	0.036319613	0.017294893	0.04923324	0.081171586
25	426	0.058685446	0.017785991	0.04923324	0.080680488
		1.476997189			
	P-BAR	0.04923324			

iii. After the control limit calculations are obtained, the next step is to create a control chart graphic which functions to map the data limits. The purpose of making this control chart graph is to find out whether the data is within control limits or not.



The graph clearly depicts that the process is in control as all the points lie within the control limits.

Now, let us check how well the process's performance is depicted using Yield and sigma level.

vi. Yield is the percentage of non-defective items and thus it is given by the formula as:

Yield = (1-(total number of defectives/total number of items inspected)) *100

vii. Sigma level can then be calculated as the two tailed z-value treating Yield as the area under the curve with a shift of +1.5 which is the industry standard. The formula used is given as:

Sigma Level = NORM.S.INV(0.5+(Yield/100/2)) + 1.5

Using these formulas, the results obtained are:

DPMO	16405.96197	0.016405962
SIGMA	3.634377108	

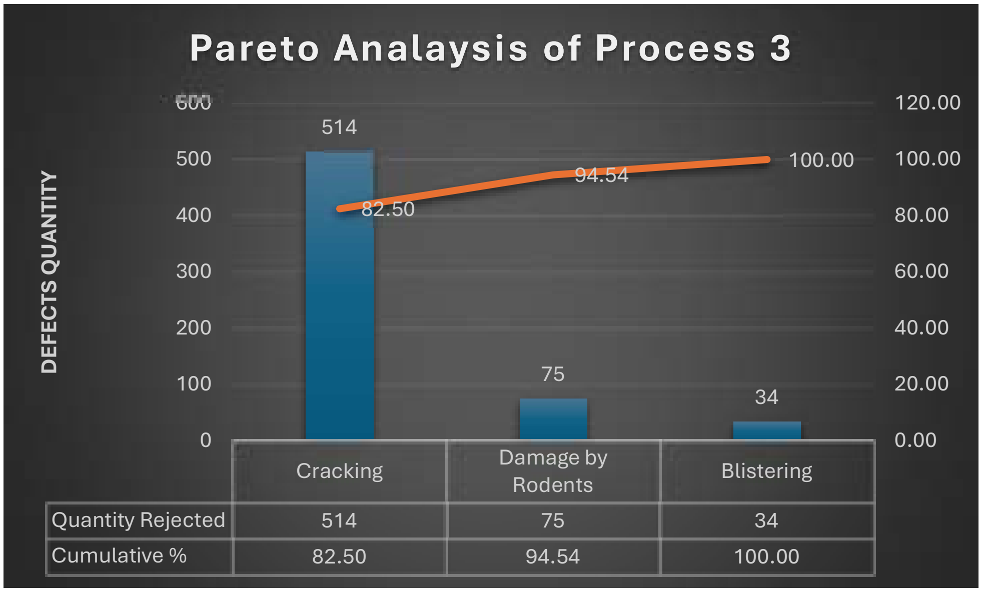
As we can see, the Sigma Level is just 3.634377108, which is quite low as compared to the other products manufactured by the company. Thus, there is scope of improvement so we will start the defect analysis here. So, we move onto the next stage of our methodology, i.e. Analyse.

5. ANALYSE

After going through the measurement stage, the next step is the stage of identification and analysis. Basically, this stage is the stage of identification and analysis regarding the main problems and in the end, we will find out how to anticipate the causes of the main defects.

i. Pareto Chart: Firstly, we will plot Pareto Chart to identify the defects which are the ―Vital Few. For that, let us calculate the cumulative percentage of defects.

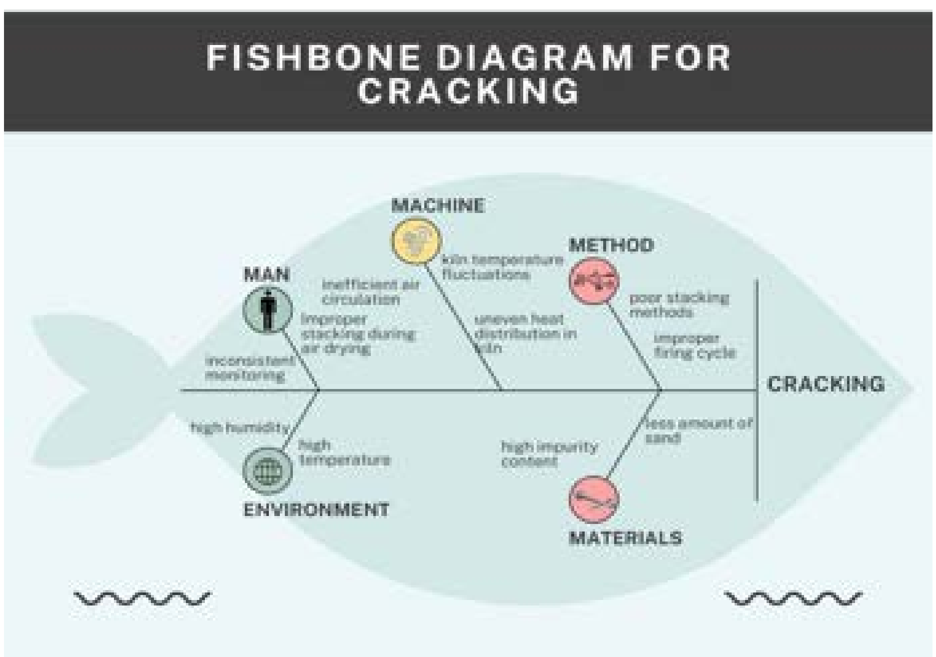
Defects	Quantity Rejected	Rejection %	Cumulative %
Cracking	514	82.50	82.50
Damage by Rodents	75	12.04	94.54
Blistering	34	5.46	100.00
Total Sum	623		



We can see from the pareto chart that around 80% of the defect type is ‘Cracking.’ Therefore, we need to work upon this defect.

So, now we will work on this defect to improve the sigma level.

ii. Cause & Effect analysis or Ishikawa Diagram or Fishbone diagram: Cause &Effect analysis was conducted and a Cause & Effect diagram categorizing the causes in 5 generic categories were prepared as shown:



Since there are many causes, and this is not pointing out to any specific reason we must go with 5-why analysis.

iii. 5-Why analysis of top defect of Stage 3

DEFECT TYPE		CRACKING
WHY 1	QUESTION	Why did the product crack?
	ANSWER	Because the firing process was improper.
WHY 2	QUESTION	Why was the firing process improper?
	ANSWER	Because the temperature inside the kiln was not evenly distributed.
WHY 3	QUESTION	Why was the temperature uneven in the kiln?
	ANSWER	Because of inefficient air circulation and lack of proper arrangement.
WHY 4	QUESTION	Why was the air circulation inefficient?
	ANSWER	Because the kiln's design or maintenance did not support optimal airflow and the firing is not well kept on check.
WHY 5	QUESTION	Why was the kiln not properly designed or maintained?
	ANSWER	Because regular checks and updates to the system were not part of SOPs and temperature was not well looked upon.
	Corrective measure	Regular checks and updates for the kiln system, specifically regarding temperature control and maintenance.

ACTION PLANNING FOR FAILURE MODES

	Defects	Suggestive Action Plan
1	Cracking	• Use shaded drying zones to slow down evaporation. • Avoid direct contact between pieces. • Install fans or ducts for even airflow

2	Damage by Rodents	• Use metal mesh covers, elevated racks, or closed chambers during drying. • Store semi-dried tiles in closed or netted sheds to prevent access. • Regularly clean the drying area; remove leftover clay or waste.
3	Blistering	• Ensure homogeneous clay mixing and proper de-airing • Introduce a pre-airing step where tiles are placed under low airflow before full drying.

4. IMPROVE AND CONTROL

The above suggestions were provided to the company and they further implemented these changes according to their company terms and standards. Sufficient time and resources were dedicated to this procedure aiming to improve the sigma level, i.e. the performance of the process. After this, new data was recorded to monitor the improvements (if any) that were achieved by following the mentioned procedure. This data was recorded in a span of 4 days, resulting into 12 shifts i.e. 12 timestamps. The number of defectives arising through each defect were counted for each lot being produced in a continuous process.

i. Defects Check Sheet Post Analysis:

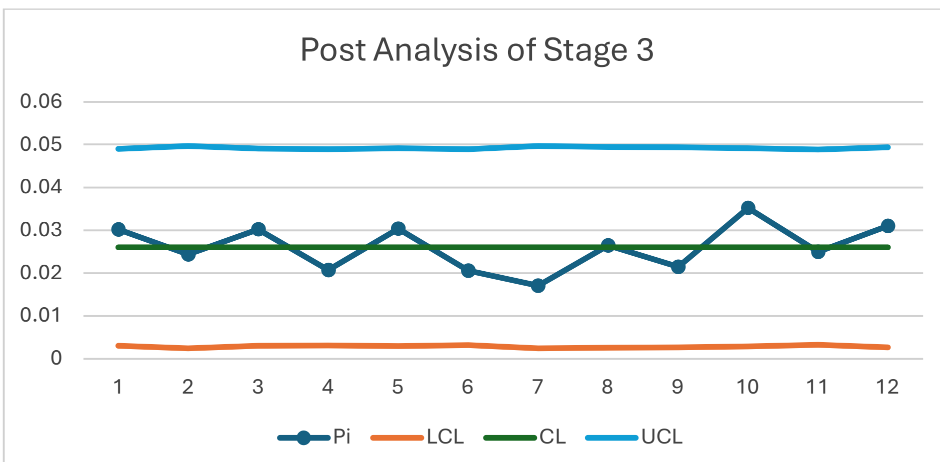
	Cracking	*Damage by Rodents*	*Blistering*	*Total Defectives*	*Sample Inspected*
Shift 1	10	3	0	13	431
Shift 2	7	1	2	10	410
Shift 3	8	2	3	13	430
Shift 1	7	2	0	9	434
Shift 2	6	6	1	13	428
Shift 3	2	5	2	9	437
Shift 1	7	0	0	7	410
Shift 2	6	5	0	11	416
Shift 3	7	0	2	9	419
Shift 1	9	4	2	15	426
Shift 2	6	4	1	11	440
Shift 3	10	0	3	13	419
COUNT	85	32	16	133	5100

Here, we can see that the frequencies of the defects “Cracking,” “Damage by rodents” and “Blistering” has reduced significantly.

ii. Construction of p Chart:

Total defectives	Total Checked	Pi	LCL	CL	UCL
13	431	0.030162413	0.00303857	0.026060338	0.049082105
10	410	0.024390244	0.00245635	0.026060338	0.049664325
13	430	0.030232558	0.003011816	0.026060338	0.049108859
9	434	0.020737327	0.003118276	0.026060338	0.049002399
13	428	0.030373832	0.002958027	0.026060338	0.049162648
9	437	0.020594966	0.003197161	0.026060338	0.048923515
7	410	0.017073171	0.00245635	0.026060338	0.049664325
11	416	0.026442308	0.00262719	0.026060338	0.049493486
9	419	0.021479714	0.00271123	0.026060338	0.049409445
15	426	0.035211268	0.00290386	0.026060338	0.049216815
11	440	0.025	0.003275236	0.026060338	0.048845439
13	419	0.031026253	0.00271123	0.026060338	0.049409445
		0.312724052			
	P-BAR	0.026060338			

iii. P-chart



As we can clearly see, no points lie outside the calculated control limits, thus the process is in statistical control. We can now measure the performance of the process after improving on the defect identified.

DPMO	8692.810458	0.00869281
SIGMA	3.878449461	

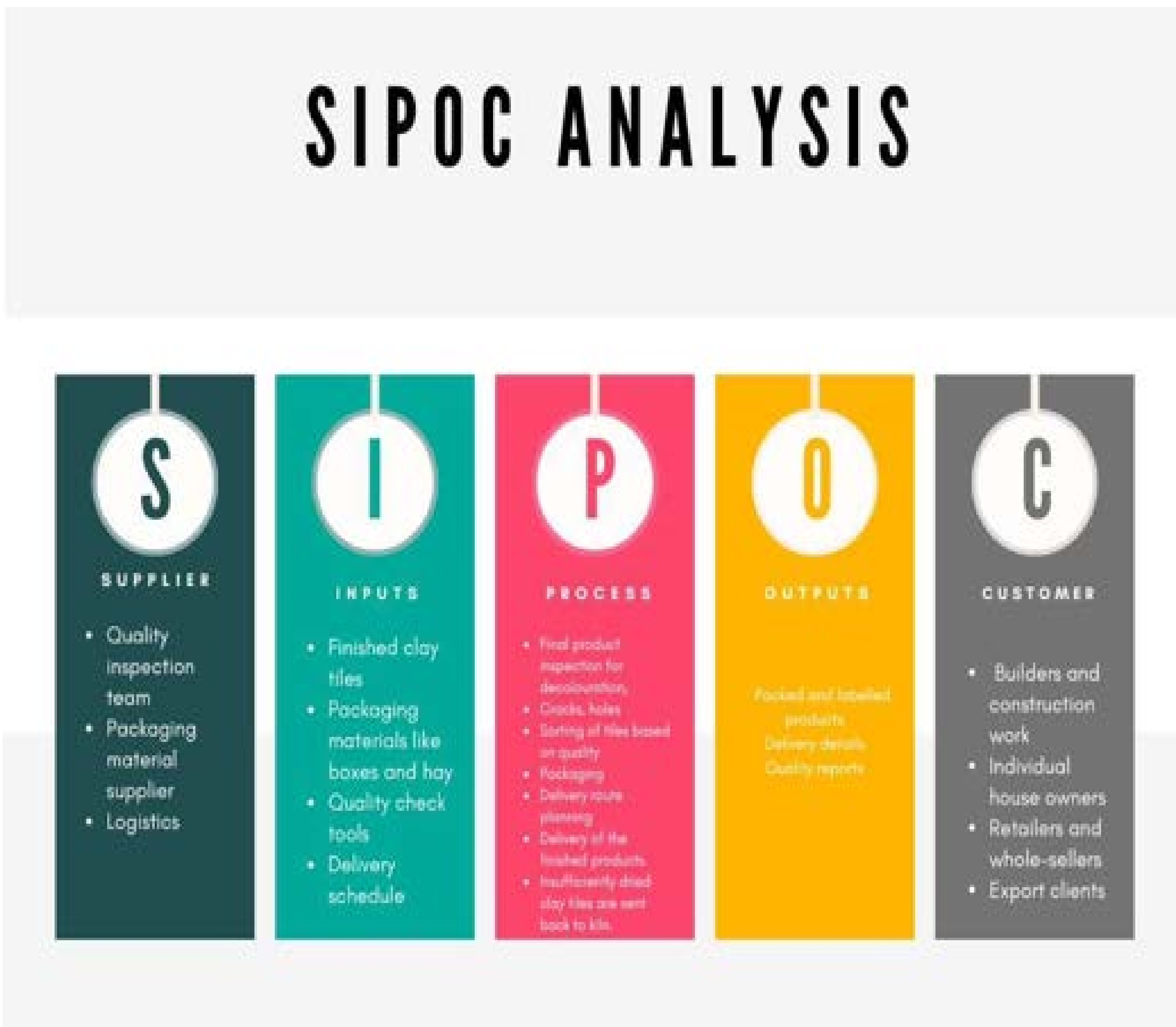
Thus, we can observe that the sigma level has increased from 3.6 to 3.9, which is significant improvement considering the shorter time-period. Standardizing the process and then observing through a longer period, the results might increase even further.

STAGE 4

1. DEFINE

Once the roof clay tile is made it is then taken to the next steps. Quality checking packaging and transportation to the customers are the steps. After the kiln baking, the final product is taken for quality checking, where the product is undergone quality checking and categorised into different categories based on their minor cracks and density. The sorted products are sent to the customers on demand. The products are transported using lorries where hay is placed in between the tile to maintain the friction and the absorb un announced rain and to provide padding.

SIPOC



The SIPOC diagram maps process flows, enumerating the supplier, inputs process, output and customers of the process that helps further investigation of the problem

Defects in the various processes of Stage 2 which are identified by the company are:

1. Lime accumulation

Due to improper sieving of clay during the initial stages, the calcim contents gets accumulated in the clay. This results in to lime accumulation in the final product.

2. Mishandling

Manual works leads to cracking of the products which cannot be further used or recycled.

3. Over drying

Due to periodic unattendance of fire in the kiln, it results to over drying of the tiles. This causes black patches on the tile; also results in shrinkage of tile.

4. Insufficient drying

Insufficient drying results in moisture in the clay which has low water retention capacity.

2. MEASURE

In the measure phase of DMAIC methodology, the current level of the process performance (in terms of sigma level) based on the seven defects identified in the define stage is established, followed by defect prioritization with the help of pareto chart.

The company collects data on the number of defective units observed through a continuous quality check process. Defectives are visually inspected. A unit is classified as defective if any defect is observed, and such units are removed from the manufacturing line. The company operates its manufacturing process in three shifts per day, typically for all seven days of the week. For this study, defect data was collected over a period of ten days, with data recorded for each of the three shifts per day.

The table below presents the number of defectives observed at the end of stage 1 for each shift. In this context, shift 1, shift 2, shift 3 represents 3 shifts of a day. Thereby there are 30 data in total. The frequency of defects that caused the parts to be classified as defective is recorded for each shift. The sample size of each shift is also noted. The table contains 5 defects types and frequency of each in the table.

i. Check sheet for pre-analysis

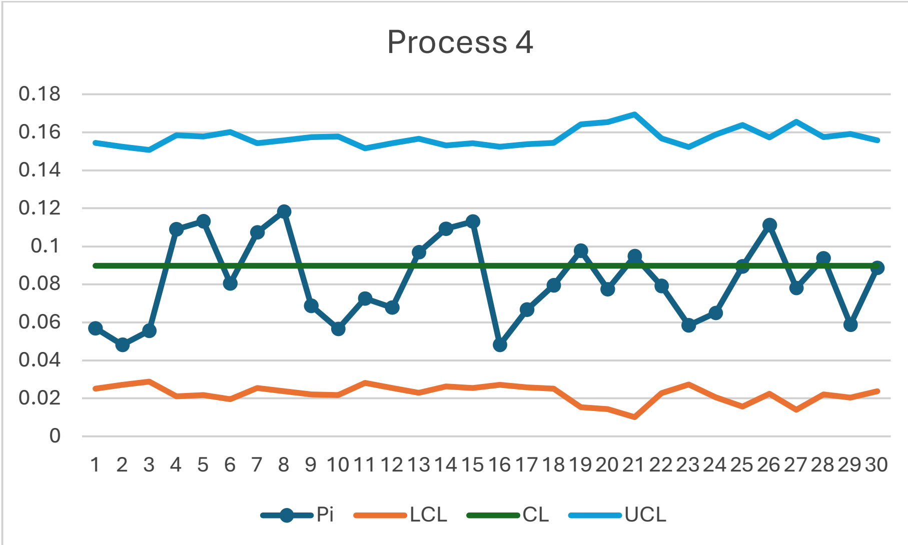
		Insufficient Drying	*Over Drying*	*Mishandling*	*Lime Accumulation*	*Total defectives*	*Samples inspected*
1	Shift 1	1	4	0	5	10	176
2	Shift 2	1	4	2	2	9	187
3	Shift 3	2	7	1	1	11	198
4	Shift 1	7	3	3	4	17	156
5	Shift 2	2	8	5	3	18	159
6	Shift 3	3	5	2	2	12	149
7	Shift 1	5	6	3	5	19	177
8	Shift 2	6	5	8	1	20	169
9	Shift 3	1	6	2	2	11	160
10	Shift 1	2	4	0	3	9	159
11	Shift 2	2	8	0	4	14	193
12	Shift 3	1	6	1	4	12	177
13	Shift 1	5	5	2	4	16	165
14	Shift 2	6	8	5	1	20	183
15	Shift 3	3	8	7	2	20	177
16	Shift 1	2	4	0	3	9	187
17	Shift 2	3	6	2	1	12	180
18	Shift 3	5	4	0	5	14	176
19	Shift 1	6	5	0	2	13	133
20	Shift 2	1	7	0	2	10	129
21	Shift 3	4	3	3	1	11	116
22	Shift 1	5	4	2	2	13	164
23	Shift 2	2	4	1	4	11	188
24	Shift 3	5	3	1	1	10	154
25	Shift 1	3	7	0	2	12	134
26	Shift 2	3	8	2	5	18	162
27	Shift 3	2	5	1	2	10	128
28	Shift 1	5	6	0	4	15	160
29	Shift 2	2	6	0	1	9	153
30	Shift 3	5	7	2	1	15	169
	COUNT	100	166	55	79	400	4918

i. Statistical Quality Control using control chart (Here, p chart)

In this project, a P control chart is used, because the P control chart is used if the defect size is the proportion of defective products in each sample taken.

Sl NO.	Total defectives	Total Checked	Pi	LCL	CL	UCL
1	10	176	0.056818182	0.025136898	0.089781261	0.154425623
2	9	187	0.048128342	0.027067017	0.089781261	0.152495504
3	11	198	0.055555556	0.028833971	0.089781261	0.15072855
4	17	156	0.108974359	0.021117958	0.089781261	0.158444564
5	18	159	0.113207547	0.021768809	0.089781261	0.157793712
6	12	149	0.080536913	0.019523572	0.089781261	0.160038949
7	19	177	0.107344633	0.025319768	0.089781261	0.154242753
8	20	169	0.118343195	0.023811693	0.089781261	0.155750828
9	11	160	0.06875	0.021981681	0.089781261	0.15758084
10	9	159	0.056603774	0.021768809	0.089781261	0.157793712
11	14	193	0.07253886	0.028049547	0.089781261	0.151512975
12	12	177	0.06779661	0.025319768	0.089781261	0.154242753
13	16	165	0.096969697	0.02301685	0.089781261	0.156545671
14	20	183	0.109289617	0.026385321	0.089781261	0.153177201
15	20	177	0.11299435	0.025319768	0.089781261	0.154242753
16	9	187	0.048128342	0.027067017	0.089781261	0.152495504
17	12	180	0.066666667	0.025859204	0.089781261	0.153703317
18	14	176	0.079545455	0.025136898	0.089781261	0.154425623
19	13	133	0.097744361	0.01541753	0.089781261	0.164144992
20	10	129	0.07751938	0.014273405	0.089781261	0.165289116
21	11	116	0.094827586	0.010154693	0.089781261	0.169407828
22	13	164	0.079268293	0.02281361	0.089781261	0.156748912
23	11	188	0.058510638	0.027234033	0.089781261	0.152328489
24	10	154	0.064935065	0.02067353	0.089781261	0.158888991
25	12	134	0.089552239	0.015695526	0.089781261	0.163866995
26	18	162	0.111111111	0.022401497	0.089781261	0.157161024
27	10	128	0.078125	0.013979027	0.089781261	0.165583495
28	15	160	0.09375	0.021981681	0.089781261	0.15758084
29	9	153	0.058823529	0.020448056	0.089781261	0.159114466
30	15	169	0.088757396	0.023811693	0.089781261	0.155750828
			2.461116697			
		P-BAR	0.082037223			

ii. After the control limit calculations are obtained, the next step is to create a control chart graphic which functions to map the data limits. The purpose of making this control chart graph is to find out whether the data is within control limits or not.



The graph clearly depicts that the process is in control as all the points lie within the control limits.

Now, let us check how well the process's performance is depicted using Yield and sigma level.

i. Yield is the percentage of non-defective items and thus it is given by the formula as:

Yield = (1-(total number of defectives/total number of items inspected)) *100

ii. Sigma level can then be calculated as the two tailed z-value treating Yield as the area under the curve with a shift of +1.5 which is the industry standard. The formula used is given as:

Sigma Level = NORM.S.INV(0.5+(Yield/100/2)) + 1.5

Using these formulas, the results obtained are:

DPMO	20333.46889	0.020333469
SIGMA	3.54690984	

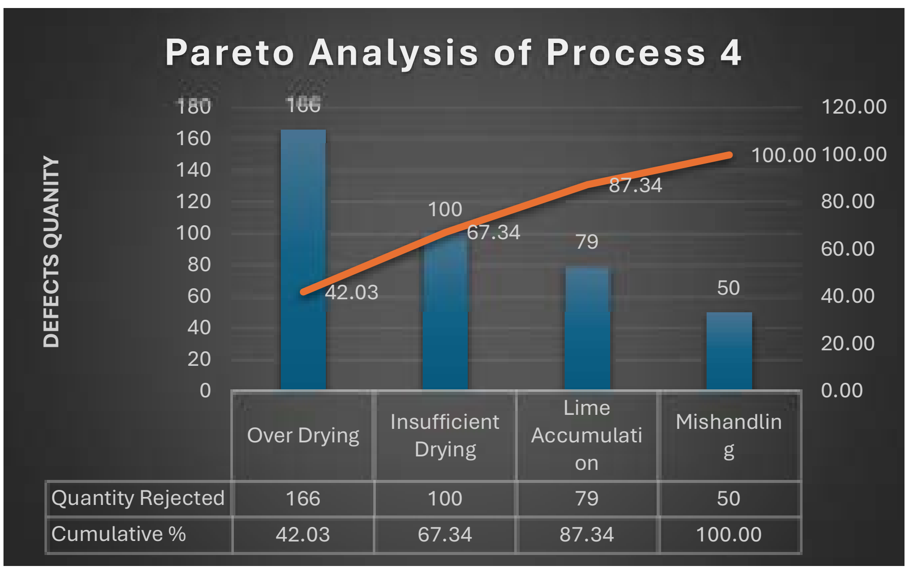
As we can see, the Sigma Level is just 3.54690984, which is quite low as compared to the other products manufactured by the company. Thus, there is scope of improvement so we will start the defect analysis here. So, we move onto the next stage of our methodology, i.e. Analyse.

3. ANALYSE

After going through the measurement stage, the next step is the stage of identification and analysis. Basically, this stage is the stage of identification and analysis regarding the main problems and in the end, we will find out how to anticipate the causes of the main defects.

i. Pareto Chart: Firstly, we will plot Pareto Chart to identify the defects which are the ―Vital Few. For that, let us calculate the cumulative percentage of defects.

SI NO.	Defects	Quantity Rejected	Rejection %	Cumulative %
2	*Over Drying*	166	42.03	42.03
1	*Insufficient Drying*	100	25.32	67.34
4	*Lime Accumulation*	79	20.00	87.34
3	*Mishandling*	50	12.66	100.00
	Total Sum	395		

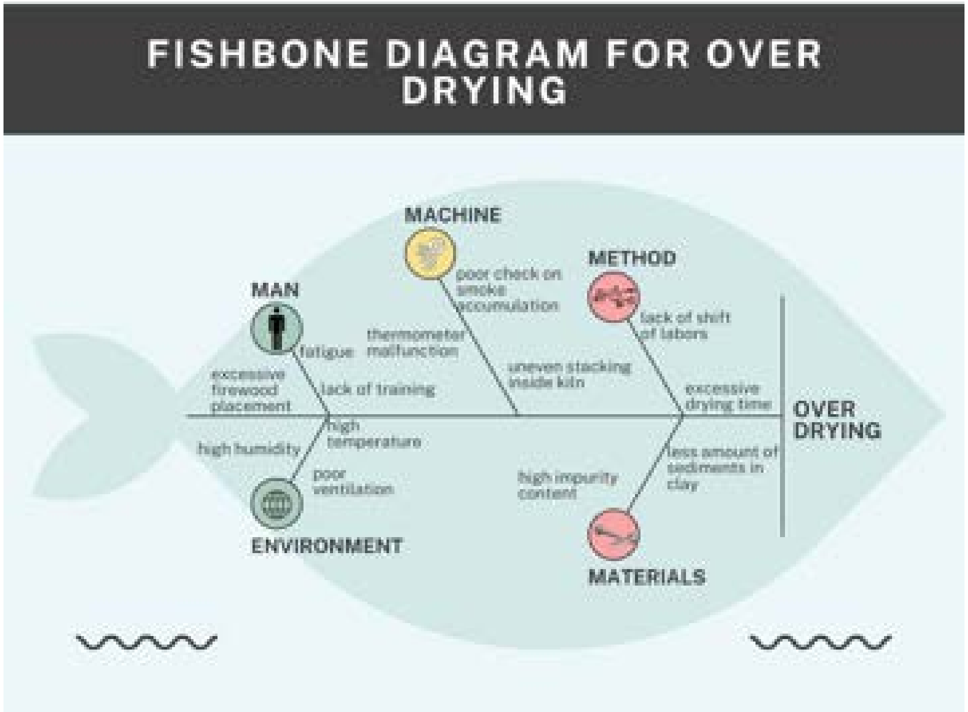


We can see from the pareto chart that chart that elbow is forming at the defect 'Lime accumulation.' Therefore, we need to work upon three defects which are over drying, insufficient drying and lime accumulation.

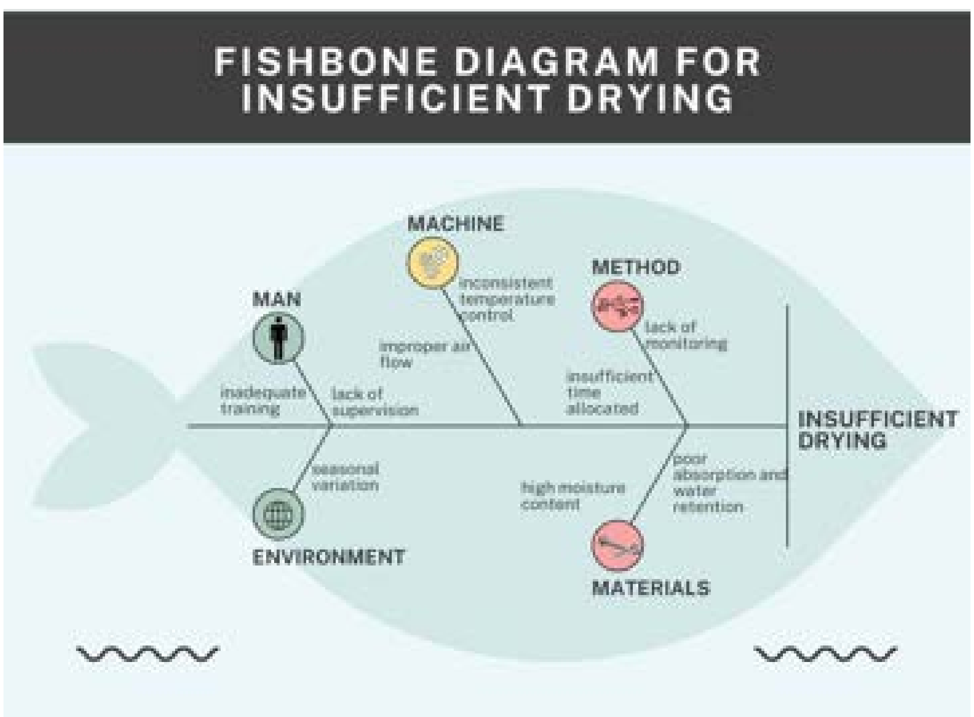
So, now we will work on these three defects to improve the sigma level.

ii. Cause & Effect analysis or Ishikawa Diagram or Fishbone diagram: Cause &Effect analysis was conducted and a Cause & Effect diagram categorizing the causes in 5 generic categories were prepared as shown:

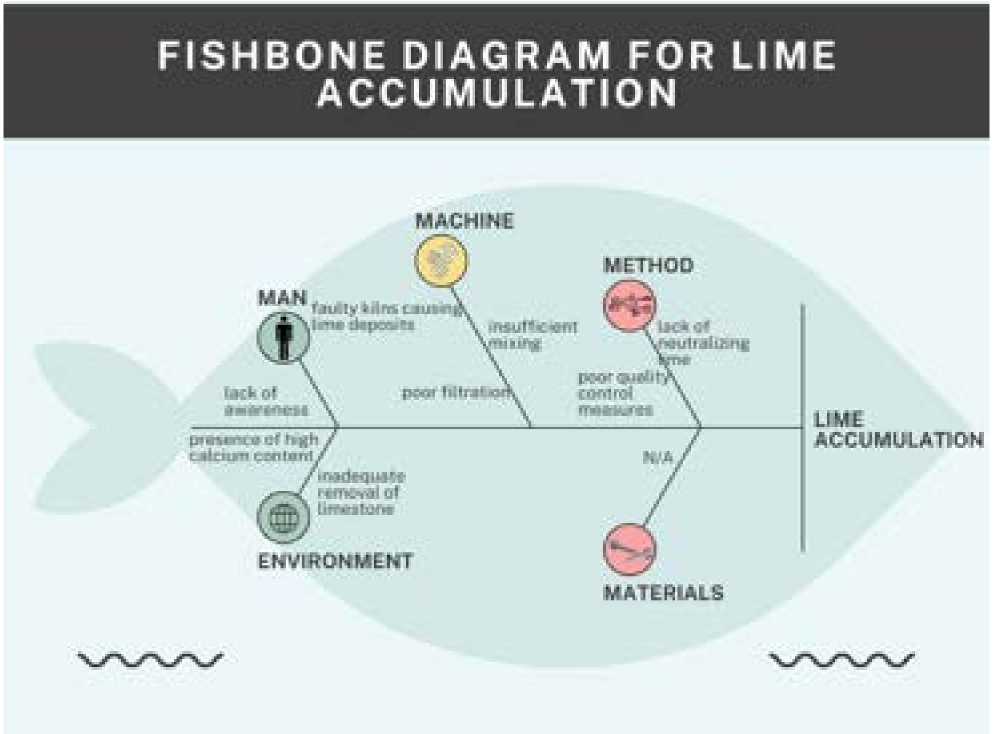
Over- drying



Insufficient-drying



Lime accumulation



Since there are a lot of possible reasons for these defects, exact reason behind the occurrences is still unknown.

iii. 5-Why analysis of top 3 defects of Stage 4

DEFECT TYPE		OVER DRYING	INSUFFICIENT DRYING	LIME ACCUMULATION
WHY 1	QUESTION	Why did over drying occur?	Why did insufficient drying occur?	Why did lime accumulate?
	ANSWER	Because the drying time was excessive.	Because the material had high moisture content.	Because the clay used had a high calcium content.
WHY 2	QUESTION	Why was the drying time excessive?	Why was there high moisture content in the material?	Why did the clay have high calcium content?
	ANSWER	Because there was no shift of labour to monitor and manage the process.	Because the material had poor water absorption and retention capacity.	Because limestone was not properly removed during preparation.

WHY 3	QUESTION	Why was there no shift of labour?	Why did the material have poor absorption and retention?	Why wasn't the limestone removed?
	ANSWER	Because of poor manpower planning and lack of scheduling.	Because of improper clay selection.	Because the filtration and screening process was ineffective.
WHY 4	QUESTION	Why was the labour planning poor?	Why was the wrong clay selected?	Why was the filtration process ineffective?
	ANSWER	Because of management oversight and lack of standard operating procedures (SOPs).	Because there were no quality checks for material before use and lack of time.	Because equipment used for screening was outdated or not maintained.
WHY 5	QUESTION	Why was there no SOP in place?	Why were quality checks not conducted?	Why wasn't the equipment maintained or upgraded?
	ANSWER	Because training and process documentation are lacking.	Because the quality assurance process is not implemented or enforced effectively.	Because there was no maintenance schedule or investment plan for machinery upgrades.
		Corrective Measures	Monitored drying schedules and parameters and adequate labour scheduling.	

4. IMPROVE

Based on the results of the previous stages, the next process is to improve the types of stage 4 defects using FMEA method which provides an overview of sources and priorities in implementing the plan. As well as developing plans for improvement and quality improvement. FMEA produces risk priority number (RPN) which will be used as a priority scale for improvement clay roof tiles. The RPN calculation results aim to find the severity rating, occurrence rating and detection values.

i. Severity value

SCALE	INFORMATION
1	No effect
2	Not too serious
3	Serious enough
4	Are serious
5	Very serious

ii. Occurrence value

SCALE	INFORMATION
1	Very rare
2	Rarely happening
3	Sometimes happens
4	Often occur
5	Happens very often

iii. Detection value

SCALE	INFORMATION
1	Definitely Detected
2	Most likely to detect
3	Maybe detected
4	Small chance of detection
5	Not detected

RISK PRIORITY NUMBER DEFECT: OVER DRYING

NO	Potential Failure Mode	Severity	Occurrence	Detection	RPN	Priority
1	Excessive Drying time	4	4	3	48	2
2	Uneven Air flow	3	3	4	36	3
3	High Temperature	4	5	3	60	1
4	Improper Stacking in the kiln	3	2	3	18	4
5	Lack of Sediments	2	2	2	8	5

RISK PRIORITY NUMBER DEFECT: INSUFFICIENT DRYING

NO	Potential Failure Mode	Severity	Occurrence	Detection	RPN	Priority
1	Excessive Moisture in the clay	5	4	2	40	1
2	High Moisture content in the environment	5	3	2	30	2
3	Inadequate drying time	5	4	1	20	3
4	Improper Stacking in the kiln	4	2	2	16	4
5	Uneven Air Flow	5	3	1	15	5

RISK PRIORITY NUMBER DEFECT: LIME ACCUMULATION

NO	Potential Failure Mode	Severity	Occurrence	Detection	RPN	Priority
1	High Calcium Content	5	4	1	20	4
2	No proper separation or washing	4	3	3	36	2
3	Low quality of clay	5	3	2	30	3
4	Use of hard water while processing	5	3	4	60	1

ACTION PLANNING FOR FAILURE MODES

i. Over drying

Rank	Failure Mode	Actionable Causes	Design Action/Potential Solutions
1	High temperature	Overheating accelerates water evaporation unevenly	• Install temperature sensors

2	Excessive drying time	Delay in replacement	• Introduce automated drying timers to ensure consistent drying durations. • Train operators to follow drying cycle logs strictly. • Perform time audits to evaluate average vs. optimal drying durations.
3	Uneven air flow	Improper stacking	• Regularly service ducts, and vents to maintain uniform airflow. • Ensure even stacking to avoid blocking air passage between tiles.
4	Improper Stacking in the kiln	Lack of personnel	• Train workers on optimal spacing and weight distribution. • Install shelves for stacking
5	Lack of Sediments	Low material quality	• Checking raw materials, water content and clay powder

ii. Insufficient drying

Rank	Failure Mode	Actionable Causes	Design Action/Potential Solutions
1	Excessive Moisture in the clay	Improper drying	• Pre-check clay in raw form using moisture testing kits before shaping • Use high quality clay • Protect clay from rain
2	High Moisture content in the environment	Rainy season	• storage area with humidity control • proper drying in kiln

3	Inadequate drying time	Lack of knowledge about drying time	• Apply Smoke during rainy season • Train workers on different types of clay and their drying time
4	Improper Stacking in the kiln	Lack of personnel	• Train workers on optimal spacing and weight distribution. • Install shelves for stacking
5	Uneven Air Flow	Improper stacking	• Regularly service ducts, and vents to maintain uniform airflow. • Ensure even stacking to avoid blocking air passage between tiles.

iii. Lime accumulation

Rank	Failure Mode	Actionable Causes	Design Action/Potential Solutions
1	Use of hard water while processing	lime popping after firing	• Blend with low calcium clay as a dilution strategy • Heavy crushing and mixing in stage 1
2	No proper separation or washing	trapped lime or salts	• Implement a two-stage filtration process for raw clay
3	Low quality of clay	Poor selection of clay	• Qualify clay only from tested Water beds • Introduce experienced clay testing team

5. CONTROL

The above suggestions were provided to the company and they further implemented these changes according to their company terms and standards. Sufficient time and resources were dedicated to this procedure aiming to improve the sigma level, i.e. the performance of the process. After this, new data was recorded to monitor the improvements (if any) that were achieved by following the mentioned procedure. This data was recorded in a span of 4 days, resulting into 12 shifts i.e. 12 timestamps. The number of defectives arising through each defect were counted for each lot being produced in a continuous process.

i. Defects Check Sheet Post Analysis:

		Insufficient Drying	*Over Drying*	*Mishandling*	*Lime Accumulation*	*Total defectives*	*Samples inspected*
1	Shift 1	8	2	3	2	12	170
2	Shift 2	1	3	4	3	11	170
3	Shift 3	3	0	0	5	9	187
4	Shift 1	5	1	3	3	12	160
5	Shift 2	0	7	0	0	8	178
6	Shift 3	2	2	2	7	13	167
7	Shift 1	4	6	3	7	15	170
8	Shift 2	0	3	6	1	10	179
9	Shift 3	6	6	0	0	12	150
10	Shift 1	0	0	1	2	13	166
11	Shift 2	2	2	1	1	11	200
12	Shift 3	1	5	0	3	10	180
	COUNT	32	37	23	34	136	2077

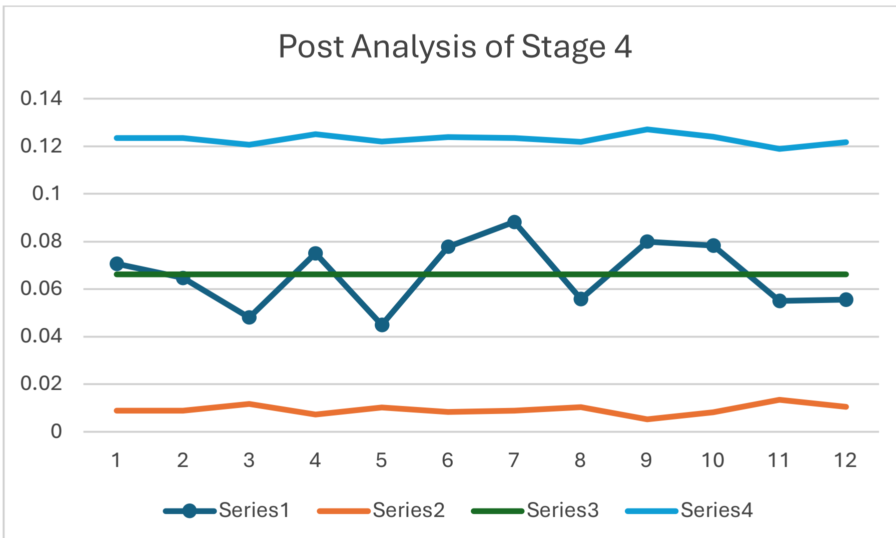
Here, we can see that the frequencies of the defects "insufficient drying," "over drying" and "lime accumulation" has reduced significantly.

i. Construction of p Chart:

Sl NO.	Total defectives	Total Checked	Pi	LCL	CL	UCL
1	12	170	0.070588235	0.00898159	0.066181718	0.123381846
2	11	170	0.064705882	0.00898159	0.066181718	0.123381846
3	9	187	0.048128342	0.011643536	0.066181718	0.1207199
4	12	160	0.075	0.007221176	0.066181718	0.12514226
5	8	178	0.04494382	0.010281763	0.066181718	0.122081673
6	13	167	0.077844311	0.008470104	0.066181718	0.123893332
7	15	170	0.088235294	0.00898159	0.066181718	0.123381846
8	10	179	0.055865922	0.010438127	0.066181718	0.121925309

9	12	150	0.08	0.005287532	0.066181718	0.127075904
10	13	166	0.078313253	0.008296534	0.066181718	0.124066902
11	11	200	0.055	0.013445806	0.066181718	0.11891763
12	10	180	0.055555556	0.010593186	0.066181718	0.12177025
			0.794180616			
		P-BAR	0.066181718			

ii. P-chart



As we can clearly see, no points lie outside the calculated control limits, thus the process is in statistical control. We can now measure the performance of the process after improving on the defect identified.

DPMO	16369.76408	0.016369764
SIGMA	3.635263064	

Thus, we can observe that the sigma level has increased from 3.5 to 3.63, which is significant improvement considering the shorter time-period. Standardizing the process and then observing through a longer period, the results might increase even further.