A case study on the DMAIC Six Sigma application to prevent injuries in the manufacturing industry

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Abstract: Ever growing rivalry and non-standard customer requirements triggered a continuous improvement need at goods manufacturing. The injury at workstations to the operators increases the actual lead time of the delivery to the final customer. This paper works on the DMAIC Six Sigma applications to reduce the injury due to burr formation while hammering in the tractor transmission manufacturing. We applied hypothesis testing, DOE, and Z test ANOVA to check the two variables relation with each other and effects of improvement actions over the process at the workstations. We applied cause and effect diagram and matrix, and FMEA that given 15 probable input variables X for the improvement. We applied the improvement actions over these X's and verified the process capability as acceptable. Finally, we reduced total injury from 2 to 0 no's/month against the target of the 0 incidents and RPN reduced from 343 to 96.

Keywords: DMAIC; Six Sigma; process capability; ANOVA; FMEA.

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1 Introduction

1.1 Six Sigma approach need

Ever growing rivalry and non-standard customer requirements triggered a continuous improvement need in goods and services. The injury at workstations to the operators increase the actual lead time of the delivery to the final customer and cost (Slack et al., 2010). During 1986–2001 Motorola extricate 800 billion rupees [Eckes, 2001; Hendricks and Kelbaugh, (1998), pp.48–53] by the application of Six Sigma technique. Similarly, 3M, GE, and Honeywell also received a big cost savings in their operations by the application of Six Sigma technique [GE Annual Report, 2002; Honeywell Annual Report, 2002; Arndt, (2004), pp.62–74; 3M Annual Report, 2003]. Six Sigma is the most effective and efficient among the techniques like Business reengineering, TQM, and Lean [Bailey et al., (2001), pp.1–3]. Hence, a business gets main gain of lead time reduction, cost-saving, and defects prevention (Stamatis, 2004; Breyfogle III et al., 2001; Pyzdek and Keller, 2010; Dale et al., 2007). DMAIC is a tool used for improvement in the manufacturing process by application of the Six Sigma [Garza-Reyes et al., (2010), pp.92–100]. We used DMAIC jointly with other tools such as the Fishbone diagram, Pareto analysis, FMEA, DOE, and ANOVA for the application of this empirical study for injury reduction in the selected workstation.

1.2 Definition

One may define Six Sigma (6σ) as a combination of many tools for continuous improvement in the given manufacturing process. In the year 1986, an American engineer Bill Smith had started it at Motorola [Tennant, (2001), p.6]. GE under leadership of Jack Welch, in 1995 prepared Six Sigma as their main business strategy. A six sigma supposed to produce a 3.4 DPMO that is defects per million opportunities (Stamatis, 2004; Knowledgehut, 2020). The manufacturing process performance and its variance are Six Sigma key explanations (Brue and Howes, 2006). Six Sigma is an organisation strategy to go for lower cost and continuous improvement for every kind of process.

2 Literature review

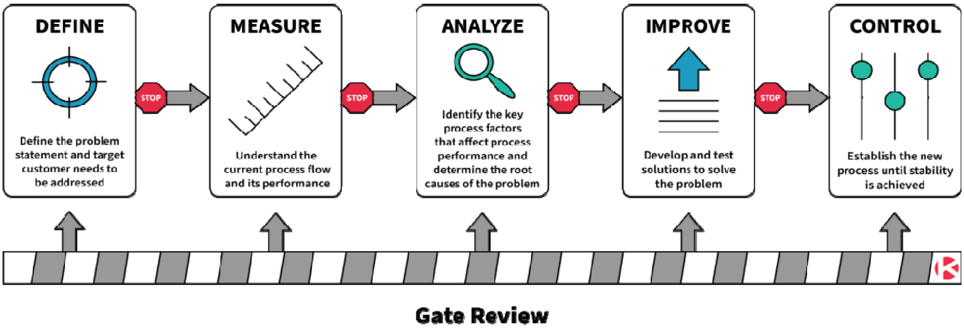
2.1 DMAIC significance

DMAIC is equivalent to PDCA technique of Deming's (1993). The DMAIC guides with a step by step approach for problem-solving (Bezerra et al., 2010). Thus, DMAIC allows the systematic and standard execution guide by working on standardised problem-solving process [Hammer and Goding, (2001), pp.58–63]. DMAIC is centred on the collection of the data, brainstorming on collected data and improvement action plan over it (Pyzdek, 2003). DMAIC's allows an actual fact and data based decision-making instead of the previous experience [Garza-Reyes et al., (2010), pp.92–100; Drmahey, 2018]. This can be also used in the process problem solving at purchase, human resource, and logistics along with manufacturing.

2.2 DMAIC step by step guide

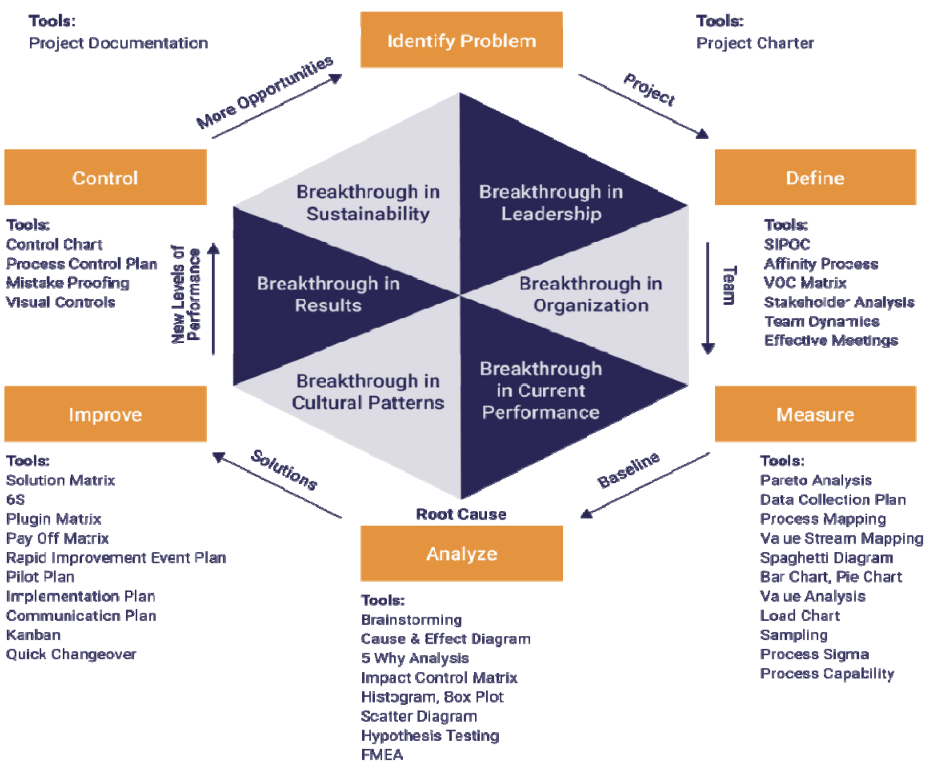
DMAIC technique is detail five stages define, measure, analyse, improve, and control (Tanner, 2020; Anderson, 2019] guide for problem solving and continuous improvements (Dale et al., 2007; Villanovau, 2020). The DMAIC in brief explained in Figure 1.

Figure 1 DMAIC technique (see online version for colours)



Source: Kanbanzone (2020)

Figure 2 DMAIC Six Sigma tools (see online version for colours)



Source: Defeo (2020)

1 *Define*: Define is the first step and it define the cross-functional team's responsibility with the fix timelines, project scope, and targets triggering the customer needs [Gijo et al., (2011), pp.1221–1234].

2 *Measure*: Measure is the second step that ticks the measurement methods we are going to use for the selected manufacturing process to be improved (Omachonu and Ross, 2004) and check the current performance of the process (Stamatis, 2004).

3 *Analyse*: Analysis is the third step determines the problems causes (Omachonu and Ross, 2004), problem why-why analysis, comparing with each other, and defining improvement chances (Adams et al., 2003).

4 *Improve*: Improve is the fourth step use and experiment the statistical methods to check possible improvements to prevent problems in the process (Omachonu and Ross, 2004; Sage Automation, 2017).

5 *Control*: Control is the fifth stage to sustain the improvement done (Omachonu and Ross, 2004) and controlling of the actual performance of the process (Corley, 2019).

Following Figure 2 explains the important tools used at each phase of the DMAIC.

3 Methodology

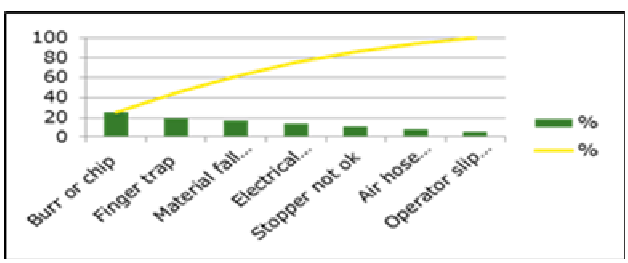
3.1 DMAIC Six Sigma application an empirical study

We have performed an empirical study of DMAIC six sigma applications at the tractor transmission manufacturing process as explained below in step by step manner.

3.2 Define

We plotted a Pareto chart for the all injury types' tractor transmission manufacturing for FY19-20 to understand the main injury occurred in the manufacturing process as shown in the Pareto Chart1 in Figure 3.

Figure 3 Pareto chart 1: total injury types contribution at the transmission in August–May 2020 (see online version for colours)



From the Pareto chart, we collected the top seven injury types which are contributing to 82% of the total injury in the transmission manufacturing process (Creately, 2020). We tracked these top seven injury's in the transmission manufacturing process as below:

1 burr and chip injury

2 finger trap injury

3 material fall on floor or slippage injury

4 electrical shock injury

5 stoppers not Ok injury

6 air hose leakage injury

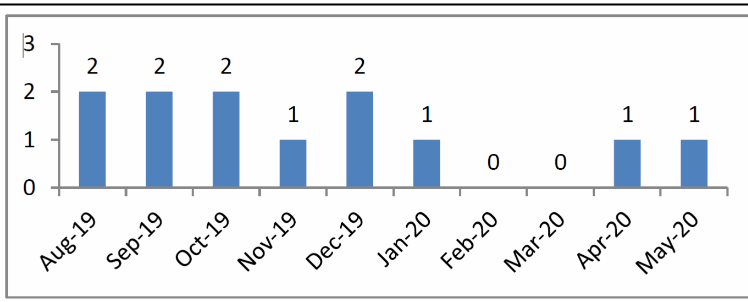
7 oil on floor or slippage injury.

We set our main scope to burr injury incidence reduction at the transmission tractor manufacturing by six sigma application from the above Pareto chart data. Further, we started the DMAIC Six Sigma with the in-process injury data collection (TQMI, 2017) in the year FY19-20 as explained in the Table 1.

Table 1 Tractor transmissions burr and chip injury contribution in FY19-20 (see online version for colours)

Which	business metric is not meeting target?	FAC, near miss, unsafe condition
Where	is the problem occurring?	Transmission assembly
When	was the problem first observed?	August 2019
Who	is affected by the problem?	Transmission Assembly employee safety
How much	is the business metric affected?	Burr and Chip injury happened 9 in FY 19, and 6 from November–May 2020
Problem statement		1. Transmission assembly using 21 hammer for assembly of roll pin for alignment, serial number punching, and crimping. 2. Two hard and brittle metal contact with uneven force creating chip or burr formation. 3. High speed burr from brittle hammer material causing deep penetration from clothes and skin puncture injury after heating with operator body. 4. This resulted in severe injury's to operators causing treatment at outside hospital.

Burr and chip injury at transmission assembly



3.2.1 *Objective*

We formed the following objective statement to answer the above listed injury incidents,

1 To identify the main injury incidents or issues in a tractor transmission production process and prevent it by the DMAIC Six Sigma application.

2 To reduce the risk priority number (RPN) in the hazard identification and risk assessment sheet HIRA of the tractor transmission manufacturing process.

Further, we prepared a project charter based on the above data to prevent these injuries. Project charter is a consolidation of the project scope, targets, and every cross functional team member's role with the fixed timeline (Pande et al., 2000). The detail project charter is mentioned in Table 2.

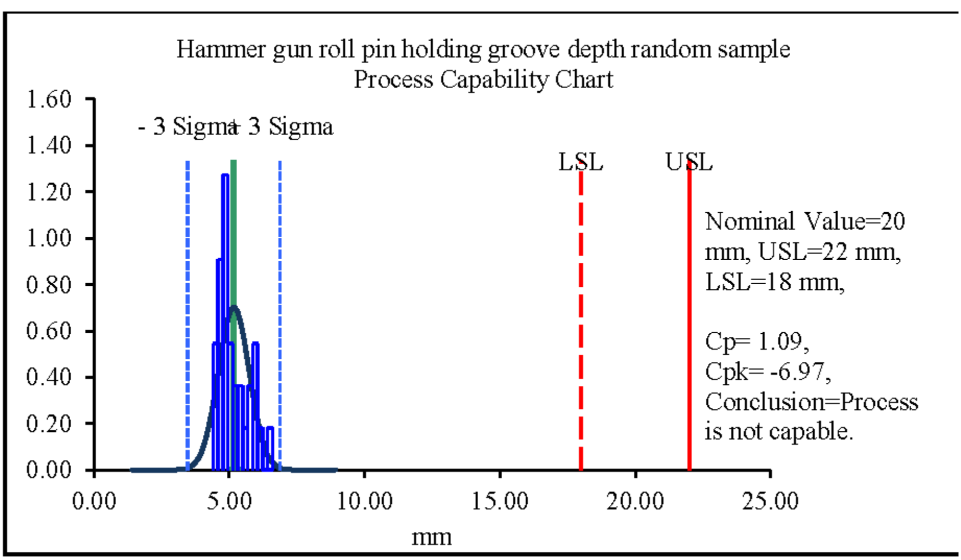
Table 2 Six Sigma project charter

Goal statement		*Reducing burr or chip injury to operator body by hammer elimination in transmission assembly*				
METRICS	*Type*	*Description*	*UOM*	*Current*	*Goal*	*% change*
	Business	Eliminating burr or chip injury to operator body	No	2/Month	0/Month	100
	Primary	Hammer elimination in transmission assembly	No	21	6	72
	Primary	HIRA RPN value reduction	No	343	96	66

3.3 Measure

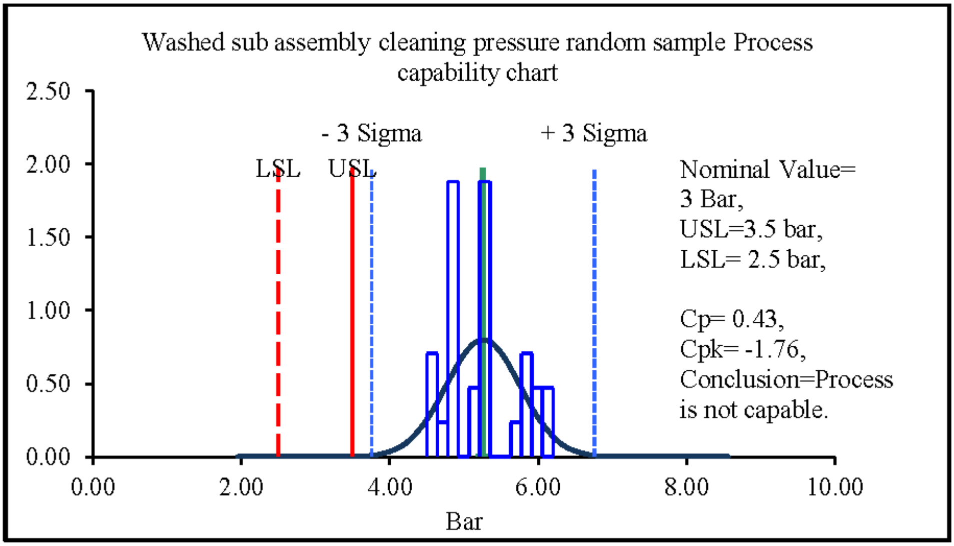
The measure is an actual fact based data collection stage to define baselines for selected process performance (Vcomply Editorial, 2017). These actual baselines compared current as well as with the after performance to check whether the actions are resulting in the improvement. We performed a process capability check to verify the process variation in the hammer gun roll pin holding groove depth as mentioned in Figure 4.

Figure 4 Process capability chart for hammer gun roll pin holding groove depth (see online version for colours)



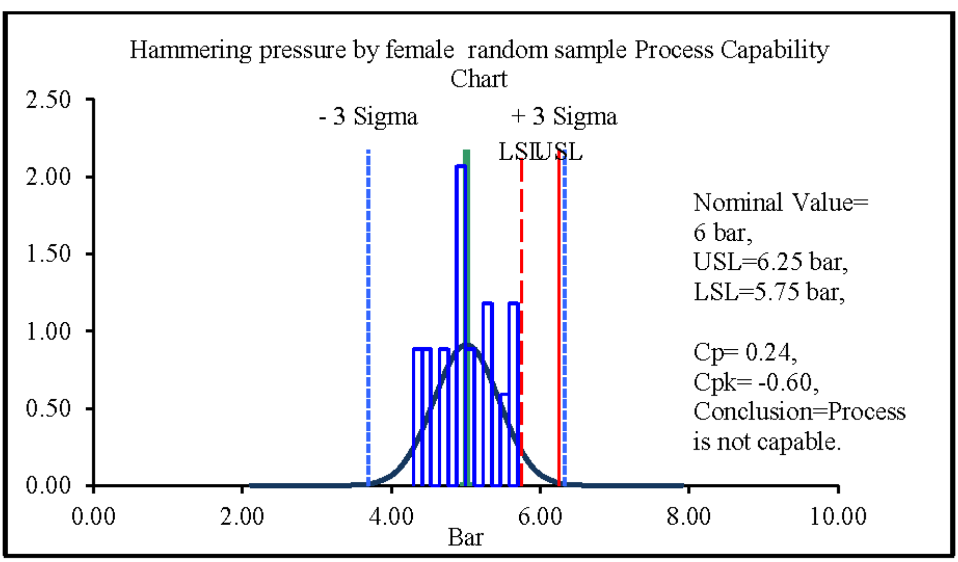
Next, we done process capability check for the washed sub assembly cleaning pressure as explained in Figure 5.

Figure 5 Process capability chart for washed sub assembly cleaning pressure (see online version for colours)



Finally, we performed process capability check for the hammering pressure by female as explained in Figure 6.

Figure 6 Process capability chart for hammering pressure by female (see online version for colours)

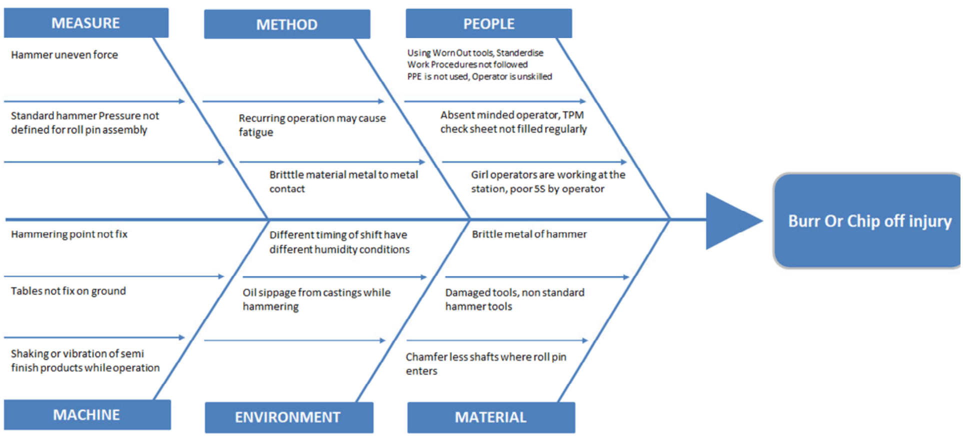


Process capability check study above explained that all the process capabilities are > 1.33 and need a significant improvement.

3.4 Analyse

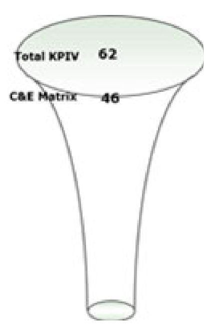
We performed cross functional team brainstorming with cause-and-effect diagrams, cause-and-effect matrix, and FMEA (Pyzdek, 2003) to verify, validate, and finalise the problem root cause (Henshall, 2017). We found probable root causes that is inputs X after the brainstorming with a cause-and-effect diagram over the burr and chip injury as shown in Figure 7.

Figure 7 Cause and effect diagram brainstorming on problem burr and chip injury (see online version for colours)



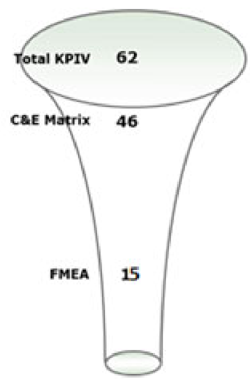
Next, we performed funnelling by cause and effect matrix on all the probable root causes as shown in Figure 8.

Figure 8 C&E probable root causes funnelling (see online version for colours)



We got total 57 probable input variables X and funnelled 46 out of 57 by the C&E matrix to perform FMEA over it. Next, we performed the FMEA to verify the system reliability as shown in Figure 9.

Figure 9 FMEA funneling of the probable root causes of the injuries (see online version for colours)



As explained in the Table 3 we found out 15 probable root causes or input X,

Table 3 Probable root causes or input X

Sr no	*Input variable*	*Effect*
X1	Roll pin holding while hammering	Roll pin slip, hammer slip, high speed burr creation, roll pin bulging.
X2	Two hard metal contact	High speed burr creation, roll pin bulging.
X3	High air pressure while cleaning on washing machine	High speed burr spread.
X4	Burr contact with body	Burr injury to body.
X5	Hole not matching of two components	Roll pin slip, hammer slip, high speed burr creation, roll pin bulging.
X6	Roll pin OD	Roll pin slip, hammer slip, high speed burr creation, roll pin bulging.
X7	Material of hammer wood	Hammer slip.
X8	Brand of hammer	Play in hammer, high wear and tear.
X9	Hammering force variation	Play in hammer results in wrong shot.
X10	Operator fatigue	Manual force variation.
X11	Hammer audit frequency	Hammer wear checking.
X12	TPM audit frequency	Fixtures, Pneumatic guns not Ok.
X13	5S audit frequency	Exact tools are not available.
X14	Operator gender	Hammering force variation.
X15	Operator state of mind	Hammering force variation.

3.5 Improve

The improve stage identify a solution to prevent probable input X (Omachonu and Ross, 2004; 6sigma, 2017). We pointed out, checked, and applied solutions over problems to stop the injury incidence. Stamatis (2004) guides the DOE a statistical tool used in the improve stage to check multiple input X effects (Roy, 2001; Antony and Kaye, 2000).

The DOE improves the performance of the process, reduces variation, and improve cost cutting (Montgomery, 2009). Therefore, we used the DOE on total of two input parameters to check whether the improvement actions are worth. A DOE tool ANOVA used for verifying means differences of more than two populations (Moore et al., 2009). We used the two-way ANOVA for two input factor effect verification (Moore et al., 2009). Figure 10 shows the F test ANOVA for checking hammering pressure variance by hammer gun used by female and male.

Figure 10 ANOVA F test (see online version for colours)

Null Hypothesis (Ho)	Hammering pressure variance by hammer gun, female, male are equal			
Alternate Hypothesis (Ha)	Hammering pressure variance by hammer gun, female, male are different			
Type of Test : F-test/ ANOVA	**Assumptions :**	**Normality**	**Randomness**	**Homogeneity**
		P-value -2.34 E-10	No	No

Statistical Results

One way ANOVA				
Hammering Pressure by gun in bar	Hammering Pressure by Female in bar	Hammering Pressure by Male in bar	State Hypothesis	
6	5.2	5.6	H0-Group variance are equal	
6.05	4.7	5.9	H1-Group variance are different	
6.05	5.9	5.2		
6	4.6	6.7	Select Test	
6.05	5.4	7.2	Performing F test for variance	
6	5.6	5.6		
6.05	4.4	5.5	Level of significance=0.05	
5.95	4.9	5.9		
5.9	5.2	5.6	Extract relevant statistic	
5.95	5.6	5.9	VAR(Group A)=	0.002789744
5.94	5.1	6.5	VAR(Group B)=	0.185641026
6.05	4.9	6.2	VAR(Group C)=	0.307564103
6.05	5.2	5.7	Fmax	110.2481618
			dfl	12
			dfs	12
			Fcri	2.686637112
			Pvalue	2.344741E-10
			Decision	
			Since Fmax>Fcri (Pvalue<0.05), Accept H1	

hammering Pressure by male, female, hammer gun analysis

Conclusion- There is a significant variation in hammering pressure by male, female, hammer gun analysis

From Figure 10, we concluded that there is a significant variation in hammering pressure by male, female, and hammer gun.

We further used the two-way ANOVA for two input factor effect verification (Moore et al., 2009). Figure 11 shows the F test ANOVA for checking gender effect on hammering pressure. From this study, we concluded that gender effects hammering pressure.

From Figure 11, we deployed following two key improvements at the manufacturing process:

1 Hammer is replaced by hammer gun to achieve constant pressure of hammering for preventing burr or chip off.

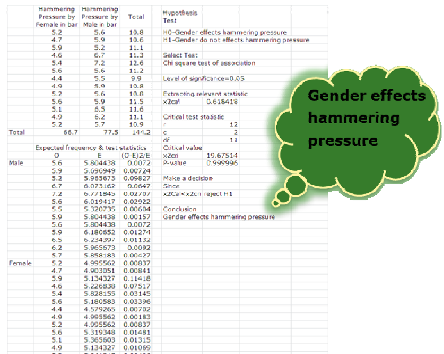
2 Deployment of boys only at hammer and girls or boys at hammer gun usage points.

We further carried out the after FMEA of the injury incidence at the transmission manufacturing process and got the below results as shown in Figure 12 where we identified 13 parameters checked by statistical test to validate the improvement actions results.

Figure 11 ANOVA Z test (see online version for colours)

Null Hypothesis (Ho)	Gender effects hammering pressure			
Alternate Hypothesis (Ha)	Gender do not effects hammering pressure			
Type of Test : **Chi square test of association**/ ANOVA	**Assumptions :**	**Normality**	**Randomness**	**Homogeneity**
		P-value -0.99	No	No

Statistical Results



	Hammering Pressure by Female in bar	Hammering Pressure by Male in bar	Total
	5.2	5.6	10.8
	4.7	5.9	10.6
	5.9	5.2	11.1
	4.6	6.7	11.3
	5.4	7.2	12.6
	5.6	5.6	11.2
	4.4	5.5	9.9
	4.9	5.9	10.8
	5.2	5.6	10.8
	5.6	5.9	11.5
	5.1	6.5	11.6
	4.9	6.2	11.1
	5.2	5.7	10.9
Total	66.7	77.5	144.2

Expected frequency & test statistics

	O	E	(O-E)2/E
Male	5.6	5.804438	0.0072
	5.9	5.696949	0.00724
	5.2	5.965673	0.09827
	6.7	6.073162	0.0647
	7.2	6.771845	0.02707
	5.6	6.019417	0.02922
	5.5	5.320735	0.00604
	5.9	5.804438	0.00157
	5.6	5.804438	0.0072
	5.9	6.180652	0.01274
	6.5	6.234397	0.01132
	6.2	5.965673	0.0092
	5.7	5.858183	0.00427
Female	5.2	4.995562	0.00837
	4.7	4.903051	0.00841
	5.9	5.134327	0.11418
	4.6	5.226838	0.07517
	5.4	5.828155	0.03145
	5.6	5.180583	0.03396
	4.4	4.579265	0.00702
	4.9	4.995562	0.00183
	5.2	4.995562	0.00837
	5.6	5.319348	0.01481
	5.1	5.365603	0.01315
	4.9	5.134327	0.01069
	5.2	5.041817	0.00496

Hypothesis Test
H0-Gender effects hammering pressure
H1-Gender do not effects hammering pressure

Select Test
Chi square test of association

Level of significance=0.05

Extracting relevant statistic
x2cal 0.618418

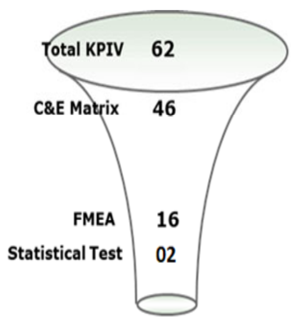
Critical test statistic
r 12
c 2
df 11
Critical value
x2cri 19.67514
P-value 0.999996

Make a decision
Since
x2Cal<x2cri reject H1

Conclusion
Gender effects hammering pressure

Conclusion- Gender effects hammering pressure

Figure 12 Funneling after statistical test (see online version for colours)

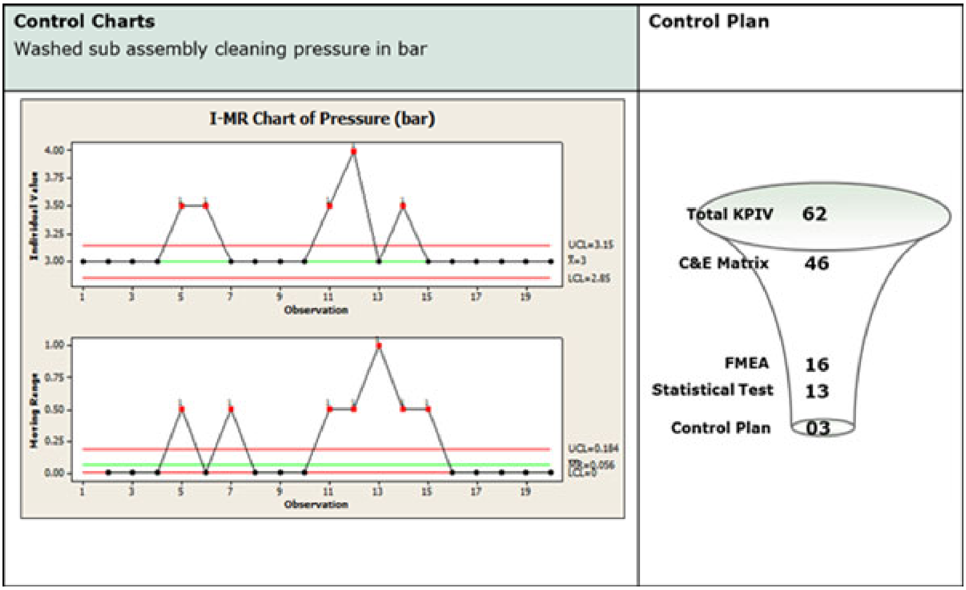


3.6 Control

We verified the sustenance of the improvements in the control stage by verifying the improvements (Rastogi, 2018). We applied the control chart I-MR at the washed sub assembly cleaning pressure as shown in Figure 13.

This helped us to verify the after improvements process stability (Omachonu and Ross, 2004; Stamatis, 2004) and to check process variations.

Figure 13 Control chart I-MR (see online version for colours)



3.7 Results

After deployment of all the improvement actions, we verified the process capability for the three input parameters X as shown in Figure 14, Figure 15, and Figure 16.

Figure 14 Process capability chart for hammer gun roll pin holding groove depth (see online version for colours)

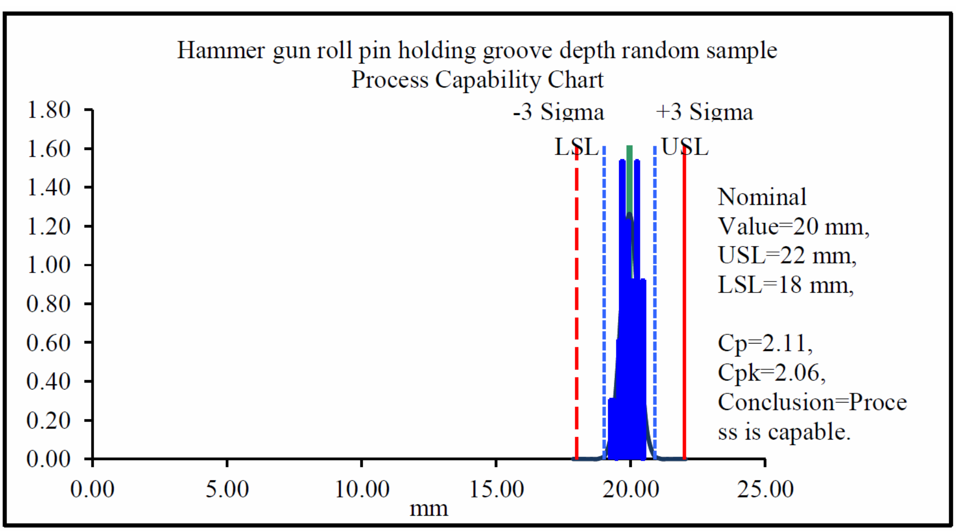


Figure 15 Process capability chart for washed sub assembly cleaning pressure (see online version for colours)

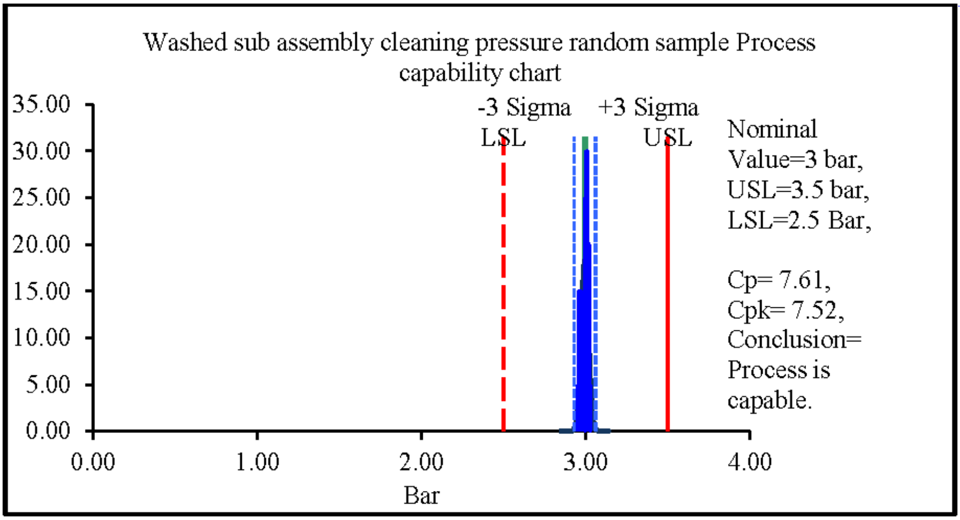
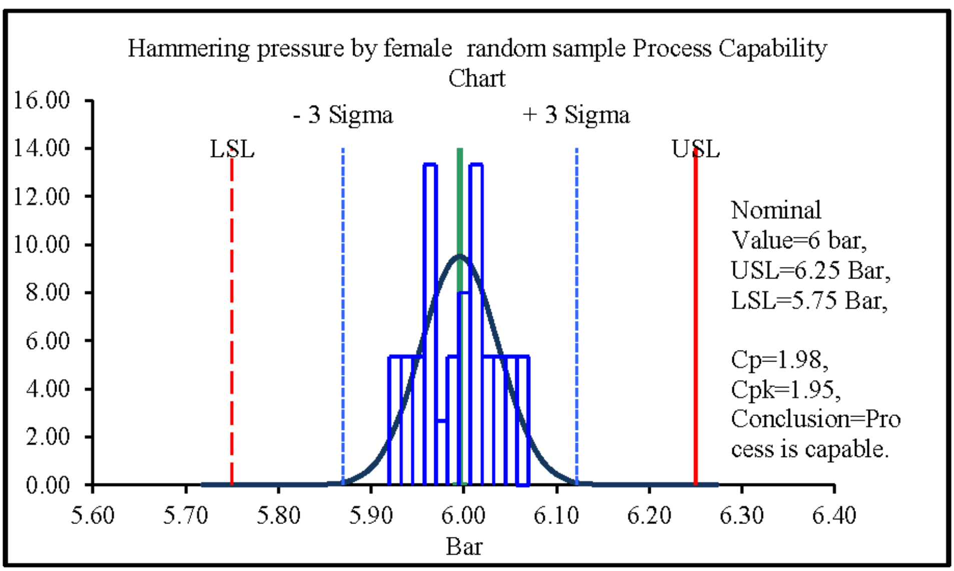


Figure 16 Process capability chart for hammering pressure (see online version for colours)



From Figure 16 process capability study, we concluded that all the improvement actions taken had reduced the injuries at manufacturing process.

Also, we plotted the number of hammer usage and RPN HIRA value reduction in Figure 17.

Figure 17 The number of hammer usage and RPN HIRA value reduction (see online version for colours)

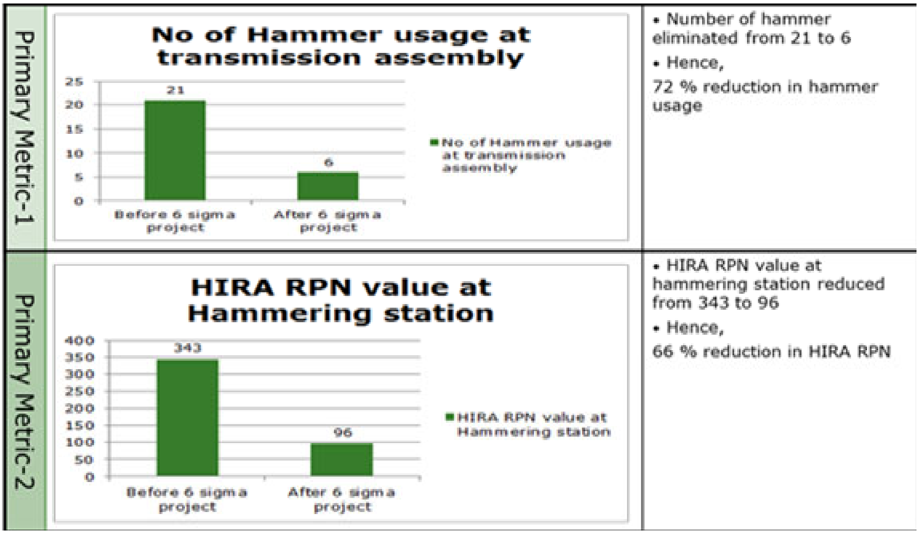
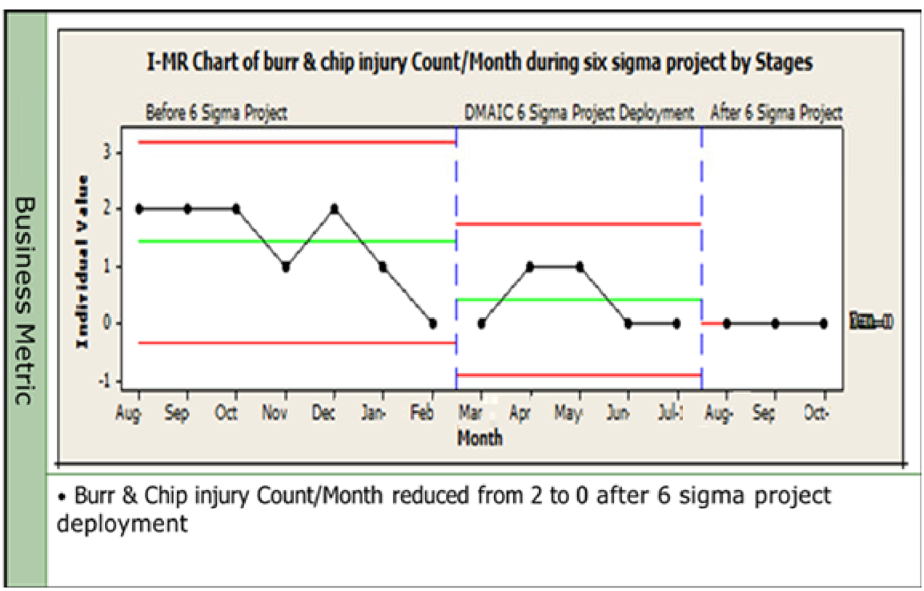


Figure 18 Burr and chip injury reduced from 2 to 0 per month (see online version for colours)



We concluded the final results of the DMAIC six sigma project application as below,

1 We reduced total number of hammers from 21 to 06 on manufacturing assembly line.

2 We reduced RPN of HIRA from 343 to 96 at hammering work station.

3 Burr and chip injury reduced from 2 to 0 per month.

4 Conclusions

The research papers unique contribution application of the DMAIC six sigma tools to verify the probable root causes of injury incidents, improvements over it, and tracking the improvement actions sustenance. We deployed the hypothesis testing, DOE, and ANOVA tools to check the two variables co relations and effects of the improvement actions. We found out the top seven injuries contributing 82% of the total injuries. We applied cause and effect diagram with the cross functional team, cause and effect matrix, and FMEA to find out the 15 probable input variables X. We applied the improvement actions over these input X variables and verified the process capability after improvement actions implementation which is found Ok. Finally, we reduced total burr and chip injury from 2 to 0 per month, hammer application points reduced from 21 to 06 numbers locations, and hammer workstation RPN of HIRA reduced from 343 to 96 as per our project charter objectives. We applied the theory of DMAIC six sigma techniques to reduce the overall safety incidence at manufacturing industry that may guide the managers to improve their workplace safety.

This research has limitations of parallel implementation of same actions at the other manufacturing industry. The managers may understand this case study and find the actions appropriate at their work place in future.

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