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RESEARCH PAPER

Application of DMAIC to Reduce the Rejection Rate of Starter Motor Shaft Assembly in the Automobile Industry: A Case Study

Sundaramali G [1*], Santhosh Raj K[2], Anirudh S[3], Mahadharsan R[4] & Senthil Kumaran S[5]

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ABSTRACT

One of the goals of the manufacturing industry in the globalisation era is to reduce defects. Due to a variety of factors, the products manufactured in the industry may not be defect-free. Six Sigma is one of the most effective methods for reducing defects. This paper focuses on implementing Six Sigma in the automobile industry's stator motor shaft assembly. The high decibel noise produced by the stator motor is regarded as a rejected piece. Six Sigma focuses on continuous improvement and aids in process optimization by identifying the source of the defect. In the Six Sigma process, the problem is measured and analysed using various tools and techniques. Before beginning this case study, its impact on the company in terms of internal and external customer cost savings is assessed. This case study was discovered to be in a high-impact area. The issue was discovered during the Core and Shaft pressing process. Further research leads to dimensional tolerance, which reduces the defect percentage from 16.5 percent to 0.5 percent.

KEYWORDS: *Six sigma; Lean management; Quality control; DMAIC; Process monitoring and control; Reliability.*

1. Introduction

The manufacturing sector has expanded dramatically in the twenty-first century. The manufacturing sector aspires to achieve high rates of growth and profitability. However, some of the parameters cannot be used as a limit to achieve better results. For example, Valles A et al and Vinodh S et al claim that using Six Sigma parameters can reduce the number of defects to 3.4 defects per million with 99.99966 percent efficiency. Six Sigma was introduced in the mid-1980s and was successfully implemented as a defect reduction method by Motorola [1], [2].

Six Sigma has successfully reformed several organisations [3]. Six Sigma is a statistical iterative strategy that focuses primarily on the customer's perspective [4]. Six Sigma is defined as a systematic, parallel-mesostructured approach to reducing variation in organisational processes through the use of improvement specialists, a structured method, and performance metrics to achieve strategic goals [5]. This process's implementation procedure is well documented [6] [6]. DMAIC (Design, Measure, Analyze, Improve, Control) is highlighted by Six Sigma [7]. Despite the fact that other quality control methods, such as poke yoke, exist, Six Sigma methods effectively solve problems in high-impact projects [8]. This strategy's three primary

* Corresponding author: ***Sundaramali G***
sundaramali.g@vit.ac.in

1. *Department of Manufacturing Engineering, School of Mechanical Engineering, Vellore Institute of Technology, Vellore, Tamil Nadu, India.*
2. *Department of Manufacturing Engineering, School of Mechanical Engineering, Vellore Institute of Technology, Vellore, Tamil Nadu, India.*
3. *Department of Manufacturing Engineering, School of Mechanical Engineering, Vellore Institute of Technology, Vellore, Tamil Nadu, India*
4. *Department of Manufacturing Engineering, School of Mechanical Engineering, Vellore Institute of Technology, Vellore, Tamil Nadu, India*
5. *Department of Manufacturing Engineering, School of Mechanical Engineering, Vellore Institute of Technology, Vellore, Tamil Nadu, India.*

outcomes are higher product quality, increased profits, and defect reduction [9]. The Six Sigma methodology has been widely used to improve performance and lower costs in a variety of industrial fields [10]. Six Sigma can reduce defects in an organisation to as few as 3.4 parts per million [11]. Because there is a relationship between process variability and product specification, using statistical tools can eliminate or significantly reduce variability, making the process and product more efficient[12]. Six Sigma methodology is thus chosen to reduce rejecting defects because it has been shown to increase performance and decrease process variation. It is also in charge of quality improvement, process improvement, cycle time reduction, customer satisfaction, cost-cutting, productivity improvement, and defect elimination [13]. It is important to emphasise that it is a method for solving manufacturing and business processes. Six Sigma as a philosophy aids in changing the world and transforming an enterprise [14].

2. Literature review

The six sigma methodology can be used to improve the products, services, and processes of a company [15]. It is a methodical approach based on business strategy that aims to improve financial performance and customer satisfaction. Six Sigma is a comprehensive methodology with strategies, tools, and techniques that include total quality management principles, a strong customer focus, financial results, project management, and data analysis. DMAIC, DMADV, and DFSS are three critical methodologies in Six Sigma[16]. The Six Sigma technique, according to Swarnakar V and Vinodh S, can sustain high-impact projects [17]. If properly implemented, it leads to overall process improvement by reducing the causes of defects and can benefit organisations financially.

The reduction of rejection of the two-wheeler carburetor piston valve resulted in a yearly cost savings of 1.01 lakhs [18]. In the 1980s, Ford Motor Company promoted the philosophy "Quality is Job One," propelling them to the top of the world. They have emphasised that higher quality leads to higher customer satisfaction [19]. The automobile industry, according to Kumaravadivel A and Natarajan U, may be a good fit for the Six Sigma methodology [20]. It improves their operations and contributes to the long-term growth of the organisation. The textile industry's defect percentage was reduced from 8.25 to 2.63 using Six Sigma methods, resulting in significant production efficiency and an increase in Six Sigma level from 2.9 to 3.1 [21]. When Six Sigma was applied, the inkjet printing industry saw a baseline Six Sigma of about 3.35 with a gain of 0.37 sigma, representing the elimination of 1.88 percent of non-conforming units [10].

In any industry, various Six Sigma approaches can be used to achieve the best results [22]. According to Prashar A, integrating Six Sigma and data-driven processes always allows the company to excel by increasing productivity while decreasing rejection[23]. To achieve proper production success in industries by encouraging proper implementation and strict adherence to rules [24]. The Six Sigma method is beneficial to the automobile industry as well as other industries such as healthcare, market research, food processing, service, and textiles [25]–[28]. Several studies have been conducted by researchers to identify the benefits, challenges, and future of Six Sigma methodology in the manufacturing sector [29].

The application of the Six Sigma Methodology to the micro assembly production process was discussed [30]. The causes of defects are identified, and corrective actions are proposed to eliminate them in order to improve the quality of the micro assemblies. The number of Sigma has increased in value. The number of discrepancies decreased from 198 to 155, or 1.28 times, lowering the degree of variability. The author employed a voice of the customer (VOC) matrix and a project charter. To determine the potential causes of the long wait time, a cause and effect diagram was used. Brainstorming sessions were also held to gain a better understanding of the long call handling times, and suggestions were made to improve them. SMED analysis was also performed to assess the various changeover elements in the company. The average queue length for the first shift was reduced from 4.433 to 3.6, resulting in an estimated annual profit of $29250 [31].

The researcher completed the DMAIC phases and discovered that the green sand moulding process needed to be replaced with a shell moulding process to avoid increased hardness and casting rejection due to pinhole defects [21]. When this solution was implemented, productivity increased by 50.42 units per hour, and quality increased from 3.2 Sigma to 4.4 Sigma [32]. Goffnett SP et al. provided a summary of the past, present, and future trends of LSS as a powerful business strategy and problem-solving methodology for all industrial sectors, regardless of size or nature

G[33]. The documentation of the history and recent developments in LSS should be useful to academic researchers[34]. Sony M and Mekoth N presented a fictitious business case involving the Six Sigma DMAIC model and drone capacity and reliability [35]. The authors investigated the various dimensions that an employee must adapt to when implementing LSS. They conducted an integrative literature review for the last 25 years, and they conducted studies on the implementation aspects of LSS [36].

Desai DA investigated the improvement of cable insulation productivity through the use of Lean Six Sigma [37]. Six Sigma (Lean) (LSS). Define, measure, analyse, improve, and control (DMAIC) and failure mode effect and criticality analysis (FMECA) are used to identify one of the critical problems in a case company that is breaking and cracking in the insulation layer of cables. Three major factors were considered, each with two fixed levels (supplier, temperature, and pressure). According to the findings, the risk priority number (RPN), a productivity indicator, was reduced from 745 to 205. Furthermore, the experiment resulted in fewer defects, which resulted in increased productivity.

In terms of Indian industries, there has been little investigation into the application of Six Sigma in step-by-step procedures. Desai DA demonstrated a real-life case study, applied DMAIC Six Sigma at a small-scale jobbing engineering firm, and demonstrated that profitability could be improved as a result [38]. The same author also used Six Sigma principles to conduct a real-life case study at a small-scale foundry industry [37]. It also used the DMAIC methodology to explain foundry quality and productivity improvements. Chaurasia B et al. recently demonstrated a study using DMAIC and the strategic application of Lean Six Sigma (LSS) to improve first through (FTT) and reduce scrap formation in the Indian automotive industry [39]. As a result, there was a total breakthrough in waste reduction. As a result, the use of DMAIC for quality improvement of manufacturing processes in the automotive industry is limited [40], [41].

There is also no literature on Six Sigma motor shaft assembly. As a result, the following research is being carried out to fill this void. Producing better products or providing better services with fewer resources. It was about getting more done with less and doing it better.

3. Methodology

This study follows the Six Sigma methodology referred to as DMAIC. The steps included in all the phases have been summarised below in Table 1.

Tab. 1. DMAIC-Define, measure, analyse, improve, control

Phase	*Definition*	*Points*
Define	A problem statement is clearly specified with the boundary condition so that the problem could be solved.	-Identify and State the Problem -Identify the Impact Rating of the Problem -Identify Team Leader and Members -Plan for the remaining phases -Identify Baseline and Target
Measure	Measure suggests the recording of all the data that are related to the problem statement.	-Understand the Problem -Observe the process, collect and analyze data -Identify Suspected Sources of Variation (SSV's) for the problem
Analyze	Analysis of the measured data takes place, and source of variance (SV) hasbeen found	-Pin-point the real reasons for creatingthe problem
Improve	A solution for the SV is provided.	-Validate the pin-pointed causes -Identify solutions, evaluate andImplement
Control	Action to control the root cause for an extended period with the implementationof the solution.	-Monitor and control the pin-pointedcauses -Monitor and control the problem

- Identify the product characteristics wanted by customers.
- Classify the characteristics in terms of their criticality.
- Determine if the classified characteristics are controlled by part and process.
- Determine the maximum allowable tolerance for each classified characteristic.
- Determine the process variation for each classified characteristic.
- Change the design of the product, process, or both to achieve Six Sigma performance.

4. Case Study

This Six Sigma case study was undertaken in Automotive Industry. It was a six-month-long project with different phases having a clear-cut period to complete the task. Improve phase took the most extended period, followed by Analyze, Control, and Measure phases. The defined phase took the shortest period. The date distribution of the study is given in Table 2.

Tab. 2. Date distribution of conducting various phases of DMAIC

Phase	*Start Date*	*End Date*
Define	20.06.2019	20.06.2019
Measure	21.06.2019	05.08.2019
Analyze	06.08.2019	20.10.2019
Improve	21.10.2019	01.12.2019
Control	02.12.2019	01.01.2020

Around eight different types of Six Sigma tools were used in this work. Some of the tools are statistical and necessitate extensive data collection and work on the theoretical formula. Others include Shainin and Quality Control Tools, requiring less data and focusing on the problem-solving technique's speed, efficiency, and sustainability. Table 3 contains a detailed list of the tools used in this case study.

Tab. 3. List of tools used in the process

Phase	*Tool No.*	*Tool Name*	*Type of Tool*	*Origin*
Define	1	Variation Analysis	Data	Statistical
Measure	2	Process Mapping	Analytical	General
Measure	3	P-Chart	Data	Quality Control
Measure	4	Cause and Effect Diagram	Analytical	Quality Control
Measure	5	Pareto	Data	Quality Control
Analysis	6	Paired Comparison	Data	Shainin
Improve	7	B Vs C	Data	Shainin
Control	8	Process Capability Analysis	Data	Statistical

4.1. Identification of problem

Before starting the project, identification and defining the problem statement is essential because making a mistake in this phase will lead to the wrong outcome. The problem that is addressed in this work is "**Loud noise of stator motor**". Validation of the problem statement will lead to the classification of the problem as a driving problem or as a non-driving problem. The tool used to validate the problem is **Tool#1** Variation Analysis.

Tool#1 – Variation Analysis

There are 3 types of variation analysis

4.2. Part to part(P2P) Variation

4.3. Time to time (T2T) Variation

4.4. Stream to stream (S2S) Variation

It is well known that the value obtained in part to part variation should be greater than the value obtained in time to time variation. The value obtained in time to time variation should be greater than the value obtained in a stream-to-stream variation. Variation Analysis took 2 hours with a minimum of 8 equal intervals with at least 3 trials in each interval. Table 4 shows the results of the data collection.

Tab. 4. Variation analysis values

Time	*Part*	*Min*	*Max*	*Avg.*	*Time*	*Part*	*Min*	*Max*	*Avg.*
3.00	1	65.56	70.61	68.34	4.00	1	66.92	69.43	67.8
	2	67.7	69.4			2	65.33	68.12	
	3	66.85	69.93			3	66.7	70.3	
		2.14	1.21	0.93			1.59	2.18	0.59
3.15	1	66.03	68.79	68.18	4.30	1	67.38	69.23	67.65
	2	67.18	70.16			2	65.8	68.28	
	3	67.75	69.17			3	65.11	70.14	
		1.72	1.37	0.35			2.27	1.86	0.41
3.30	1	65.48	70.47	67.985	4.45	1	67.67	68.45	68.298
	2	66.35	69.7			2	67.83	70.28	
	3	67.62	68.29			3	66.41	69.15	
		2.14	2.18	0.04			1.42	1.83	0.41
3.45	1	67.36	70.26	68.55	5.00	1	65.2	69.94	68.305
	2	66.95	70.39			2	66.16	69.88	
	3	67.23	69.14			3	67.96	70.69	
		0.41	3.12	2.71			2.76	0.81	1.95

Calculation:
P2P Variation = 2.94 dB T2T Variation = 0.923 dBS2S Variation = 0.9 dB
Upper Control Limit (UCL): 2.575(Constant)*Average Part to Part Variation=2.575 * 2.94 = 7.5705 dBSigma = Average Part to Part variation/1.693(Constant) = 2.94/1.693 = 1.736 dB
Estimated Part to Part variation = 6 * Sigma = 6*1.736 =10.4193 dB
Estimated Part to Part variation/Tolerance*100 = (10.419/12.5) *100 = 83.35%
The ratio of estimated P2P Variation / Tolerance is more excellent than 75%, which implies a problem in the process, and not all the P2P variations are within the upper control limit. Therefore, the problem statement is accurate, and it is not a driving problem, and it is accepted as 'Big Y'.

4.2. Define phase

The define phase is used to determine the significance of the project's problem. This phase also defines the problem statement's constraints. Setting constraints aids in staying on track with the problem statement. "Impact Rating" determines the priority of the problem statement. The type of project determines the Impact Rating, the nature of the project (refer to Table 5 and Figure 1), the impact on the internal customer, the impact on the external customer, data-oriented analysis, cross-functional rating, expected savings (Lakh), and the baseline in PPM. The impact rating is detailed in Table 6.

Tab. 5. Type of six sigma projects

	Cause Known	*Cause Unknown*
Solution Known	Type-I	Type-III
Solution Unknown	Type-II	Type-IV

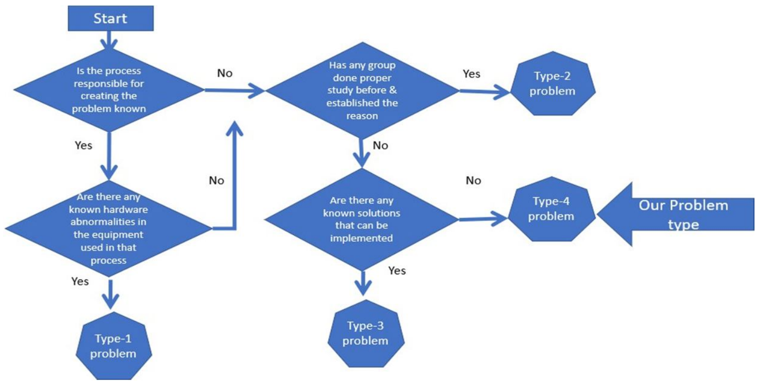

Fig. 1. Categorisation of six sigma problem

There are four type of projects in Six Sigma. Type-I, II, and III can be solved directly by improve and control Phase; it doesn't require the first 3 phases. Only Type–IV will be required to proceed from the define to control phase.

Both solution and cause of the problem known means doesnot require six sigma methodology.

Solution known and cause unknown or vise versa does not require Define, measure, and analysis phase. Can directly jump to improve and control phase.

Only the type 4 problem were both solution and cause are unknown. It requires all the 5 phase of the Six Sigma methodology.

Tab. 6. Impact factor Details

S. No.	*Criteria*	*Weightage*	*Options*	*Rating Score*	*Actual Score (Weightage * Rating Score)*
1	Type of Project	15%	Type-I	0.4	-
			Type-II	0.6	-
			Type-III	0.8	-
			Type-IV	1.0	15
2	Nature of Project	10%	Problem Solving	0.4	4
			Process Optimisation	0.6	-
			Innovation	0.8	-
			Perceived Quality	1.0	-
3	Impact of Internal Customer	10%	Low	0.2	-
			Medium	0.5	5
			High	1	-
4	Impact of External Customer	15%	Low	0.2	-
			Medium	0.5	15
			High	1	-
5	Data-Oriented Analysis	15%	No data	0.1	-
			Less Data	0.4	-
			Medium data	0.7	10.5
			Data-Intensive	1.0	-
6	Cross-Functional Rating	10%	Low	0.2	-
			Medium	0.5	-
			High	1.0	10
7	Expected Saving in ₹ Lakhs	10%	<= 1 Lakh	0.2	2
			>1 &<=5 Lakhs	0.6	-

			>5 &<=10 Lakhs	0.8	-
			>10 Lakhs	1.0	-
8	Base Line in PPM	15%	<= 10,000 PPM	0.2	-
			>10,000 &<=30,000 PPM	0.6	-
			>30,000 &<=100,000 PPM	0.8	-
			>100,000 PPM	1.0	15
	Total	100%			76.5

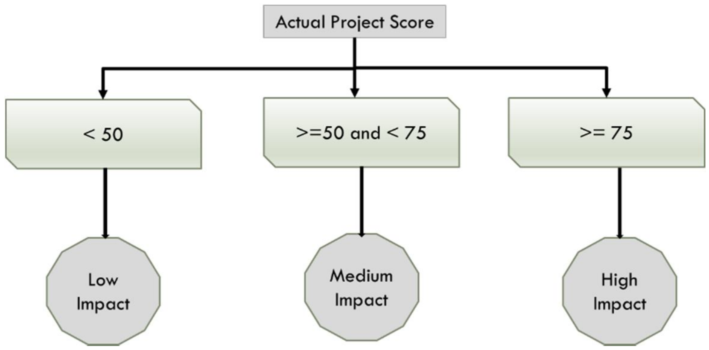

Fig. 2. Actual project score meaning

From table no. 6, the impact rating of this project is estimated to be 76.5 %, and anything above 75% (Refer Fig.No. 2) will have a HIGH impact on the firm.

Problem Statement/Big Y - "The noise produced by the 2-wheeler stator motor is very high."

Existing rejected Product: - 165,000 PPM

Target reject product: - Approx. 33,000 PPM (20% of existing rejection product)

Novelity

- Define a problem statement as Type 1, Type 2, Type 3 or Type 4 statement.
- Introduced an actual project score.
- Criteria and weightage of the problem statement are in table 6
- based on the actual project score the industry or the Project manager can decide to continue the project or drop the project or can be implemented later.
- Methods used in other paper are the directly to the problem statement and solution they have not analysed how important for the company to solve this problem.

4.3. Data collection and measure phase

Collection of data that is actually or expected to relate with the problem statement are noted down, and three toolshave been used in this phase.

Tool#2 – Process Mapping

Armature assembly

The starter motor is made up of an armature shaft, a stack, and copper coils. Initially, the shaft is assembled with the stack under pressure, and then a commutator bar is attached to its bottom. Once attached, the armature is moved to the winding machine, where copper coils wind the armature and commutator. Once completed, the commutator is welded with copper wire, and the voltage difference is checked. Finally, the armature is moved to the coating section, where it is coated.

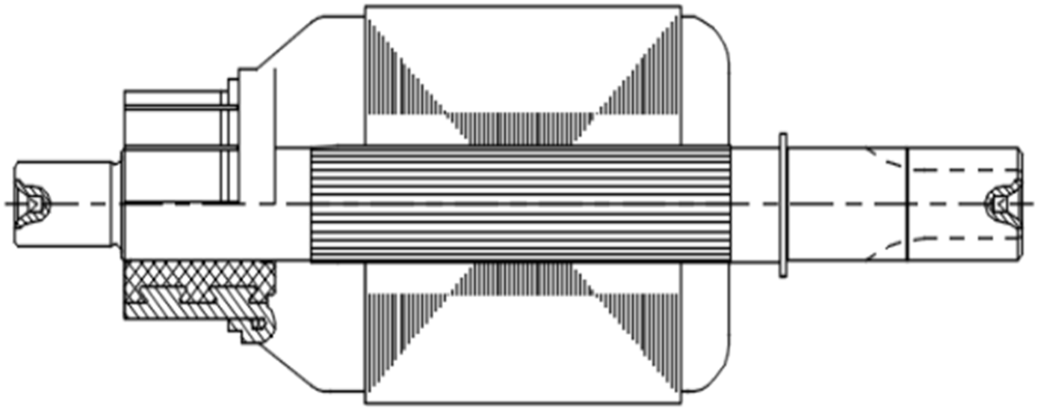

Fig. 3. Cross-section view of armature

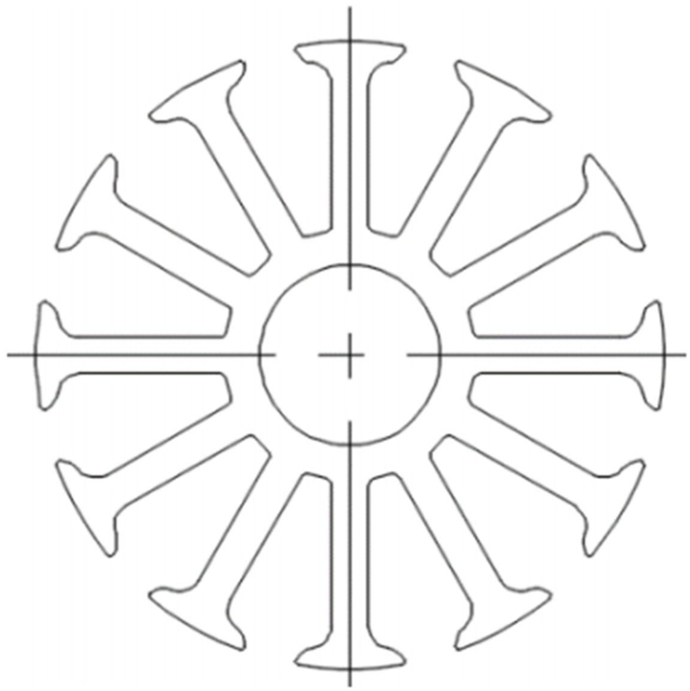

Fig. 4. Cross-section view of lamination pack

A process map is a flow chart that describes the manufacturing process of a product. In this case, it is the production of the Stator motor. "Will there be any unstable events that could happen to cause the problem?" is asked in the opposite direction from the stage of problem identification. This is done in the opposite direction to reduce the amount of time required to identify the problematic stage. In this case study, core and shaft pressing was expected to be a difficult stage. A flowchart of the Stator motor manufacturing process is shown in Figure 3.

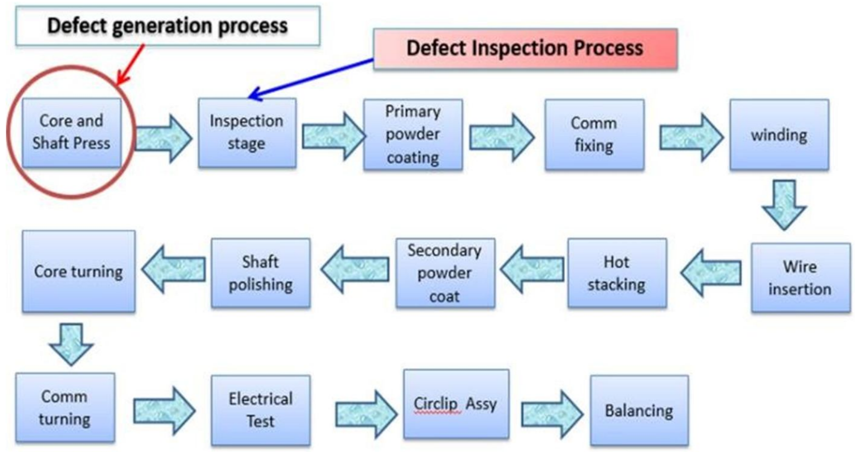

Fig. 5. Process flow Cchart

Tab. 7. Process parameter

Process parameter	*Standard*	*Observed*	*Conclusion*	*Correction*	*Permanent action*
Shaft checking pressure	2-4 bar	2.5 bar	OK	NA	NA
Hydraulic pressure forcore pressing	40 to 60kg/cm^2	50kg/cm^2	OK	NA	NA
Input air pressure	4 – 6 bar	5 bar	OK	NA	NA
Pressing load	400-1000kg	1400kg	Not OK	Capture point to be set	NA
Intermediate toolpressure	-	10 -20 kg/cm^2	OK	NA	NA

Tool #3 – P-Chart

The P-Chart is an essential tool for detecting process irregularities. A p-chart was created to depict the number of products manufactured and rejected over the last six months since the research project. Changes in suppliers, machine maintenance work, machine breakdowns, operator changes, tool condition, and other factors could contribute to abnormal behavior.

Figure 4 shows that no such abnormalities were discovered, which could explain why the defect percentage is so high (PPM). It has been confirmed that defective products are not affected by external factors and no rejection pattern. Table 7 lists the process parameters that have been studied.

Tab. 8. Past 6 months data

Month	*Numbers Inspected*	*Numbers rejected*
Jan 2019	1914	354
Feb 2019	2302	346
Mar 2019	4316	776
Apr 2019	1436	209
May 2019	2456	420
June 2019	3120	479

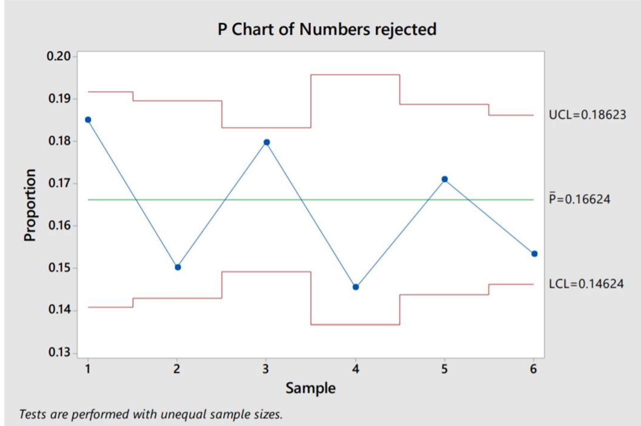

Fig. 6. P chart on number of rejection

- UDL (+) = Median (+) + 1.45*d
- LDL (+) = Median (+) – 1.45*d
- UDL (-) = Median (-) + 1.45*d
- LDL (-) = Median (-) – 1.45*d

Tool#4 - Cause and Effect Diagram

The cause-and-effect diagram is used to identify potential sources of variation in that process. A cause-and-effect diagram was used to identify up to 15 SSVs in the Core Pressing Stage. SSVs are also listed in Table 9.

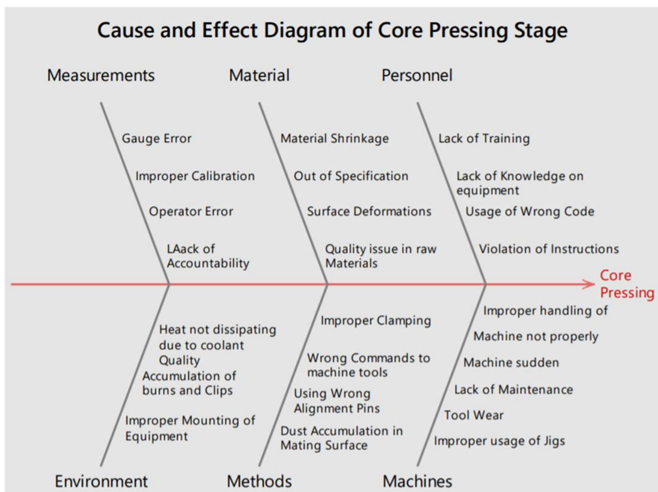

Fig. 7. Cause and effect diagram of core pressing stage

Tab. 9. Details of suspected source of variations

S.no.	*Suspected Source of Variation*	*Type of Cause*	*Design SSV or Variation SSV*	*Stoppage time (Seconds)*
1	Core ID top side	Operational Cause	Variation SSV	477
2	Core ID bottom side	Operational Cause	Variation SSV	539
3	Core Face out	Operational Cause	Variation SSV	364
4	Shaft run-out	Operational Cause	Variation SSV	448
5	Shaft knurling diameter run out	Operational Cause	Variation SSV	658
6	Shaft knurling diameter bottom	Operational Cause	Variation SSV	691

7	Shaft knurling diameter middle	Operational Cause	Variation SSV	498
8	Knurling diameter top	Operational Cause	Variation SSV	354
9	Knurling tie tapper	Operational Cause	Variation SSV	441
10	Interference bet shaft middle lamination	Operational Cause	Variation SSV	463
11	Interference bet shaft bottom lamination	Operational Cause	Variation SSV	430
12	Interference bet shaft top lamination	Operational Cause	Variation SSV	419
13	Pressing load	Scientific Cause	Variation SSV	672
14	Push of load	Scientific Cause	Variation SSV	498
15	Shaft run-out after pressing	Operational Cause	Variation SSV	546

Tool #5 - Pareto

According to Pareto's law, 20% of the SSVs cause 80% of the problems. The Pareto tool is used to prioritize the problem/defects. The Pareto tool is used to separate the critical few causes of a problem or effect from the insignificant many, i.e., focusing on a few SSVs. According to the law in Figure 6, three SSVs have been identified as the source of variation. They are

1. Shaft knurling diameter bottom
2. Pressing load
3. Shaft knurling diameter run-out

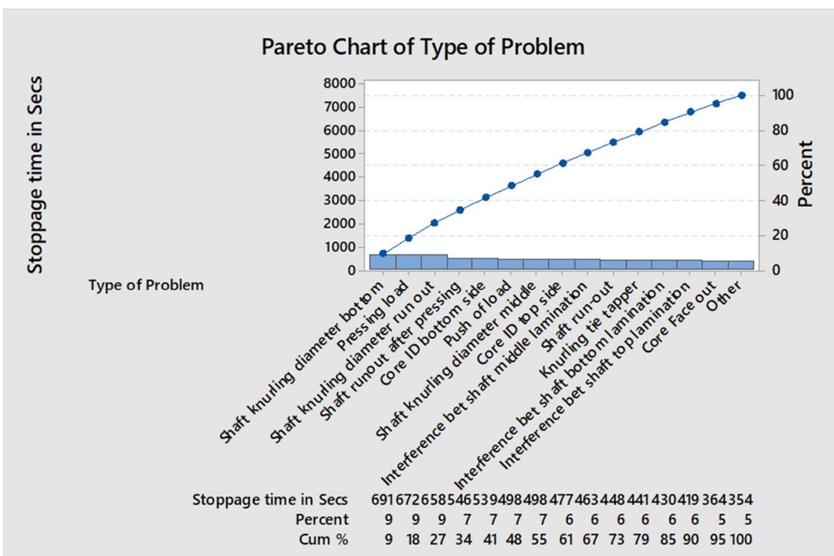

Fig. 8. Pareto chart of type of problem

4.4. Phase analysis

Know coming to the analysis stage. In this stage, analysis of data that have been recorded in the measure takes place.

Tool #6 - Paired Comparison

The paired comparison tool is one of the Shainin tools in Six Sigma that processes less data. The parameters mentioned above were measured on 8 Best of Best (BOB) and 8 Worst of Worst (WOW) parts. The measured parameters are arranged in ascending order to yield the total count. If the total count exceeds 6, the parameters are the confirmed causes. The root cause of the problem is revealed in Table 10.

Fig. 9. Good sample

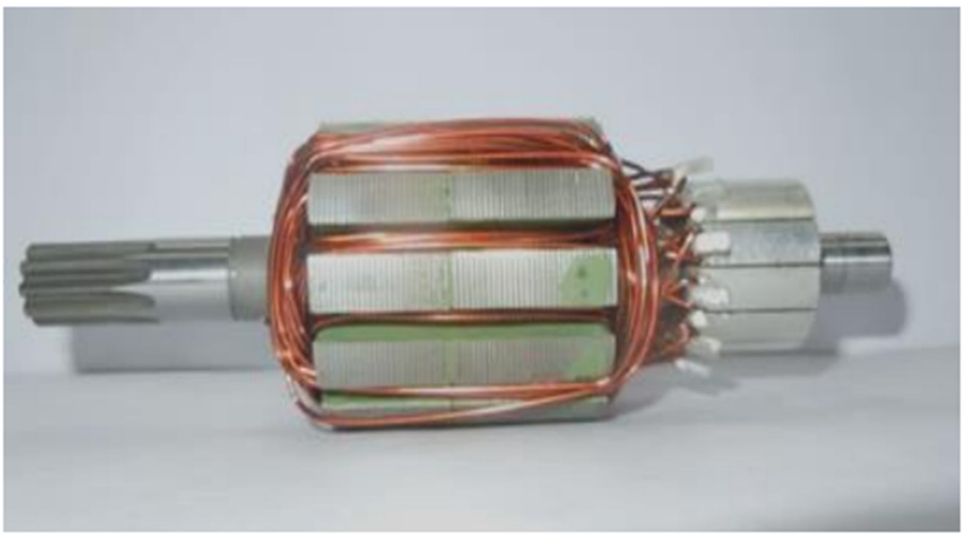

Fig. 10. Bad sample

Tab. 10. Paired comparison results/ count estimation of SSV's

S. No	*Bush end (spec 12.35-12.46 mm)*	*S. No*	*Shaft run-out before the core pressing*	*S. No*	*Interference between shaftbush side lamination bottom*
G1	327	G3	1	G5	0.067
G5	327	G8	2	G1	0.077
G2	326	G4	3	G2	0.086
G6	340	G5	4	G7	0.086
G3	340	G6	4	G3	0.09
G4	345	G7	4	G6	0.09
G7	346	B3	6	G4	0.095
B4	350	B1	8	B1	0.1
B5	350	B2	8	B5	0.1
G8	357	G1	9	G8	0.107
B1	361	G2	9	B1	0.111
B2	362	B4	13	B2	0.112
B6	362	B5	14	B6	0.112

B3	363	B8	14	B3	0.113
B7	370	B6	19	B7	0.12
B8	372	B7	20	B8	0.122
END COUNT	13	END COUNT	11	END COUNT	13

The following changes are suggested to improve the process:

1. The new Bush end specification has been changed from 12.35-12.46 to 12.30-12.35. Because less than 12.30 may cause other functional issues, a lower specification of 12.30 is frozen.
2. Shaft run-out before core pressing was reduced to 0-0.5 micron. The higher specification of 5 microns is set.
3. Modified specification of interference between bottom shaft bush side lamination to 0.067-0.1 microns. Since less than 0.67 microns can result in other functional problems, lower specification is frozen at 0.067 microns.

4.5. Improve phase

Improve phase validates the acquired solution. Tool #7 – B Vs C

B Vs C, which stands for Better Vs Current. This tool is used to identify whether there is any type of improvement in respect to defect percentage. B Vs C is the only tool that is available in the Improve Stage. Table 11 shows the data used in the B vs C operation.

Tab. 11. Validation using B vs C

Test	*Better*	*Current*
1st Trial	8.98	16.22
2nd Trial	10.17	15.10
3rd Trial	11.03	17.62
Median	10.17	15.10
Range	2.05	2.22
D (Difference Between Two Medians)	4.93	
d (Average of Two Ranges)	2.13	
D/d	2.31	
Average	10.06	16.31

The D/d ratio was found to be 2.31, which is greater than 1.25, and hence confirms that there is no overlap. Also, there is a difference in the component.

4.6. Control phase

Tool #8- Process Capability Analysis

Process capability analysis tool identifies whether there is any improvement in the product or not and checks for controlling parameters how long it can be controlled. Table 12 gives the required parameters.

Tab. 12. Control table

S. No.	*Description*	*Records*
1	Part Number selected for Validation	26024659(u69)
2	Average of B	10.06
3	Average of C	16.31
4	$X_b - X_c$ (Amount of Improvement)	6.25
5	Sigma(b)[Standard Deviation]	4.47
6	K*Sigma(b)	3.7*4.47=16.539
7	Is $X_b - X_c$<= K*Sigma(b)	Yes
8	Confidence level of improvement	@90%

Before starting this project, the defect ratio was 16.5%, and Process Capability Index (CPK) value was 0.25. After implementing the required changes, the defect ratio dropped to 0.5%, and the CPK value improved to 0.74. Figure 7 shows the improvement in the other parameters.

Tab. 13. Details of the component

S. No.	*Description*	*Records*
1	Part number selected for validation	BMW SHAFT AND CORE ASSEMBLY
2	Better Condition	Interference less than 110 micron
3	Current Condition	Interference > 160 micron
4	Sample size	3 batches
5	Sample type	Nos/Batch
6	Response decided for monitoring	Run out on bearing diameter after core assembly <20micron
7	Lot quantity (for batches)	60

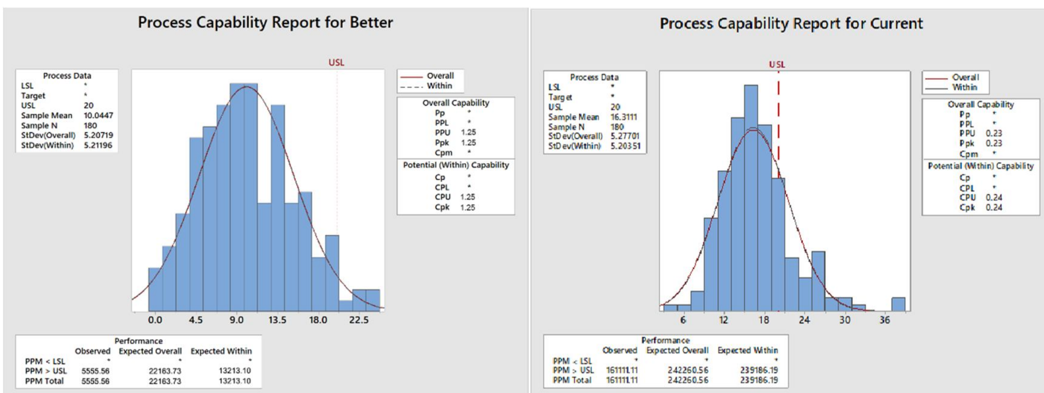

Fig. 11. Process capability for current condition and better condition

Comparison between before and after implementation are shown in Table 13.

Tab. 13. Comparison between before and after implementation

Implementation	*Current CPC*	*Better CPK*	*Level of implementation*	*Defects level*
Before	0.25	-	@	16.5%
After	-	1.25	90%	0.5%

5. Conclusion

Six Sigma is the relentless pursuit of reducing variation in all critical processes in order to achieve improvement. Six Sigma can have an impact on the organization's bottom line or top line, as well as increase customer satisfaction on all levels. This research work focuses on selecting the correct problem statement by categorising it as a driving problem or a non-driving problem, as well as the project's impact on cost-cutting and company development. It also describes the precise methodology for determining the root cause and leading cause, as well as how to proceed.

The implementation of these calculations resulted in a new situation for the manufacturing process. The best possible solution has been proposed after a thorough analysis of the problem. The defect rate was reduced from 16.5 percent to 0.5 percent without reducing the number of products produced. The cost avoided as a result of this case study is estimated to be $97,000. From sigma level 1.0 to sigma level 2.0, the CPK for the process increased from 0.24 to 1.25.

6. Further Research Direction

More efforts can be made in the future to incorporate more digital transformation concepts into Six Sigma application processes. Attempts at quality control and management in the automotive industry can also be made using other methodologies such as DMADV and DFSS. Six Sigma can be used in fields other than automotive and healthcare.

References

[1] A. Valles, J. Sanchez, S. Noriega, and B. Gómez Nuñez, "Implementation of Six Sigma in a manufacturing process: A case study," *Int. J. Ind. Eng. Theory Appl. Pract.*, Vol. 16, No. 3, (2009), pp. 171-181.

[2] S. Vinodh, S. G. Gautham, and A. Ramiya R., "Implementing lean sigma framework in an Indian automotive valves manufacturing organisation: A case study," *Prod. Plan. Control*, Vol. 22, No. 7, (2011), pp. 708-722.
Doi: 10.1080/09537287.2010.546980.

[3] B. Tjahjono *et al.*, "Six sigma: A literature review," *Int. J. Lean Six Sigma*, Vol. 1, No. 3, (2010), pp. 216-233.
Doi: 10.1108/20401461011075017.

[4] Y. H. Kwak and F. T. Anbari, "Benefits, obstacles, and future of six sigma approach," *Technovation*, Vol. 26, Nos. 5-6, (2006), pp. 708-715.
Doi: 10.1016/j.technovation.2004.10.003.

[5] J. Antony, M. Sony, M. Dempsey, A. Brennan, T. Farrington, and E. A. Cudney, "An evaluation into the limitations and emerging trends of Six Sigma: an empirical study," *TQM J.*, Vol. 31, No. 2, (2019), pp. 205-221.
Doi: 10.1108/TQM-12-2018-0191.

[6] J. A. Ghani, I. A. Choudhury, and H. H. Hassan, "Application of Taguchi method in the optimization of end milling parameters," *J. Mater. Process. Technol.*, Vol. 145, No. 1, (2004), pp. 84-92.
Doi: 10.1016/S0924-0136(03)00865-3.

[7] M. Smętkowska and B. Mrugalska, "Using Six Sigma DMAIC to Improve the Quality of the Production Process: A Case Study," *Procedia - Soc. Behav. Sci.*, Vol. 238, (2018), pp. 590-596.
Doi: 10.1016/j.sbspro.2018.04.039.

[8] G. Sundaramali, S. Abinav Shankar, and M. Manoj Kummar, "Non-conformity recovery and safe disposal by Poka Yoke and hallmarking in a piston unit," *Int. J. Product. Qual. Manag.*, Vol. 24, No. 4, (2018), pp. 460-474.
Doi: 10.1504/IJPQM.2018.093445.

[9] G. Ombach and J. Junak, "Design of PM brushless motor taking into account tolerances of mass production - Six sigma design method," *Conf. Rec. - IAS Annu. Meet. (IEEE Ind. Appl. Soc.*, (2007), pp. 2139-2146.
Doi: 10.1109/IAS.2007.324.

[10] E. V. Gijo, J. Scaria, and J. Antony, "Application of six sigma methodology to reduce defects of a grinding process," *Qual. Reliab. Eng. Int.*, Vol. 27, No. 8, (2011), pp. 1221-1234.
Doi: 10.1002/qre.1212.

[11] S. K. Gandhi, A. Sachdeva, and A. Gupta, "Reduction of rejection of cylinder blocks in a casting unit: A six sigma DMAIC perspective," *J. Proj. Manag.*, Vol. 4, (2019), pp. 81-96.
Doi: 10.5267/j.jpm.2019.1.002.

[12] R. S. Raman and Y. Basavaraj, "Defect reduction in a capacitor manufacturing process through six sigma concept: A case study," *Manag. Sci. Lett.*, Vol. 9, No. 2, (2019), pp. 253-260.
Doi: 10.5267/j.msl.2018.11.014.

[13] N. F. Habidin and S. M. Yusof, "Critical success factors of lean six sigma for the malaysian automotive industry," *Int. J. Lean Six Sigma*, Vol. 4, No. 1, (2013), pp. 60-82.
Doi: 10.1108/20401461311310526.

[14] Y. Narottam, K. Mathiyazhagan, and K. Kumar, "Literature review: Continuous improvement through Lean Six Sigma," *Int. J. Product. Qual. Manag.*, Vol. 28, No. 1, (2019), pp. 3-27.
Doi: 10.1504/IJPQM.2019.102423.

[15] J. Antony, M. Kumar, and M. K. Tiwari, “An application of Six Sigma methodology to reduce the engine-overheating problem in an automotive company,” *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.*, Vol. 219, No. 8, (2005), pp. 633-646.
Doi: 10.1243/095440505X32418.

[16] N. F. Habidin, S. Mohd Yusof, and N. Mohd Fuzi, “Lean Six Sigma, strategic control systems, and organizational performance for automotive suppliers,” *Int. J. Lean Six Sigma*, Vol. 7, No. 2, (2016), pp. 110-135.
Doi: 10.1108/IJLSS-04-2015-0013.

[17] V. Swarnakar and S. Vinodh, “Deploying Lean Six Sigma framework in an automotive component manufacturing organization,” *Int. J. Lean Six Sigma*, Vol. 7, No. 3, (2016), pp. 267-293.
Doi: 10.1108/IJLSS-06-2015-0023.

[18] P. Parsad and D. R. Prajapati, “Reduction of rejection of an automobile part using Six Sigma approach,” no. February, 2015, [Online]. Available: https://www.researchgate.net/publication/272742514_Reduction_of_Rejection_of_AN_Automobile_Part_Using_Six_Sigma_Approach.

[19] S. Nallusamy, R. Nivedha, E. Subash, V. Venkadesh, S. Vignesh, and P. Vinoth Kumar, “Minimization of rejection rate using lean six sigma tool in medium scale manufacturing industry,” *Int. J. Mech. Eng. Technol.*, Vol. 9, No. 1, (2018), pp. 1184-1194.

[20] A. Kumaravadivel and U. Natarajan, “Application of Six-Sigma DMAIC methodology to sand-casting process with response surface methodology,” *Int. J. Adv. Manuf. Technol.*, Vol. 69, No. 5-8, (2013), pp. 1403-1420.
Doi: 10.1007/s00170-013-5119-2.

[21] R. K. Misra and A. Chauhan, “Six Sigma approach for reducing rejection of in-house cast component,” *Int. J. Six Sigma Compet. Advant.*, Vol. 9, Nos. 2-4, (2015), pp. 208-221.
Doi: 10.1504/IJSSCA.2015.074964.

[22] G. Sundaramali *et al.*, “Reduction of hole misalignment in turbocharger center housing,” *Int. J. Qual. Reliab. Manag.*, Vol. ahead-of-print, No. ahead-of-print, (2021).
Doi: 10.1108/ijqrm-08-2020-0285.

[23] A. Prashar, “Adoption of Six Sigma DMAIC to reduce cost of poor quality,” *Int. J. Product. Perform. Manag.*, Vol. 63, No. 1, (2014), pp. 103-126, (2014).
Doi: 10.1108/IJPPM-01-2013-0018.

[24] J. De Mast and J. Lokkerbol, “An analysis of the Six Sigma DMAIC method from the perspective of problem solving,” *Int. J. Prod. Econ.*, Vol. 139, No. 2, (2012), pp. 604-614.
Doi: 10.1016/j.ijpe.2012.05.035.

[25] Sameer Kumar and Michael Sosnoski, “Using DMAIC Six Sigma to systematically improve shopfloor production quality and costs,” *Int. J. Product. Perform. Manag.*, Vol. 58, No. 3, (2009), pp. 254-273.
Doi: 10.1108/17410400910938850.

[26] D. M. A. Kulasooriya and K. K. A. N. Kumarasinghe, “Application of Six Sigma Methodology in Glazing and Printing Processes: The Case of Lanka Wall Tiles PLC,” *NSBM J. Manag.*, Vol. 1, No. 2, (2016), p. 127.
Doi: 10.4038/nsbmjm.v1i2.14.

[27] A. Pugna, R. Negrea, and S. Miclea, “Using Six Sigma Methodology to Improve the Assembly Process in an Automotive Company,” *Procedia - Soc. Behav. Sci.*, Vol. 221, (2016), pp. 308-316.
Doi: 10.1016/j.sbspro.2016.05.120.

[28] R. Sharma, “Overall equipment effectiveness measurement of TPM manager model machines in flexible manufacturing environment: A case study of automobile sector,” *Int. J.*

Product. Qual. Manag., Vol. 26, No. 2, (2019), pp. 206-222.
Doi: 10.1504/IJPQM.2019.097767.

[29] P. Jirasukprasert, J. A. Garza-Reyes, V. Kumar, and M. K. Lim, "A six sigma and dmaic application for the reduction of defects in a rubber gloves manufacturing process," *Int. J. Lean Six Sigma*, Vol. 5, No. 1, (2015), pp. 2-22.
Doi: 10.1108/IJLSS-03-2013-0020.

[30] A. Smolenceva and F. Miftakhutdinova, "Applying the Six Sigma Methodology," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 666, no. 1, 2019, doi: 10.1088/1757-899X/666/1/012039.

[31] R. Adhyapak, A. Baby, and S. Koppuravuri, "Reduction in call handling time in transportation service industry using lean Six Sigma DMAIC methodology," *Int. J. Product. Qual. Manag.*, Vol. 27, No. 3, (2019), pp. 352-368.
Doi: 10.1504/IJPQM.2019.101495.

[32] K. Soundararajan and K. Janardhan Reddy, "Productivity and quality improvement through DMAIC in SME," *Int. J. Product. Qual. Manag.*, Vol. 31, No. 2, (2020), pp. 271-294.
Doi: 10.1504/IJPQM.2020.110027.

[33] S. P. Goffnett, A. N. Paquet, O. M. Strong, and K. P. McCarron, "Replication of a Six Sigma black belt case study: GEP box's paper helicopter experiment in a drone logistics scenario," *Int. J. Product. Qual. Manag.*, Vol. 27, No. 1, (2019), pp. 17-65.
Doi: 10.1504/IJPQM.2019.099628.

[34] J. Antony, R. Snee, and R. Hoerl, "Lean Six Sigma: yesterday, today and tomorrow," *Int. J. Qual. Reliab. Manag.*, Vol. 34, No. 7, (2017), pp. 1073-1093.
Doi: 10.1108/IJQRM-03-2016-0035.

[35] M. Sony and N. Mekoth, "Broadening the Lean Six Sigma concept through employee adaptability: A literature review," *Int. J. Product. Qual. Manag.*, Vol. 28, No. 3, (2019), pp. 279-298.
Doi: 10.1504/IJPQM.2019.103522.

[36] F. Dweiri and S. Ishaq, "Cable insulation productivity improvement using Lean Six Sigma," *Int. J. Product. Qual. Manag.*, Vol. 30, No. 4, (2020), pp. 488-508.
Doi: 10.1504/IJPQM.2020.108573.

[37] D. A. Desai, "Quality and productivity improvement through Six Sigma in foundry industry," *Int. J. Product. Qual. Manag.*, Vol. 9, No. 2, (2012), pp. 258-280.
Doi: 10.1504/IJPQM.2012.045195.

[38] D. A. Desai, "Improving productivity and profitability through Six Sigma: Experience of a small-scale jobbing industry," *Int. J. Product. Qual. Manag.*, Vol. 3, No. 3, (2008), pp. 290-310.
Doi: 10.1504/IJPQM.2008.017500.

[39] B. Chaurasia, D. Garg, and A. Agarwal, "Lean Six Sigma approach: A strategy to enhance performance of first through time and scrap reduction in an automotive industry," *Int. J. Bus. Excell.*, Vol. 17, No. 1, (2019), pp. 42-57.
Doi: 10.1504/IJBEX.2019.096903.

[40] R. Ben Ruben, S. Vinodh, and P. Asokan, "Implementation of Lean Six Sigma framework with environmental considerations in an Indian automotive component manufacturing firm: a case study," *Prod. Plan. Control*, Vol. 28, No. 15, (2017), pp. 1193-1211.
Doi: 10.1080/09537287.2017.1357215.

[41] P. N. Ramkumar and K. P. Satish, "Statistical investigation of Lean Six Sigma for waste reduction in Indian SMES by identify rank define analyse improve control model," *Int. J. Product. Qual. Manag.*, Vol. 30, No. 2, (2020), pp. 252-277.
Doi: 10.1504/IJPQM.2020.107815.