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# Six Sigma Study for Defect Reduction in a Connector Manufacturing Company

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***Abstract: This paper discusses a Six Sigma study done at a connector manufacturing company for reducing the occurrence of high defect rate during SIM card connector production. Process improvement is done by following DMAIC (Define-Measure-Analyze-Improve-Control) methodology. Gauge Repeatability and Reproducibility study done during measure phase established that the measurement system is sufficient. Pareto analysis has shown that brush height variations and insertion depth variations account for nearly 70% of defects and a regression analysis established a linear relation between these two types of defects. During the improve phase, the bending machine is modified by augmenting with pilot pins and holes and these changes resulted in significant reduction of above defects. Control charts were drawn in the last phase for monitoring the improved process. Annual saving of a company after the implementation of Six Sigma is about 2 million INR and the sigma level had changed from 3.6 to 4.2.***
***Keywords: Six Sigma, DMAIC, DPMO, Sigma level, MSA, Gauge R&R, Fish-bone diagram, Regression, Capability study, SIM card connectors, Control charts***

## I. INTRODUCTION

Six Sigma was proposed by Motorola, in the mid-1980s, as an approach to reduce the defects in their business processes so as to improve production, productivity and quality, as well as reducing operational costs [1]. Six Sigma is used to measure process variation. Six Sigma methodology uses model such as DMAIC, includes team based problem solving, measurement, improvement and control. Combination of both metric and methodology gives Six Sigma management system. Particularly, a Six Sigma level refers to 3.4 defects per million opportunities (DPMO) [2], or in other words, to have a process which produces 3.4 defects per every one million products produced. Six Sigma was mainly introduced in manufacturing processes. However marketing, billing, insurance, human resource, purchasing and call centers are also implementing the Six Sigma methodology with the aim in continuously reducing the failures throughout the organization's processes [3]. Adan and Salvador (2009) conducted a case study in a semiconductor manufacturing company by the application of design of experiments in Six Sigma. Chhikara et.al.(2009) reviewed and examined the advancement of six sigma practices in Indian manufacturing industries. Gijo, Scaria, and Antony (2011) explored a systematic DMAIC methodology to reach a world-class quality level by reducing the defects of a grinding process. Anup and Shende (2011) utilized the DMAIC phases to decrease the rework in belt Industry by increasing the process performance from better utilization of resources. Shanmugaraja et. al. (2011) conducted a case study by proposing innovative analysis for controlling defects for improving quality and productivity including Taguchi experiments in DMAIC methodology. Shashank et.al. (2013) conducted a work on the reduction of welding defects using six sigma discussing quality and productivity improvements in manufacturing company.

This study was conducted in a connector manufacturing company in India, to find a better solution for reducing the defects of SIM card connector by the application of Six Sigma. Section 2 gives a brief description of DMAIC methodology and its implementation details are discussed in section 3.

## II. DMAIC MODEL

One of the Six Sigma's distinctive approaches to process and quality improvement is DMAIC [4]. The DMAIC model includes stages as Define, Measure, Analyze, Improve and Control that helps to achieve best solution for problems facing in organization. Each DMAIC phase has separate statistical and problem solving tools helps in the analysis of problem. DMAIC methodology is shown in Fig. 1.

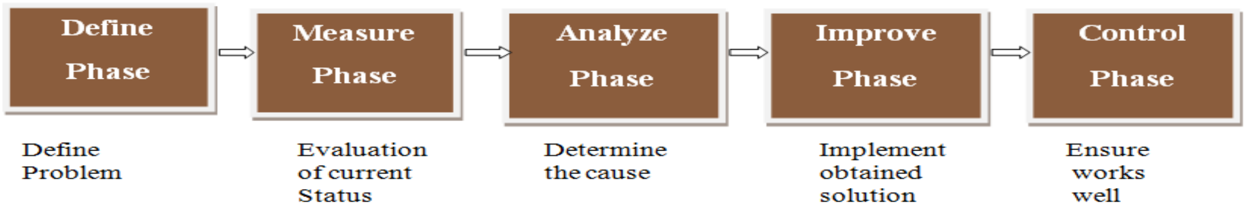


Fig. 1 DMAIC Methodology

## III. SIX SIGMA IMPLEMENTATION

Application of Six Sigma methodologies for defect reduction related to SIM card connectors are done in five phases detailed above.

### A. *Define Phase*

First stage of Six Sigma methodology is the "Define" phase, where we define the title of the project including the scope and boundary of the project. This is done mainly by listening to the Voice of the Customer (VOC). A project charter is a tool used to document the targets of the project and other parameters developed by Team leader or Champions with its members to state the project's information structure. Project charter for this project is shown in TABLE I.

TABLE I
PROJECT CHART

| Project title: Reduction of defects in a SIM card connector |
|---|
| Reason for selecting the project: An average of 27,815 PPM defective SIM card connectors are found to be defective in last year, which leads to customer complaints, time, capital and resource wastage due to poor quality and affects the reputation of the company.<br>Annual loss of a company is about 3 million INR. |
| Project goal: To reach at most five sigma level. |
| Voice of Customer (VOC): High quality product |
| Expected Financial Benefits: At least 2 million INR cost savings after reducing defects |
| Expected Customer Benefits: Meet the Voice of Customer |

In order to identify the flow of the production process, a process mapping tool is available in "define" phase is SIPOC process map. This chart helps in understanding the section wise input, process steps and their outputs. SIPOC process map for SIM card connector production process is in TABLE II

TABLE II SIPOC DIAGRAM

| Supplier | Input | Process | Output | Customer |
|---|---|---|---|---|
| External customer | Plastic material | Molding process | Molded insulator | Assembly department |
| External customer | Metal strip | Stamping process | Stamped contact strip | |
| Stamping section | Stamped contact strip | Electro-plating process | Plated contacts | |
| Molding and Electroplating Section | Molded base<br>Plated contacts | Stripping of contacts<br>Bending process<br>Combining base and contacts | Final connector | Inspection department |
| Inspection team | Final connector | Inspection | Inspection Report | Quality department |
| Inspection team | Final connector | Quality Testing | Quality test reports | Assembly department |
| Assembly department | Accepted connector | Packing and Shipping | Packed final connector | External customer |

### *B. Measure Phase*

The second phase of DMAIC methodology is the "measure" phase mainly describes the measure of the current status of connector defective values produced last year, Fig. 2 shows the PPM (Parts per Million) defectives of SIM card connector in 2016. These defects caused a loss of 3 million INR and many customer complaints.

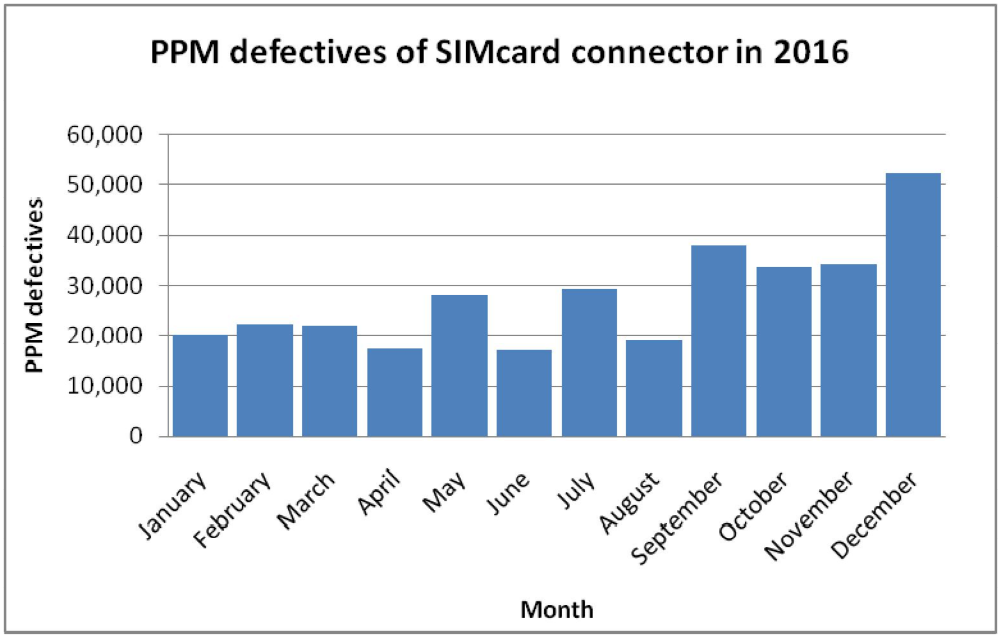


Fig. 2 Graphical representation of PPM defectives in 2016

Different types of defects found in the connector with number of defectives (duration of four months) and their percentages is shown in TABLE III. From this data, Pareto Chart is drawn (see Fig. 3) which is helpful in identifying critical defects. It is clear that about 70% of the total defective percentage is caused by the following defects: brush height variation, insertion depth variation and molding defects.

TABLE III
TYPES OF DEFECTS IN SIM CARD CONNECTOR

| SL. NO. | Types of defects | Number of defects | Percentage of defects | Cum. % of defects |
|---|---|---|---|---|
| 1 | Brush height variation | 3744 | 30.54 | 30.54 |
| 2 | Insertion depth variation | 2808 | 22.91 | 53.45 |
| 3 | Molding defects | 1967 | 22.86 | 76.31 |
| 4 | Coplanarity problem | 1380 | 11.26 | 87.57 |
| 5 | Contact shorting | 520 | 4.24 | 91.81 |
| 6 | Reader damage | 453 | 3.7 | 95.51 |
| 7 | Insulator flash | 346 | 2.82 | 98.33 |
| 8 | Feeding problem | 157 | 1.28 | 99.61 |
| 9 | Others | 48 | 0.39 | 100 |
| | Total | 11423 | 100 | |

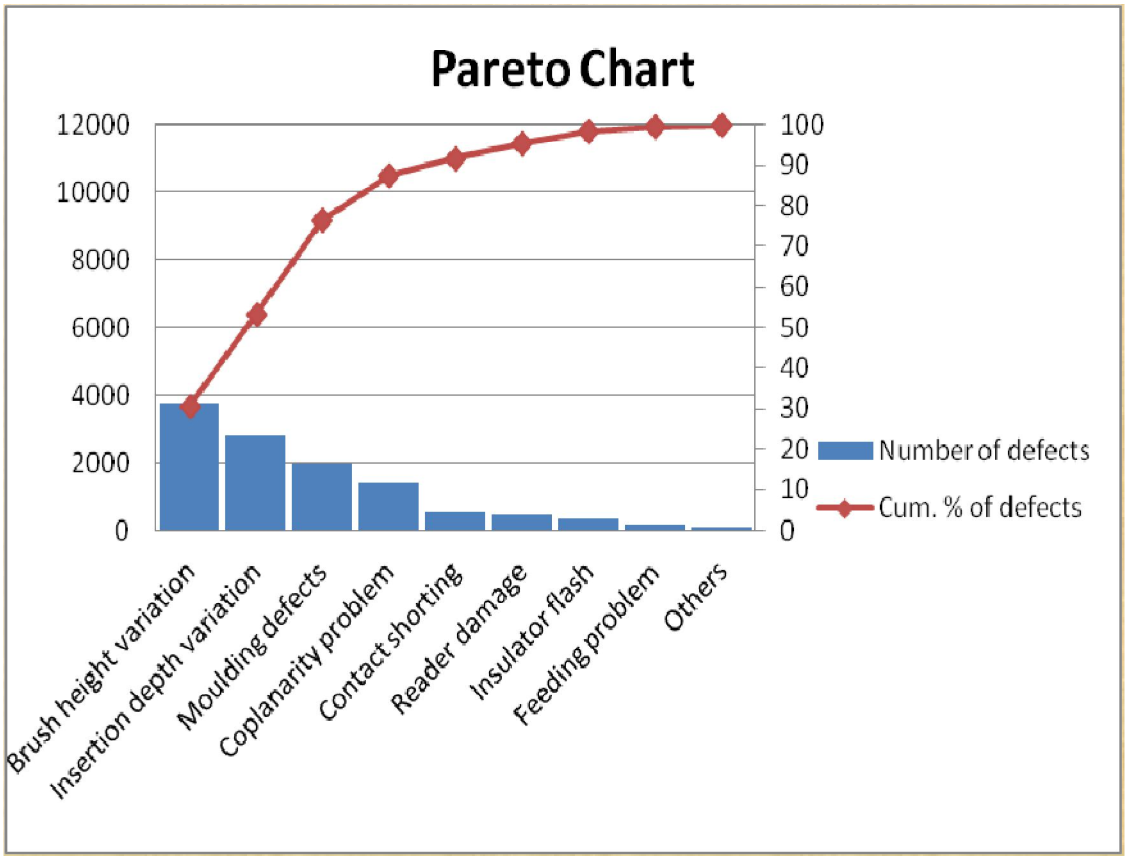


Fig. 3 Pareto diagram for defect types

It is important to determine corresponding DPMO (Defects Per Million Opportunities), Sigma level, and Yield of the company before the implementation of Six Sigma and corresponding expected values after the implementation of Six Sigma. These values are listed in TABLE IV.

TABLE IV
CURRENT AND EXPECTED STATE

| DPMO | | SIGMA LEVEL | | YIELD | |
|---|---|---|---|---|---|
| Current | Expected | Current | Expected | Current | Expected |
| 17596 | 3428 | 3.6 | 4.2 | 98.20% | 99.65% |

Measurement System Analysis (MSA) is one of the tool used in Measure phase and it is the critical part of Six Sigma project. Key element is that the variability of measurement system should be small with its total variability [5] during measurements. Gauge R&R (Repeatability and Reproducibility) should be calculated before doing the measurements in the gauge as it represents the percentage variability due to appraiser and the gauge [6].

Repeatability/Equipment variation is the ability of the measuring instrument to give same measurement during repetition by same operator at same operating conditions, while Reproducibility/Appraiser variation is the measuring instrument to give same measurement during repetition by different operator at different operating conditions. Thus mathematical definition of gauge R&R is the square root of sum of the squares of variation due to repeatability and reproducibility. Number of distinct categories (ndc), explains the number of non-overlapping 97% confidence intervals that will span the expected product variation [6], depends on the ratio of part to gauge R&R variation. In our study dimensions are taken by three operators in three repetitions on ten sample parts. Gauge R&R data sheet is in Fig. 4a and Fig. 4b.

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**GAUGE R&R DATA SHEET**

PART NAME **: SIM Card connector(contact brush height)**
SPECIFICATION **: 0.61 ±0.07 mm**

INSTRUMENT USED: **Micro.vu**
DESCRIPTION **: 0-10mm,L.C-0.01mm**

| APPRAISER/ TRIALS | PART 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | AVERAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A1 | 0.56 | 0.57 | 0.56 | 0.58 | 0.61 | 0.60 | 0.58 | 0.61 | 0.62 | 0.59 | 0.588 |
| A2 | 0.55 | 0.56 | 0.56 | 0.57 | 0.62 | 0.60 | 0.57 | 0.60 | 0.62 | 0.60 | 0.585 |
| A3 | 0.56 | 0.58 | 0.57 | 0.58 | 0.61 | 0.61 | 0.57 | 0.61 | 0.63 | 0.60 | 0.592 |
| AVERAGE | 0.557 | 0.570 | 0.563 | 0.577 | 0.613 | 0.603 | 0.580 | 0.607 | 0.623 | 0.597 | 0.589 |
| RANGE | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.011 |
| B1 | 0.62 | 0.54 | 0.59 | 0.57 | 0.60 | 0.65 | 0.63 | 0.65 | 0.52 | 0.56 | 0.593 |
| B2 | 0.61 | 0.54 | 0.59 | 0.57 | 0.61 | 0.66 | 0.64 | 0.65 | 0.51 | 0.57 | 0.595 |
| B3 | 0.62 | 0.56 | 0.58 | 0.57 | 0.61 | 0.66 | 0.62 | 0.65 | 0.52 | 0.56 | 0.595 |
| AVERAGE | 0.616 | 0.547 | 0.586 | 0.572 | 0.605 | 0.654 | 0.630 | 0.653 | 0.517 | 0.564 | 0.594 |
| RANGE | 0.01 | 0.02 | 0.01 | 0.00 | 0.01 | 0.01 | 0.02 | 0.00 | 0.01 | 0.01 | 0.009 |
| C1 | 0.58 | 0.60 | 0.60 | 0.62 | 0.64 | 0.55 | 0.58 | 0.58 | 0.54 | 0.60 | 0.590 |
| C2 | 0.58 | 0.60 | 0.60 | 0.62 | 0.64 | 0.56 | 0.58 | 0.59 | 0.54 | 0.60 | 0.590 |
| C3 | 0.58 | 0.60 | 0.59 | 0.62 | 0.63 | 0.55 | 0.59 | 0.57 | 0.53 | 0.61 | 0.587 |
| AVERAGE | 0.580 | 0.600 | 0.597 | 0.620 | 0.637 | 0.552 | 0.584 | 0.580 | 0.537 | 0.603 | 0.589 |
| RANGE | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.008 |
| PART AVERAGE | 0.584 | 0.572 | 0.582 | 0.590 | 0.618 | 0.603 | 0.598 | 0.613 | 0.559 | 0.588 | 0.591 |
| RANGE(Rp) | | | | | | | | | | | 0.059 |
| R =(RANGE(A) +RANGE(B) + RANGE(C))/3 | | | | | | | | | | | 0.009 |
| MAX AVERAGE (X)-MIN AVERAGE(X)= X dif | | | | | | | | | | | 0.005 |

Fig. 4a Gauge R&R data sheet

**MEASUREMENT UNIT ANALYSIS**

REPEATABILITY= EQUIPMENT VARIATION(EV)
EV= R x K1
**EV= 0.005**

REPRODUCIBILITY= APPRAISER VARIATION(AV)
AV= SQRT( [(Xdif x K2)$^2$ - (EV)$^2$ / nr] )

**AV= 0.002**

REPEATABILITY & REPRODUCIBILITY( R&R)
GRR= SQRT( (EV)$^2$ + (AV)$^2$ )
**GRR= 0.005**

PART VARIATION(PV)
PV= Rp x K3
**PV= 0.019**

TOTAL VARIATION(TV)
TV= SQRT ( (GRR)$^2$ + (PV)$^2$ )
**TV= 0.020**

| Trials(r) | K1 |
|---|---|
| 2 | 0.8862 |
| 3 | 0.5908 |

| Appraiser | 2 | 3 |
|---|---|---|
| K2 | 0.7071 | 0.5231 |

n= No. of parts
r= Trials

| PARTS | K3 |
|---|---|
| 2 | 0.7071 |
| 3 | 0.5231 |
| 4 | 0.4467 |
| 5 | 0.4030 |
| 6 | 0.3742 |
| 7 | 0.3534 |
| 8 | 0.3375 |
| 9 | 0.3249 |
| 10 | 0.3146 |

**% TOTAL VARIATION (TV)**
%EV= 100[EV/TV]
**%EV=** 25.00%

%AV= 100 [AV/TV]
**%AV= 10.00%**

% R & R= 100[GRR/TV]
**% R & R= 25.00%**

**TOLERANCE 0.14**
**<u>% TOLERANCE</u>**
% EV= 100 [EV/TOLERANCE]
**% EV= 3.57%**

%AV= 100 [AV/TOLERANCE]
**%AV= 1.43%**

% R & R= 100[R&R/TOLERANCE]
**% R & R= 3.57%**

**ndc =** [PV/GRR]*1.41
**ndc = 5.358**

Fig. 4b Gauge R&R data sheet

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*C. Analyze*

The third phase of DMAIC methodology is the "analyze" phase. The cause-and-effect diagram, also known as Ishikawa or fishbone diagram is a systematic questioning technique for seeking root causes of problems [7]. This tool is used for knowing the purpose of cause and effect of problem. There are five main categories normally used in a cause-and-effect diagram, namely: machinery, manpower, method, material and measurement (5M). Fish-bone diagram for the main defect, brush height variation is shown in Fig. 5.

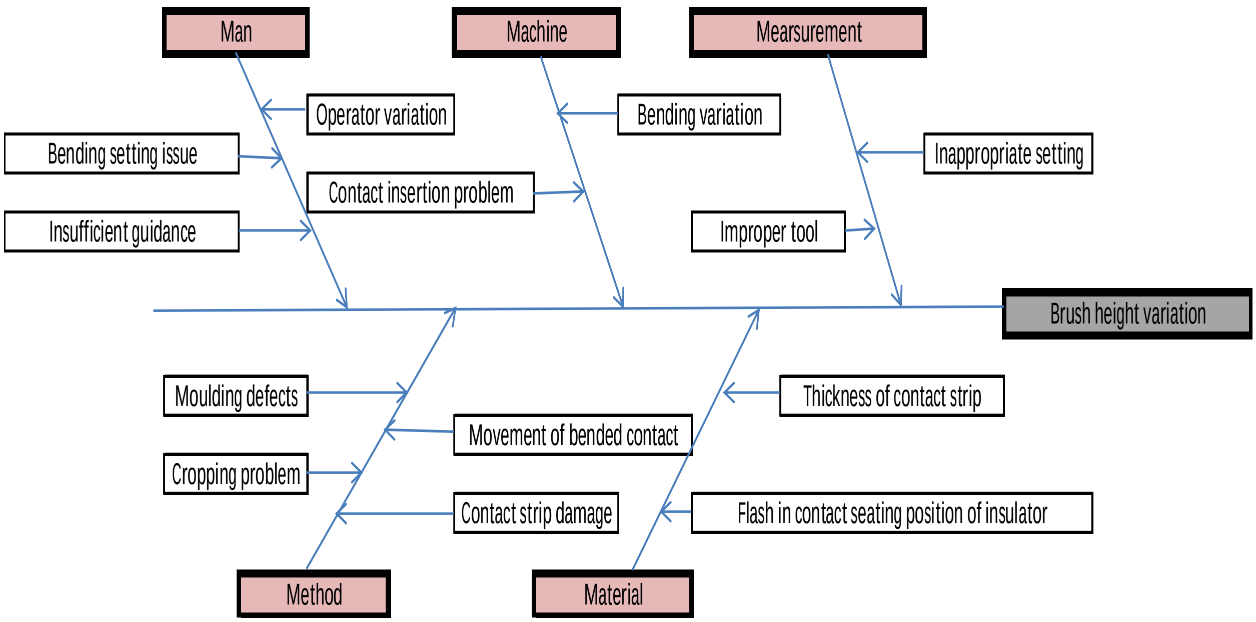


Fig. 5 Fish-bone diagram for Brush height variation

Fish-bone diagram, the team made conclusion that the main root cause for this problem is the Assembly machine bending variation. This is seen in contact bending section. It is important to identify the factors leading to root cause. Why-Why analysis is a tool used to determine the factors affecting the root causes of problem. This analysis also helps to identify the relationships of different causes, Why-Why analysis for assembly machine bending variation is shown in Fig. 6.

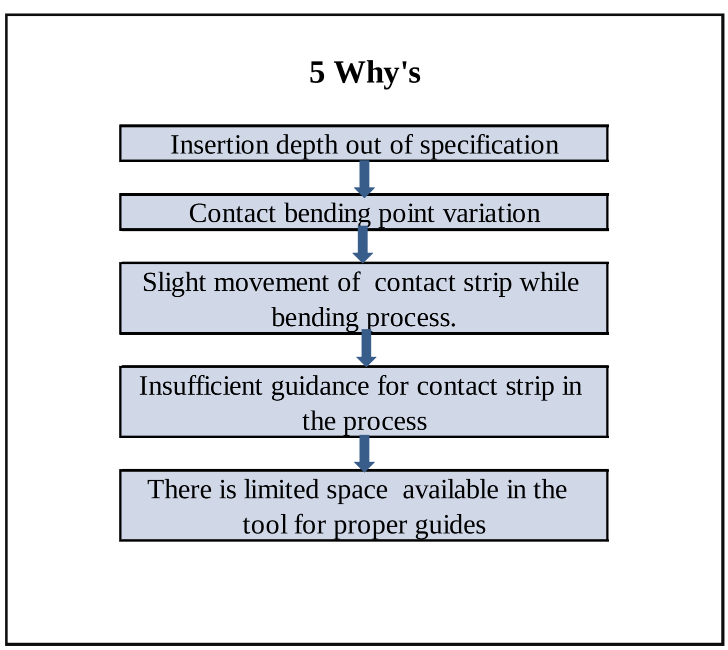


Fig. 6 Why-Why analysis

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Three main customer complaints related to brush height variations are:
1) Variation in contact positioning.
2) Safe contacting is not guaranteed.
3) Brush contact getting stuck in Fig. 7.

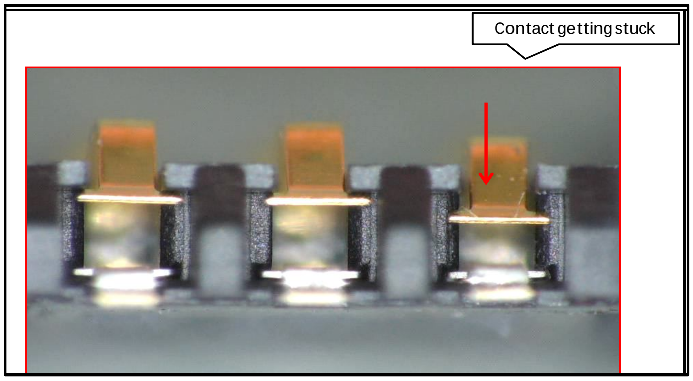


Fig. 7 Connector contacts getting stuck

Assembly machine bending variation is due to insufficient guidance of contact strip in the machine which leads to insertion depth variation also. From Pareto chart, it is the second largest defect occurring in this connector. There may be chances of variation occurring to both brush height and insertion depth, they are formed from same contact strip. Plotting the collected the data on contact insertion depths and brush heights of same connector, a linear relationship is seen thus obtaining a regression model. The variability observed in the model is explained by the coefficient of determination, $R^2$ is 0.98. Regression plot is shown in Fig. 8. Assumptions related to linear regression model are satisfied such as data should be continuous and there is no outlier in the linear plot. Next is the assumption about the independence of residuals, proved by Durbin-Watson test, with test statistic obtained as 2.047 and constant variance of residuals satisfying homoscedasticity. It is important to consider all the assumptions on regression to make it clear that the model developed is accepted and is assured to predict values. Thus the model can be used to predict the values of brush heights from insertion depths.

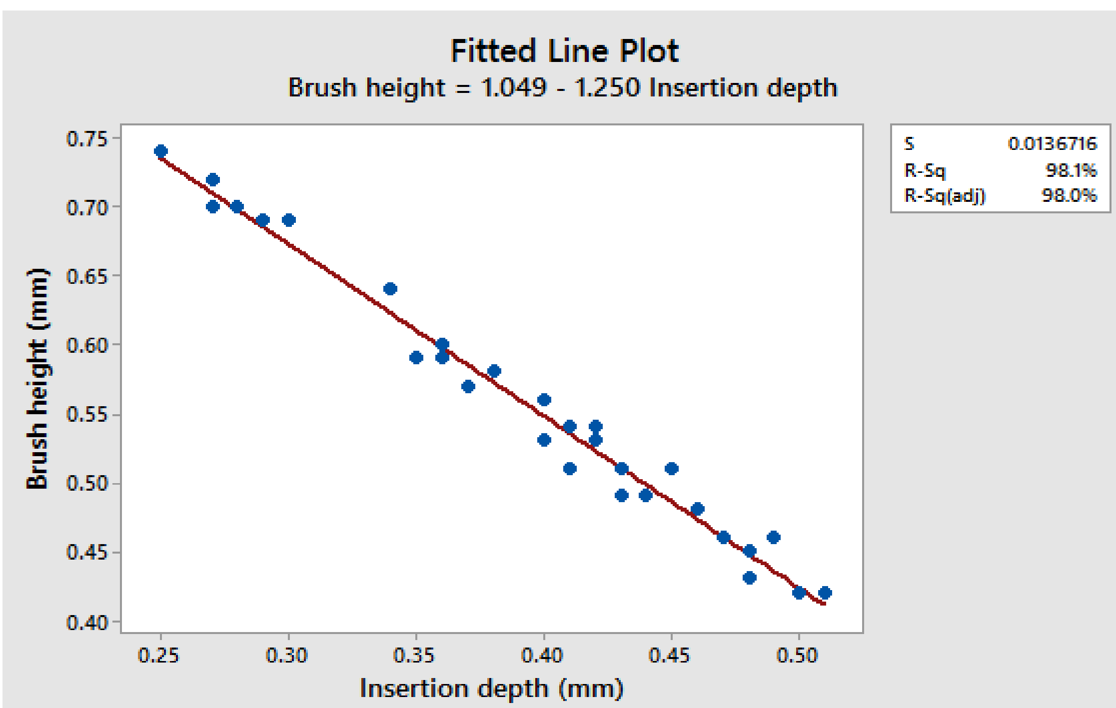


Fig. 8 Regression plot for insertion depth and brush height

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Insertion process is considered as an uncontrollable process because it is very difficult to detect the point at which the limit goes out of its specification in massive production stage. Process capability study is performed on the contact insertion process of the connector in order to check whether the insertion depths are within the specification set by the customer. Data on insertion depths of connectors are noted by taking sample SIM card connectors. Process capability study of collected data using MINITAB statistical software is shown in Fig. 9. Capability index Cp=0.64 is less than one specifies that insertion process is poorly targeted to center. Also the value of Cpk was obtained as 0.53 which is much lesser than 1.5 in order to reach Motorola 6σ capability indicating a poor capability. Performance indices, Pp=0.54 and Ppk=0.45 values are lower and has large variation between them. Thus there is an urgent need of improvement.

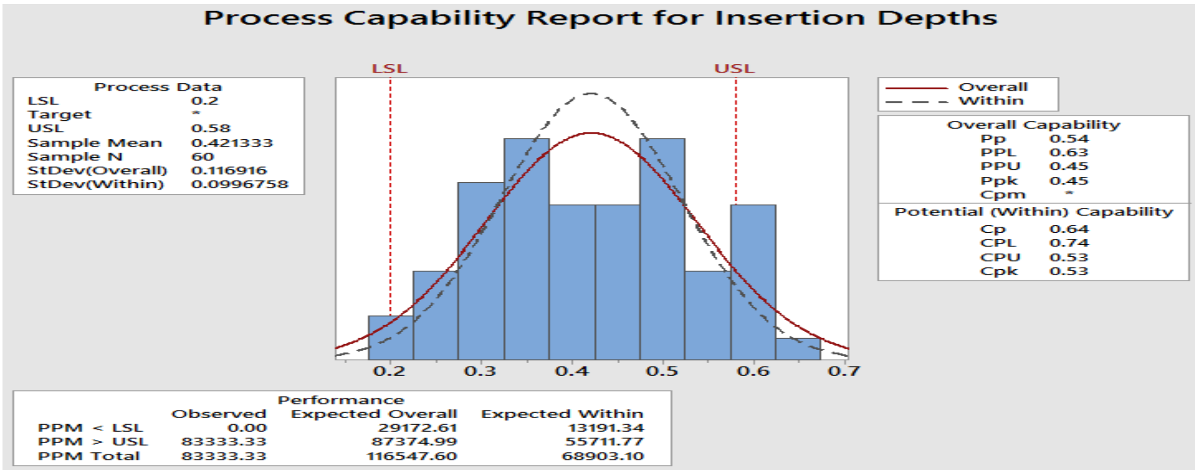


Fig. 9 Capability study of insertion process

*D. Improve*

After the identification of root cause, the DMAIC "improve" phase aims at identifying solutions and to reduce them. A proper process design improvement is done to reduce the play of contact strip in bending process in order to ensure correct bending of contacts. Pilot pins and holes fixtures (shown in Fig. 10 and Fig. 11) are provided in the bending machine at different bending stages with an improved design to ensure correct positioning of contact strip during bending process to avoid bending point variation.

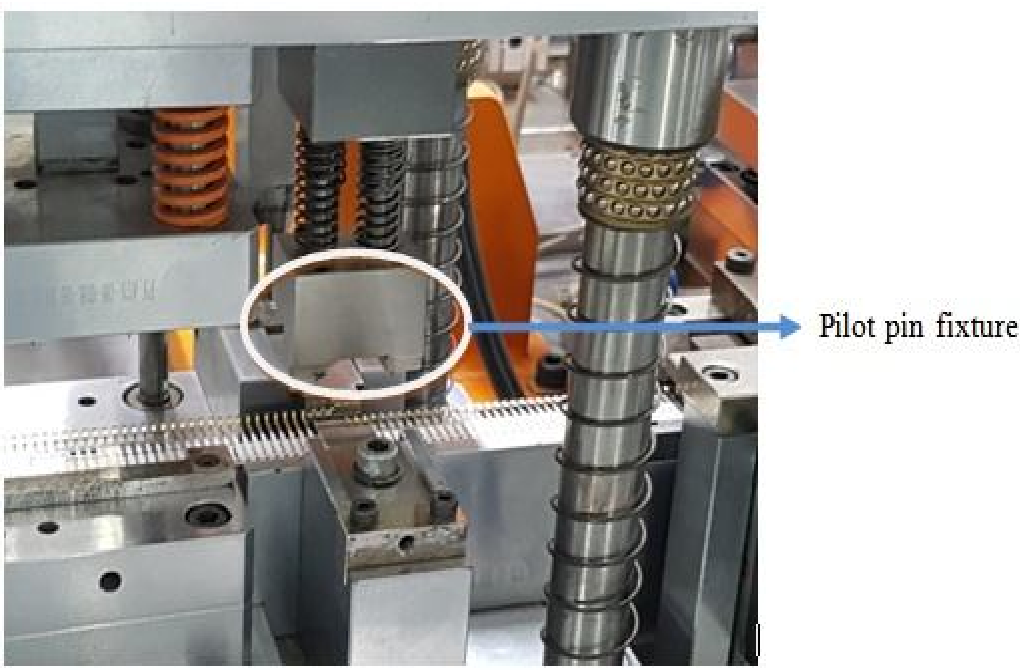


Fig. 10 Pilot pin implementation

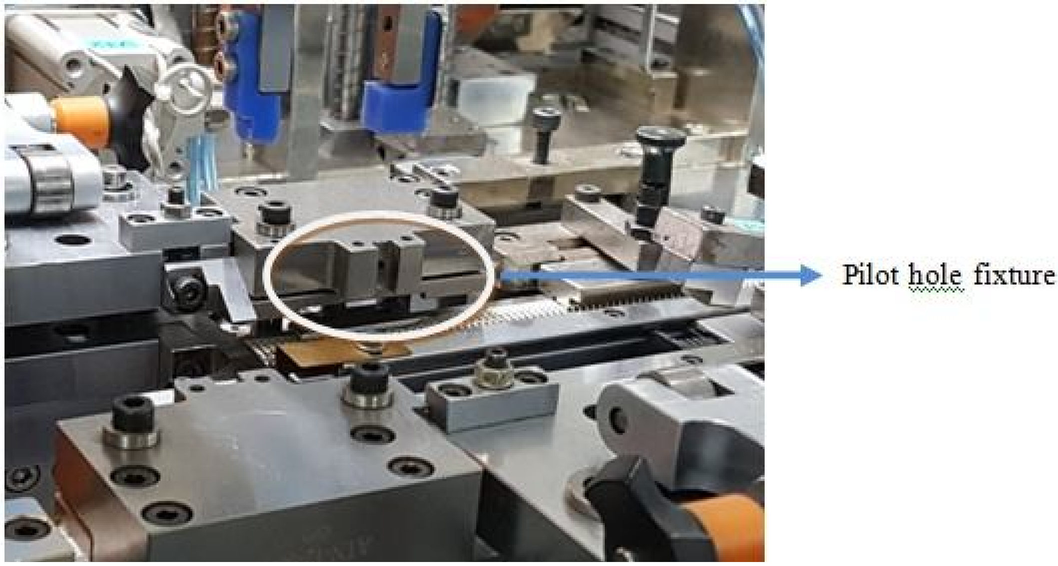


Fig. 11 Pilot hole implementation

PPM defective data was collected after improvement, obtained lower DPMO of 3428 and a larger value for Sigma Level of 4.2 with higher yield.

*E. Control*

The aim of the control phase is used to check whether the improved process is in control. Control chart shows the performance of process over a specified period of time with lower and upper control limits. Xbar-R chart is the most appropriate control chart for this situation. Data was collected after the improve stageand corresponding control charts are drawn is shown in Fig. 12 and Fig. 13.

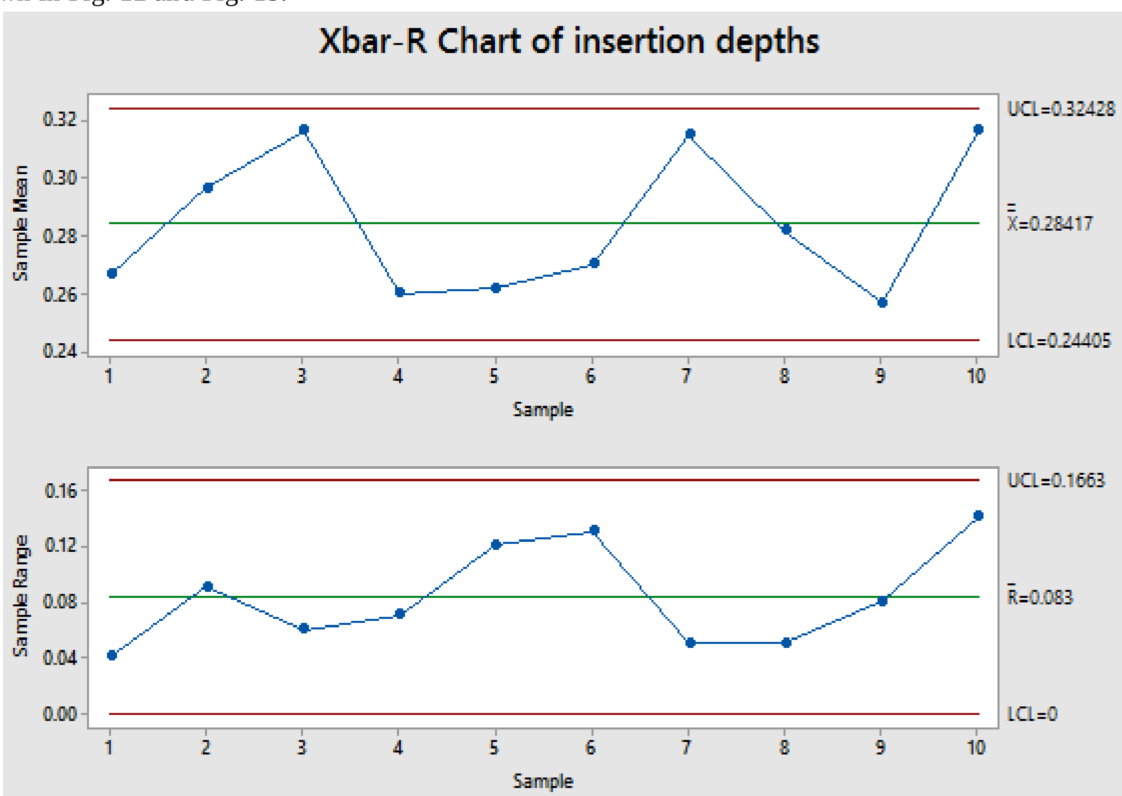


Fig. 12 Xbar-R chart for insertion depth

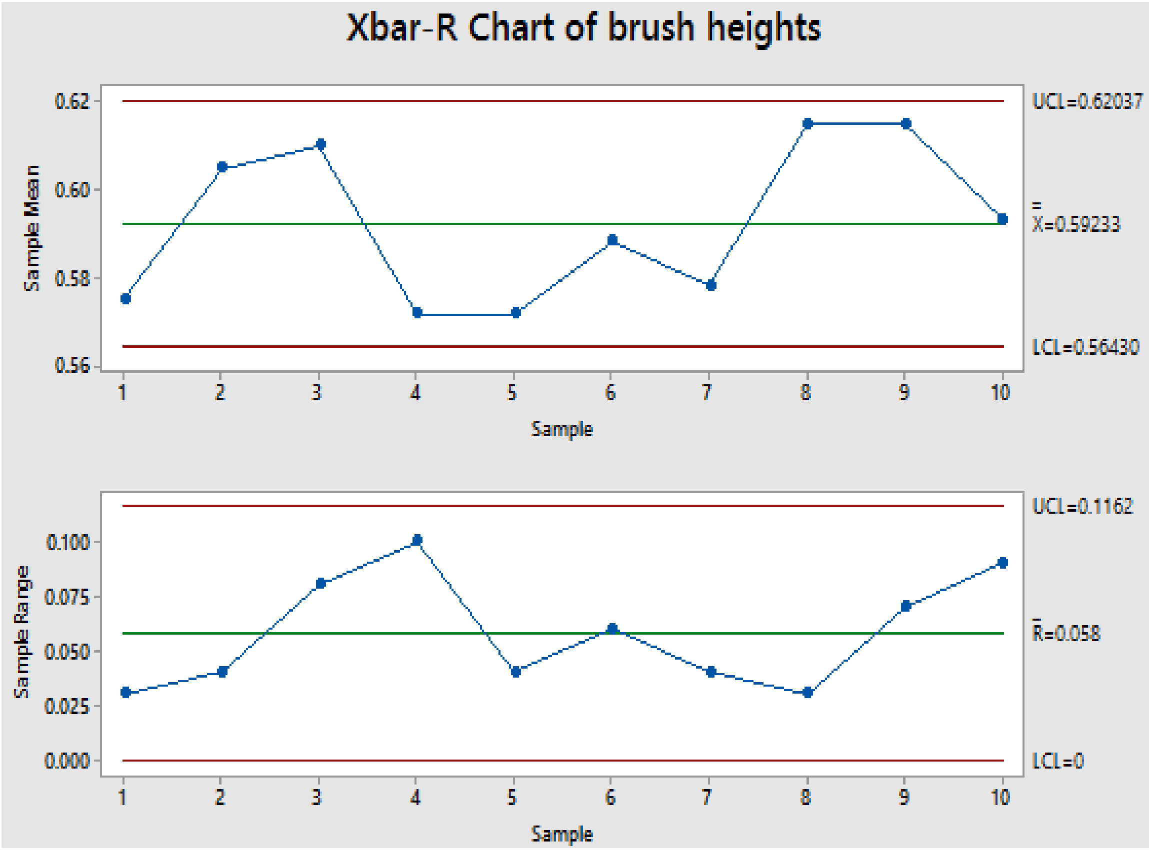

Fig. 13 Xbar-R chart for brush height

From the above control charts, it is clear that the insertion depth values and brush heights are within the control limits. Continuous process improvement should be done periodically by reviewing and updating the tolerance provided for insertion depths based on product functionality after doing continuous process capability study with the improved process design.

## V. CONCLUSION

This study was considered as a pilot project which has given confidence to the people in the organization a new approach for improvements using Six Sigma and the DMAIC problem solving methodology, capable of reducing non-conforming units. After the study of this project, DPMO changed from 17596 to 3428, sigma level from 3.6 to 4.2 and finally yield from 98.20% to 99.65%. Also a simple linear regression model is fit for the two major defects occurring in SIM card connectors making it possible to maintain relationship between them and for predicting the specification limits to be in control. Quality alert were released and training should be provided to operators and inspectors on Six Sigma and should act accordingly to reduce the opportunities of defects to get a higher sigma level.

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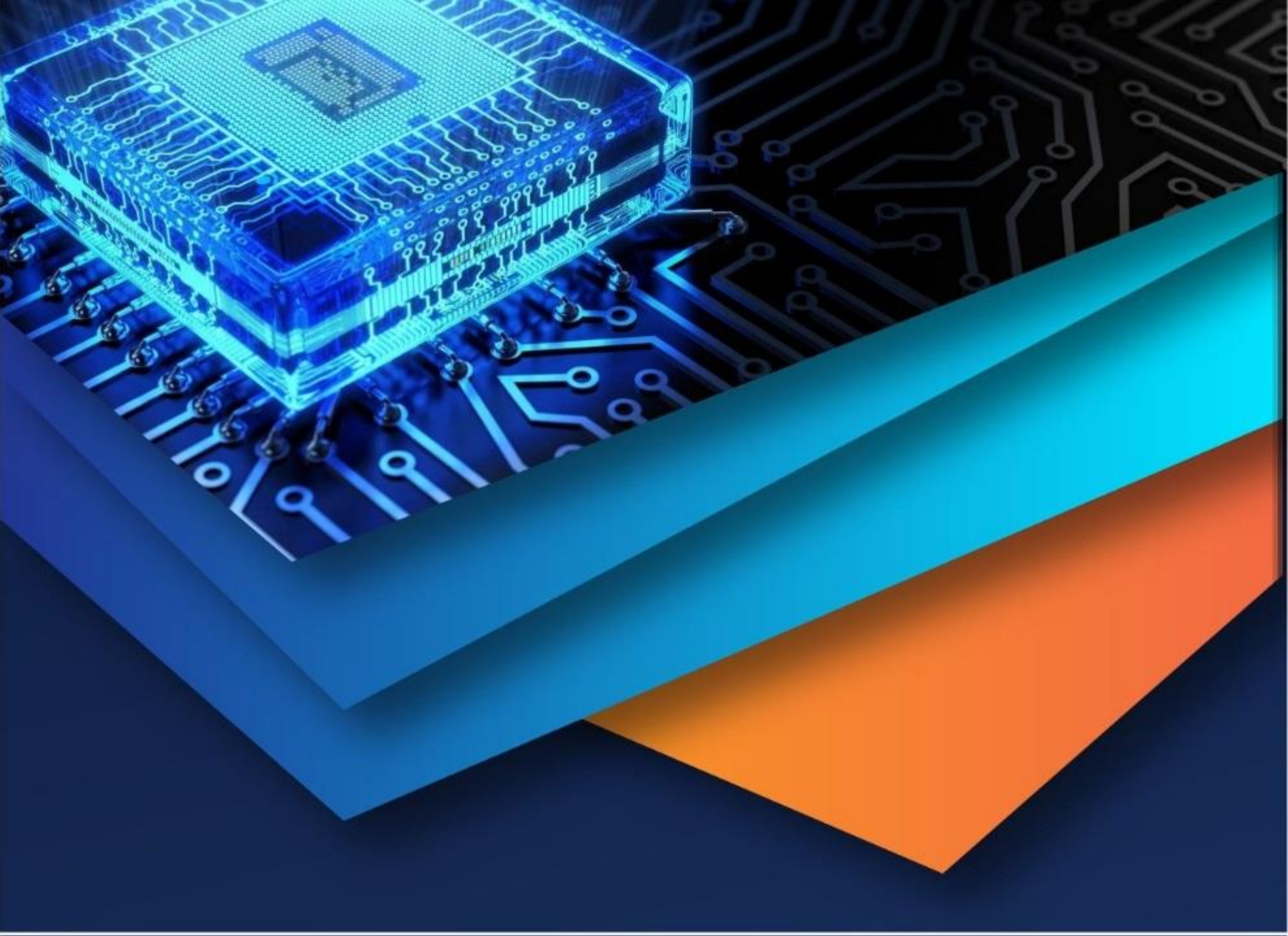

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