DMAIC Six Sigma Definition and an Analytical Implementation: Car Industry Case Studies

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***Abstract*— the purpose of this paper is to introduce DMAIC procedure under six sigma concepts and the way to implement such a methodology in a real case in order to achieve continuous quality improvement. Six -sigma is one of the most advanced managerial approaches to obtain drastic improvements in the process performance. Nowadays six sigma systemization has become a common quality-based tool used in any industry to achieve cost reduction and customer satisfaction. Six sigma methodologies would be categorized in two main approaches, DMAIC (continuous improvement) and DFSS (deep re-engineering of new products, service or process).this paper critically investigates the role of DMAIC procedure to improve and sustain the quality as well as integrating the theoretical six sigma concepts and the practical lessons learned from real successful DMAIC implementation projects .**

DMAIC (Define-Measure-Analyze-Improvement-Control) is a kind of problem solving approach employed as a quality strategy by the aim of continuous improvement .in this study, it has been tried to highlight how to DMAIC the process in real cases ,then to provided solutions and further achieved results would be obtained.

Keywords— *Index Terms*— **DMAIC procedure, Six -sigma, continuous Improvement, case study**

1. INTRODUCTION

Six-sigma is the latest step in evolution of quality process improvement. Such a methodology was born at the end of 80’s in Motorola when most of the companies did believe that producing quality would be costly, While Motorola proved such a belief in an opposite way: “the better quality, the cheaper”. It is well known that if we are able to control the variation which is the major cause of poor quality, we could get all the process work well and consequently find the result of 3.4 defects per million opportunities according to statistical point of view(six-sigma level).

As for the strategic point of view, six-sigma would be considered as a way to increase the company’s profitability by reducing the cost of poor quality, Increasing the effectiveness and efficiency of all operations to meet or exceed customer’s need and expectations. (Antoni and Banuelas, 2001) [1].

“Six-Sigma” is defined by Linderman et al. (2003)[2] as an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer defined defect rates. It would be considered as a proven and highly effective approach aims at creating the defined processes capable of what customer exactly wants. Since obtaining the higher level of customer satisfaction has been always one of the most substantial criteria each company follows, six-sigma approach is taken under consideration to achieve such a goal. Fundamentally six sigma approach is stood based on three main steps: To focus on the characteristics of the product or service which are critical to customers (CTQs), to define adequate technical specification for CTQs and to improve process capability. Based on those defined steps, to improve the process capability it is necessary to decrease process variability and other causes of errors which can be considered as the goals followed by six-sigma [7].

Methodologies followed in six-sigma topic are DMAIC and DFSS.DMAIC improves existing process while DFSS aims at generating new product, service or process. This paper tries to investigate deeply the role of DMAIC procedure and its implementation in continuous improvement under six-sigma.

2. DMAIC

DMAIC (Define-Measure-Analyze-Improvement-Control) is a kind of problem-solving approach and quality-based methodology. DMAIC approach is strongly associated with Deming’s PDCA cycle. Plan, Do, Check and Act is well known fundamental concept of continuous improvement process by the aim of looking for better solutions of improvements [5].

2.1. *DMAIC Methodology*

Such a closed loop process, as shown in Figure 2.1, aims at improving the defined process in the steps described in 2.1-2.5. Then in the sector 2.6 their objectives, activities and the tools used are clearly defined.

2.1.1. *Define the problem*

In such a phase the problem and the business case should be addressed directly. To clearly identify the process and its customers in order to know what the customer exactly wants are further objectives. This initial phase takes one or two weeks according to the criticality of the process and complexity of the facing problem.

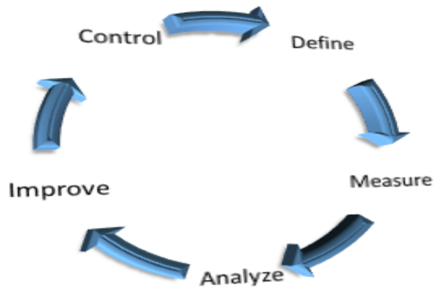

Figure 2.1 DMAIC closed loop

2.2. *Measure the performance*

The main goal of measure phase is to collect actual data in order to understand all the process variables that are affecting the process output. It is necessary to select one or more CTQs in this phase to concentrate on and finally to validate the measurement system of those defined CTQs. It takes usually two to four weeks if the data are available otherwise it depends on the difficulties to gather necessary information.

2.3. *Analyze the opportunities*

To identify, organize and validate potential root causes based on what has been obtained in the measure phase is the aim of Analyze step. In other words the objective is to identify the drivers of variation, which would be the major cause of the poor quality.

2.3.1. *Improve the performance*

Once the root causes of the defect have been identified, the focus shifts toward finding the solution for the problem using different types of statistical tools and techniques such as DOE, cause and effect, regression analysis and so on. Validation and then implementation of the solution would be employed next.

2.3.2. *Control the situation*

Here monitoring the current approach that prevents the process from reverting to its previous state should be established. It means analysis of the process performances will be taken under consideration in order to verify the process improvement compared to starting situation. Determining the new process capability and implementing control plants must be also achieved in control phase.

1.1. Steps' Objectives, activities and tools

Table 2.1 summarizes objectives, activities and the tools should be followed in DMAIC approach [2][3][4].

2.2. *Pros, Cons and CSFs*

2.4.1. *Pros*

Cost saving: To identify the wastes and unnecessary activities in each phase by the goal of avoiding rework. Note that higher efficiency and effectiveness as a result of DMAIC implementation would lead to higher business profitability and value delivering directly for the customers.

Structured statistical thinking approach: According to DMAIC methodology, the decisions would be made based on actual data in a step by step reliable measurement system. Each step has its own predefined objectives, activities and tools to follow so makes the process structured.

Long lasting solutions with great focus: Since DMAIC guide works as a repetitive cycle for identifying the root causes, eliminating the variability designing and implementing the best solutions, sustainable long lasting solutions and continuous improvement can be achieved respectively. In big firms where identifying the problems and finding out the appropriate solutions would be difficult, DMAIC is used to addressee the problem directly with a high efficiency.

2.4.2. *Cons*

Quality skill required: DMAIC implementation requires specific quality training for understanding the tools and techniques needed to be used .it must be acknowledged that this kind of quality training costs for the company.

2.4.3. *CSFs*

Implementation of customer VOC: A good process is the one in which existing and potential needs of the customer are clearly understood by the company and to be correctly translated to critical to customers [6].

Use the correct tools: success in DMAIC Process is not only in using the structured tools but also in full awareness of the tool application and the capability to put them away.

Continued top management support and commitment: having a top management fully on board from the beginning of the DMAIC application may help the process move along smoothly. Any changes applied without the support of the top management will be subjected to fail [6].

3. Six Sigma DMAIC Implementation

Although Six sigma using DMAIC methodology has been successfully applied in many manufacturing companies such as Motorola, DuPont, Toshiba ,Sony, General Electric , etc, It is worth adding that DMAIC could be used in any process, any industry and any company as a road map to decrease the variations and causes of errors and continuous process improvement respectively. The following case studies implement DMAIC step by step on car industry.

3.1. *Case 1*

The Company has produced headlight for the automobile industry for about 100 years, with several locations all around the world (especially in Europe and Far East), the Company is one of the most significant players in the field of automotive lighting providing the most important car manufacturers.

3.1.1. *Case product*

Different types of headlights are manufactured at the plant. The product in question is a headlight assembled on a car of medium segment and its production volume is 1200 units per day (or 600 pairs of lights).

3.1.2. *DMAIC Implementation on the case*

3.1.2.1. *Define*

3.1.2.1.1. *Project charter*

To provide the project charter the first two steps were taken: problem definition and goal statement. The tools taken are described in table 2.1 as a result the project charter agreed upon by the project team is shown in table 3.1.

3.1.2.1.2. *Voice Of the Customer Analysis (VOC) and Critical To Quality (CTQ)*

The steps of translating VOC to CTQ had already been taken by the company itself. The CTQ was divided into two different categories: static and Dimension related problem. By which defects could be defined respectively as incomplete pieces or loss of material in a part and not to be in the proper size. There is normally an agreement made between the client and the company which contains a list of defects and maybe a picture for them. This company's list included scraps of: Burning, Spots, Lines due to the mold, Flow, Start-up, white dots, Lines due to the handling. Note that all the scraps were defined at the end of the process while the product was completed.

3.1.2.2. *Measure*

To make sure of the historical data the company has

Table 2.1 DMAIC objectives, activities and tools

Phase	objectives	Activities	Relevant tools
Define	To identify the scope of the problem, objectives and deliverables of the project.	▪ To identify the process and customer needs ▪ To map the process	▪ Project charter ▪ SIPOC ▪ Stakeholder Analysis ▪ VOC Analysis ▪ CTQ Tree ▪ Kano Analysis
Measure	To translate the problem into measurable form by using statistical tools.	▪ To verify the measurement system reliability ▪ To identify process variables ▪ To measure current process capability ▪ To identify potential output	▪ Data Collection Plan ▪ Gage R&R ▪ Data Display ▪ Process capability ▪ Process Performance
Analyze	To identify potential influence factor and to define the improvement goals.	▪ To analyze the process ▪ To do data analysis	▪ Cause and Effect Diagram ▪ Histogram ▪ Statistical Regression ▪ ANOVA ▪ Sampling ▪ Hypothesis Testing ▪ Pareto
Improve	To identify, validate and apply the solutions to the problem.	▪ To search the possible solution and identify a more valid one	▪ DOE ▪ Brainstorming ▪ Time Series Plot ▪ QFD/House Of Quality ▪ FMEA
Control	To analyze the process performance compared to starting situation.	▪ To implement control plants ▪ To verify that the improvement obtained is structural.	▪ Control Charts ▪ Time Series Plot

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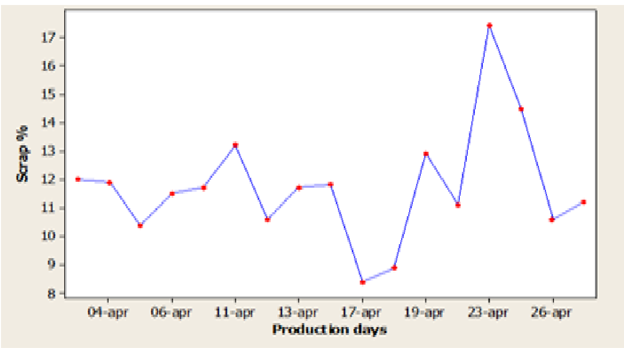
Table 3.1. Project Charter

Project charter		
Project title	Scraps reduction on a thermoplastic component molding process	
Plant	XXX	
sponsor	YYY	
Indicators and value	Scrap from Internal supplier process: 12%	
Benefit impact area	Component production process, Field Management	
Project target	Scraps reduction: 8% (target stretch: 6%)	
Project field	Project/Process of component, Field Management	
attendance	Supplier/Manufacturing/sub supplier raw material	
Project time	From	to

been provided, 12% of daily scrap, the team decided to collect new data since the given one was a bit confusing and unreliable. The days of observations weren't in a logical order and the data was way scattered. To have both statistical data needed and the sequence of the observation, Time series plot was highly recommended as the data collection plan. As Figure 3.1 represents the observations started on April 4th, daily scrap was calculated each day until April 26th the average reached to 12%. The project team decided to stop the observations and accept the amount as reliable data, and also the standard deviation is more than 2% which proves the high variability, the major cause of poor quality.

3.1.2.2.1. *Identify Potential Output*

To make the metrics clearer some questions were rose: first in what shape did the problem occur? Second when did the problem occur and third what machines/equipments were used when the problem occurred? On the other hand raising these questions led the team to define Type of defect, Time of defect (day, hour, and shift), hand DX or SX [1] to be put under consideration in the Analyze phase.



Descriptive Statistics: Scarto

Variable	Mean	StDev	Minimum	Maximum
Scarto	11,753%	2,056%	8,400%	17,400%

Figure 3.1 Daily Scrap Percentages

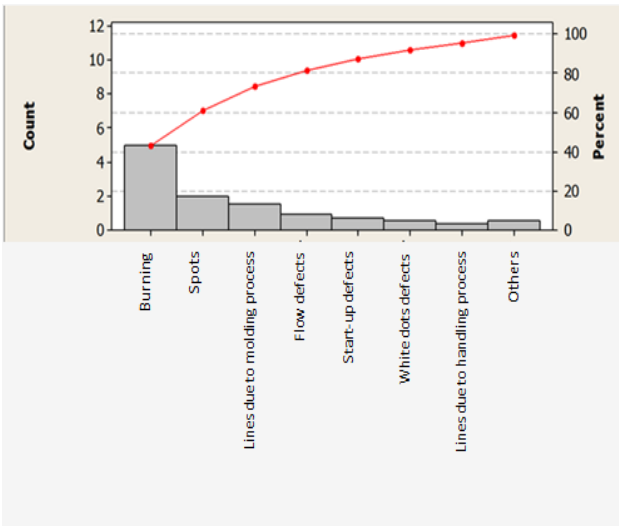
[1]It was a mold with two stamps (two positions) , right(DX) and left (SX).

3.1.2.3. *Analyze*

To estimate the proportion of total scrap, all types of defects provided by CTQs were studied in a Pareto diagram shown in figure 3.2. results revealed that burning pieces ranked first by almost 50 % out of total scrap .so it named as the most frequent failure to be studied upon to reduce the level of scrap.

3.1.2.3.1. *Validation of Root Causes*

Investigation of other factors such as hour, day and shift was still needed. But the point is the analysis was done only in terms of the most frequent defect which was burning. Box Plot and ANOVA were highly recommended in order to analyze the influential factors and their variability. Figure 3.3 depicts the BoxPlot for the defect burning vs. the factor hour in which the lowest and the highest volume of burning pieces for each hour and also the size of the first and third quartile can be seen. Figure 3.4 presents one way ANOVA for burning vs. hour in which P-value <0.05 meant that statistical significant effect could be captured.



Count	5,0	2,0	1,5	0,9	0,7	0,5	0,4	0,5
Percent	43,5	17,4	13,0	7,8	6,1	4,3	3,5	4,3
Cum %	43,5	60,9	73,9	81,7	87,8	92,2	95,7	100,0

Figure 3.2 Pareto of Defects

On the other hand, R-sq=4.31% represented deniable hour influence since R-sq was really small (near zero compared to the overall variability). The same analysis was done over burning vs. day and also shifts. The R-square for day and shift represents about 3% and 4% respectively, so again it was concluded that these studied factors couldn't be considered with significant effects(see figure 3.5)and deeper analysis like DOE was needed to see the influences of other parameters.

3.1.2.3.2. *DOE Analysis*

To verify which process parameters and in which weight were really influent on the process, a DOE analysis was performed. Flow of process was asked as the first step, and then influential factors were defined based on historical feeling, asking experts and also experiments. Defined items should be tested in next phase which is "improve. Following a deep analysis of a thermoplastic molding process, involving raw material supplier, fundamental root causes which led to scrap was identified as raw material dehumidification step, material plasticization, tool conditioning and Final control.

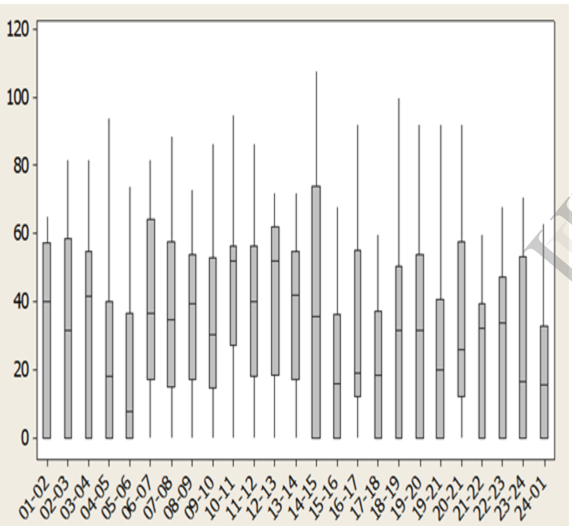


Figure 3.3 BoxPlot burning vs. hour

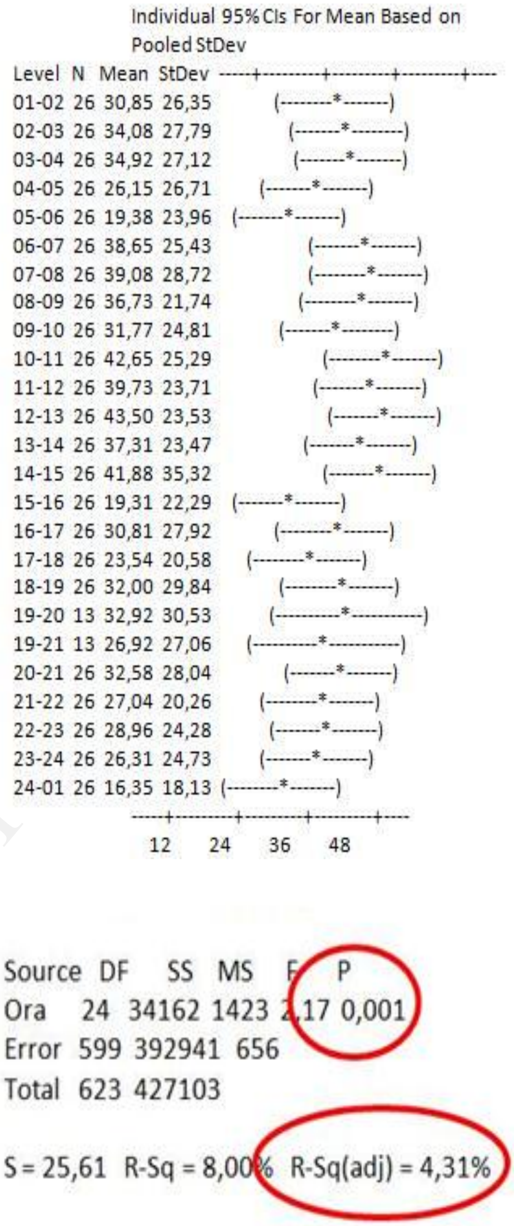


Figure 3.4 one way ANOVA - burning vs. hour

3.1.2.4. *Improve*

3.1.2.4.1. *Define influent factors*

To find a solution for the causes, it was decided to find out the influential factors on each cause first. Thus the flow of the process was asked from the company to be used to brainstorm the influential factors. Finally the brainstorming and listening to experts were led to the following list of factors shown in table 3.2. These factors have been revised and assessed to be narrowed than to only four critical and influential ones based on experiment: Temp dehumidification, Screw back pressure, Screw rotation speed, Injection speed.

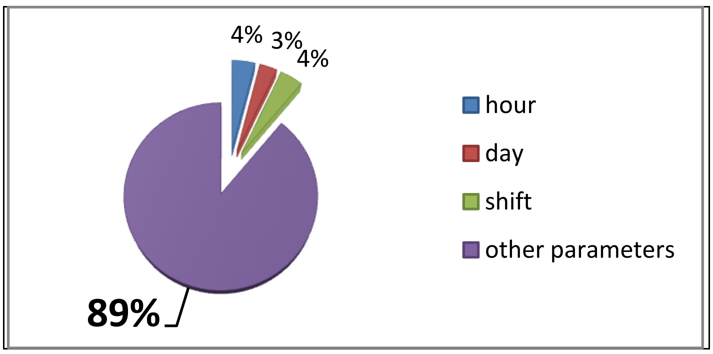


Figure 3.5 Overall Variability of Parameters

Table 3.2 Influent Factors

<table>
<tr><th colspan="7">Raw material dehumidification</th></tr>
<tr><td>Factor</td><td colspan="2">material humidity percentage</td><td colspan="4">Max temperature of dehumidification</td></tr>
<tr><td rowspan="2">Description</td><td colspan="2" rowspan="2">Material viscosity is exponential decreasing function of humidity</td><td colspan="4">High dehumidification temperature and time bring to material oxidation</td></tr>
<tr><td colspan="2">a) Increment of polymer viscosity: pressure and temperature locally high change the polymer and makes burning</td><td colspan="2">b) Punctual creation of long chains: a high difference of viscosity and then part of melted material comes apart.</td></tr>
<tr><th colspan="8">Material plasticization</th></tr>
<tr><td>Factor</td><td>Cylinder temperature</td><td>Rotation speed of the screw</td><td>Screw back pressure</td><td>Injection Speed</td><td>commutation</td><td>Post Pressure</td><td>Material</td></tr>
<tr><th colspan="8">Tool conditioning</th></tr>
<tr><td>Factor</td><td>Nozzle temoerature</td><td colspan="2">Hot chamber temperature</td><td colspan="2">Tool’s fix part temperature</td><td colspan="2">Tool’s mobile part temperature</td></tr>
</table>

3.2. Full Factorial Design

To achieve the goal of finding the best combination of the DOE factors to minimize the total daily scrap, it was decided to run a full factorial DOE with the 4 factors mentioned before. As table 3.3.a shows 8000 pieces were decided to be tested in overall of 16 runs (2^4), so each combination would be 500 in two hands of the mold, each 250 and also each combination was tested for a day. The high sample size was a very critical point of the project. Unfortunately when dealing with aesthetic defects, the sample size must be very high. The sample size should be high in order to correctly discriminate different performance in terms of percentage of waste. While managing continuous characteristics, few units are sufficient for each combination, and while handling aesthetic defects, the sample size must be much higher. There was so much fear about certain combinations; that they could determine a lot of waste because of different set-ups and also there was a high risk on repeating it only once .table 3.3.b shows how full factorial design was applied.

Table 3.3. Full Factorial Design

Full Factorial Design	
Factors	4
Base Design	4;16
Runs	16
Replicates	1
Blocks	1
Center Points	0

(a)

Worksheet 1 ***

→	C1	C2	C3	C4	C5	C6	C7	C8
	StdOrder	RunOrder	CenterPt	Blocks	Temp. Dehumidification	Screw P	Screw RV	Injection V
1	1	1	1	1	65	5	67	29
2	2	2	1	1	80	5	67	29
3	3	3	1	1	65	12	67	29
4	4	4	1	1	80	12	67	29
5	5	5	1	1	65	5	90	29
6	6	6	1	1	80	5	90	29
7	7	7	1	1	65	12	90	29
8	8	8	1	1	80	12	90	29
9	9	9	1	1	65	5	67	32
10	10	10	1	1	80	5	67	32
11	11	11	1	1	65	12	67	32
12	12	12	1	1	80	12	67	32
13	13	13	1	1	65	5	90	32
14	14	14	1	1	80	5	90	32
15	15	15	1	1	65	12	90	32
16	16	16	1	1	80	12	90	32

(b)

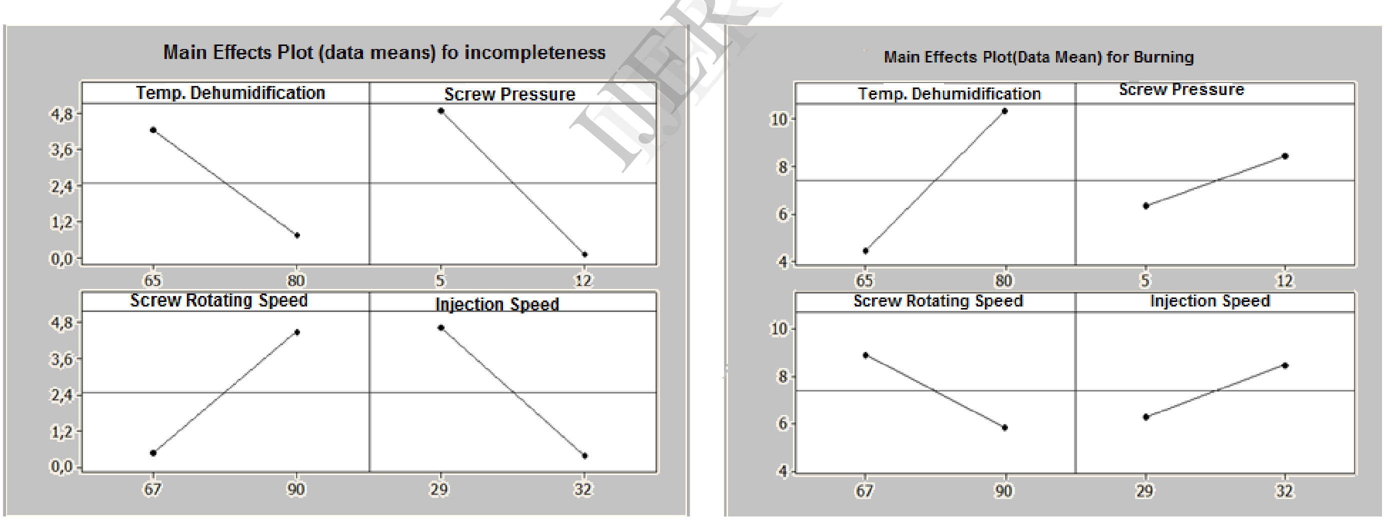


Figure 3.6 Main Effects Plot

3.2.1.1.1. *Experimental Result Analysis*

Analysis of experiment showed that single factors can't have a unique regulation to optimize amount of scraps, because reduction of one type of defect (e.g. not complete) can cause increment of another defect (e.g. burning) as shown in figure 3.6. As the results revealed the relationship between parameters and scraps were complicated and opposite and it could create critical- Situations because opposite correlations made higher risks while decreasing parameters.

The key point and the main activity here was to find the best set-up and trade-off to minimize the total scrap in opposite situation of factors so process parameters optimization was done to reach the optimized level (figure 3.7) which were: Temperature Dehumidification equals to 80°, Screw back pressure equals to 12, Screw speed equals to 90 and Injection speed equals to 32.

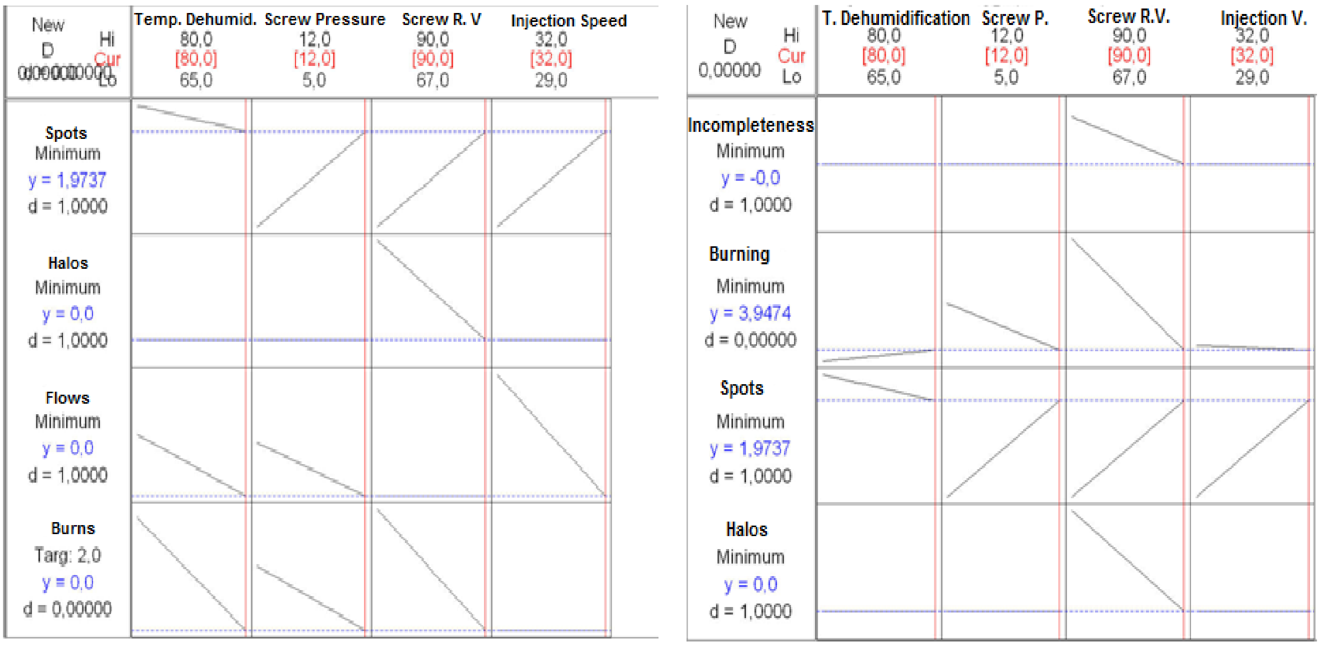


Figure 3.7 Optimized Levels

3.2.1.1.2. *Scraps after new set-up*

After implementation of new set of process parameters, daily average scrap was observed to be below target of 8%, close to stretch target of 6% and Standard Deviation was also decreased of about 30% of the previous amount. See figure 3.8.

3.2.1.2. *Control*

The experiment had shown which combination of parameter values was the best compromise; it was absolutely necessary that this configuration was maintained over time. The results of the DOE were presented to the operational staff and they've been requested to register the set-up for the following parameters at the beginning of each shift: Screw back pressure, Screw speed and Injection speed. Also operators were required to control the drying temperature. Monitoring has been established on an hourly basis. Operators must absolutely respect the values of set-up identified to minimize the scrap and also to control the dehumidification temperature overtime. Beside that some decisions have been made to improve the process: First to implement process control as it's been said before, Second to record final scrap data which would have no cost for the company and third to invest on providing the company with new machinery. It's also worth noting that the observations for the next year showed an average scrap of 6.5% which was near the stretch target.

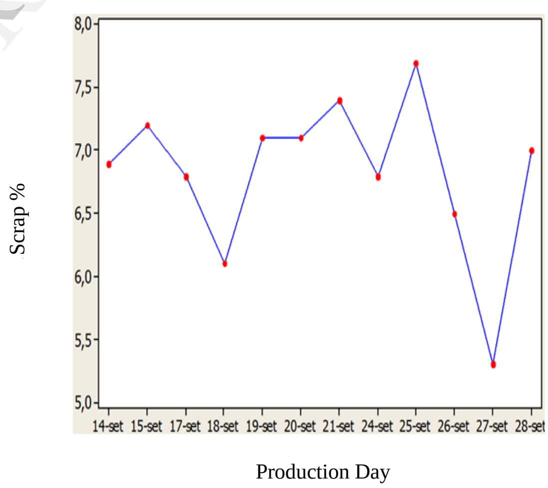


Figure 3.8 Daily scrap percentages

3.2. *Case 2*

This case is also a car industry DMAIC application and the steps would be the same as what has been followed in the first one.

3.3.1. *Case Product*

The product under study is the steering box which converts the rotation of steering wheel into a swivelling movements of the wheel as shown in figure 3.9.

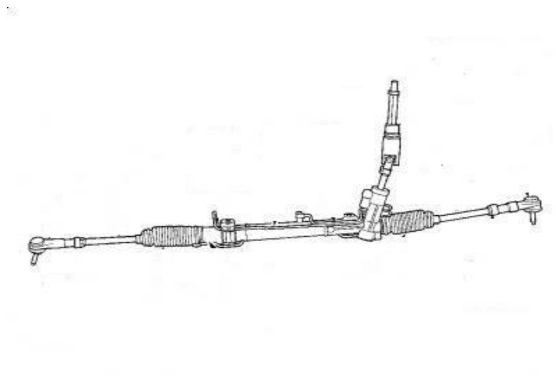


Figure 3.9 Steering Box

3.3.2. *DMAIC Implementation on the case*

3.3.2.1. *Define*

3.3.2.1.1. *Problem Statement*

The problem is a strong heartbeat metal, noticeable in the front passenger side (rough ground). The beat is associated with the steering box and the box consists of 3 main components: bush, pinion and housing. The aim of study is to analyze some parameters and dimensions in particular for the bush. Bush has been put under consideration since project team considered it as the most critical component. The critical part is also included 3 main parts named Flat, Rib and Pad which is shown in figure 3.10.

In define phase the project team has decided to define some relevant characteristics as S4: external tooth thickness in contact with the seat, S5: inside diameter of bush, S6: internal tooth thickness in contact with the rack and S3: Outer diameter bushing (figure 3.11).

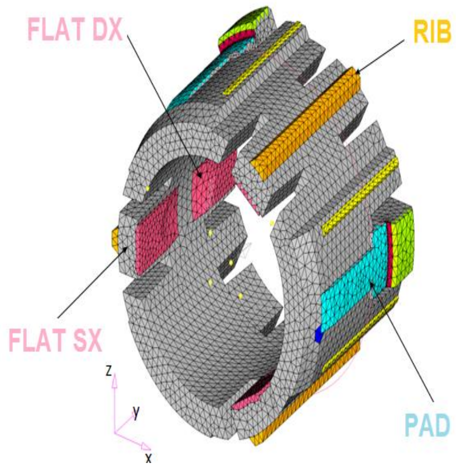


Figure 3.10. Bush Parts

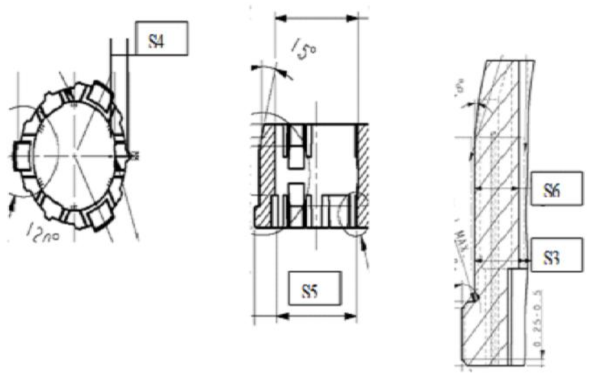


Figure 3.11. Bush relevant characteristics

3.3.2.1.2. *Project Charter*

Table 3.4 represents the project charter .

Project charter		
Project title	Steering gear noise reduction	
Plant	XXX	
sponsor	YYY	
Indicators and value	Plant final control:18% Customer claim:7% Warranty =1.4%(within 3 months)	
Benefit impact area	Quality department	
Project target	Plant final control : 0% Customer claim : 0% Warranty =0.1%(within 3 months)	
Project field	Design department, supplier	
Attendance(participants)	E&D , Quality , Supplier	
Project time	From	To

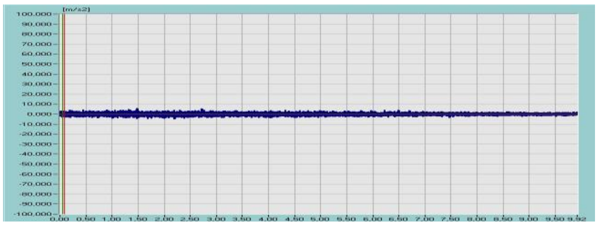
Table 3.4. Project Charter

3.3.2.2. *Measure*

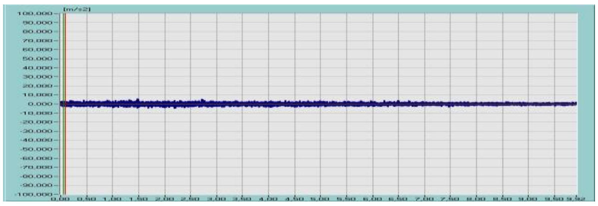
To integrate the subject of people's observations and the experts it was decided to check the noisy boxes and non-noisy ones under the factor of temperature. Two different temperature situations were put under study: first Normal temperature which is around 20-22 $^{\circ}$ C, second 50° C which is an extreme that some parts of the country can go up to. Figure 3.12 represents that the temperature could exceed the noise

To check whether dimensions were related to noise or not and to see the relationship between noise and characteristics it was decided to apply a data collection on the main dimensional parameters of bush, box and rack. To do the collection 10 random systems were chosen and disassembled so all parameters in each system could be evaluated (Figure 3.13).

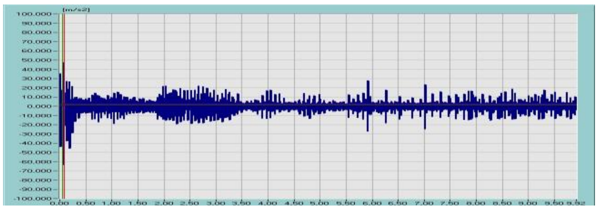
Then 12 samples of the noisiest pieces and the extreme values of dimensional parameters were chosen based on the methodology of Design of Experiment. Note that the components are part of normal production; in particular the bushes are related to the cavity (mold) 1 and 4.In addition three more random samples were chosen and put aside if the first ones didn't answer well.The parameters were decided to be checked are shown in table 3.5.



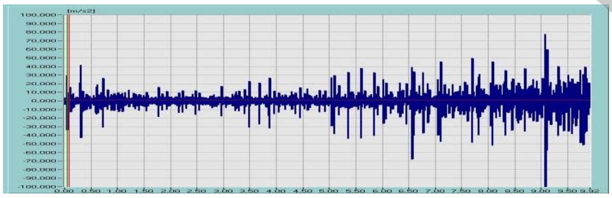
(a) not noisy boxes- Normal Temperature



(b)Not noisy boxes- 50° C



(c) noisy boxes-normal temperature



(d) noisy boxes-50˚C

Figure 3.12 evaluating temperature

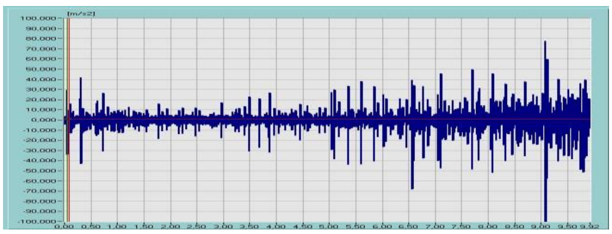


Figure 3.13. Evaluating Dimensions

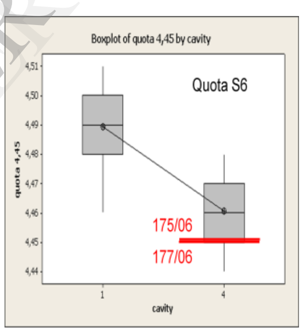
3.3.2.3. *Analyze*

So far a passive approach has been applied.10 systems from normal productions and 40 characters have been chosen before assembly. To define the root cause which is the aim of the Analyze part the next steps were decided to be taken as the following: random selection, measurement, assembly, Green light check (subjective, final control) and Measurement of the acceleration.

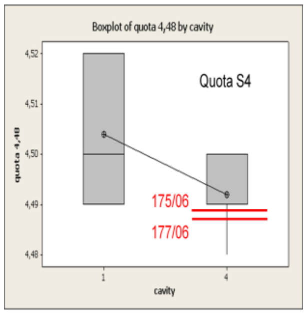
3.3.2.3.1. *Results of the First Experiment*

Out of ten boxes that were checked, 2 seemed noisy which were marked by the code 175/06 and 177/06. Then to force the extremes and to verify if the values of the key characteristics of the noisy boxes were significantly different from those related to the not noisy ones, new 12 samples were checked by the critical characteristics through Box plot.

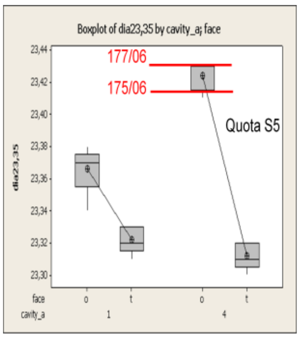
Among all values have been checked, the two noisy boxes bolded in four as shown in the figures 3.14. As it can be seen some points are clear out of the graphs note that the red values represent the noisy boxes: Low values of S4 and S6 are most critical in terms of noise, High values of S5 are most critical, Low values of S3 is proving to be more critical (although the correlation is not obvious) and The parameters S4 and S5 have a strong negative correlation, with the increase of S4, S5 falls.



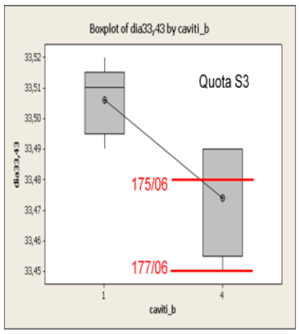
(a) S6



(b) S4



(c) S5



(d) S3

Figure 3.14. BoxPlot

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Table 3.5 DOE

Factors					
Gear Number	Rack dia	Housing inner dia	Bushings		
			S5	S3	Cavity Number
1	23,95	32,99	23,35	33,37	6
2	23,95	32,99	23,35	33,38	6
3	23,95	32,99	23,42	33,45	8
4	23,95	33,04	23,32	33,43	1
5	23,95	33,04	23,38	33,38	7
6	23,95	33,04	23,4	33,45	8
7	23,99	32,99	23,42	33,43	8
8	23,99	32,99	23,39	33,38	7
9	23,99	32,99	23,3	33,45	1
10	23,99	33,04	23,39	33,39	7
11	23,99	33,04	23,32	33,43	1
12	23,99	33,04	23,36	33,38	6

	measured dispersion	tol.
S5	23.32 - 23.42	23,35-23,45
S3	33.37 - 33.45	33,43-33,63

(orange)	High Value
(yellow)	Low Value

3.3.2.3.1. *Design of Experiment*

After finding out the critical characteristics, deeper analysis must be done. It's been decided to evaluate the noise and a significant variable empirically name total energy absorbed by the system and the maximum energy all evaluated by two sensors. As a result the total energy has been very effective in representing the phenomenon of noise: higher energy corresponds to a greater noise.

To see how effective the energy was on noise, two variables which were found dependent by the DOE, interaction plot was chosen since as a definition an interaction plot displays the levels of one variable on the X axis and has a separate line for the means of each level- of the other variable. The Y axis is the dependent variable. The plots are illustrated in figures 3.15 and 3.16. as the figures represent by increasing S5 the energy gets high while it shrinks down when S5 decreases. And the best sets out of the graph are: S5 must be set low so S3 gets irrelevant and since S4 is negatively related to S5 we must set it high,S3 must be set low,The best Housing diam to make S5 irrelevent can be set as 33,04.

As a result Finite Element Analysis confirms experimental results as the bushes with small diameter S5 (and high S4) show a greater interference with the box and then neutralize the phenomena of vibration noise .Consequently it was decided to change the mold cavity 7 and 8 in accordance with the results.

3.3.2.4. *Improve*

To start this part of DMAIC approach, the procedure would be followed as the steps respectively: To change the molds of cavities 7 and 8, To evaluate process capability of molds of cavities 7 and 8, To validate plan for 7 and 8 cavities, To define the new specifications, To do recovery plan for the production, To plan for validation of other cavities and to define new Control Plan.

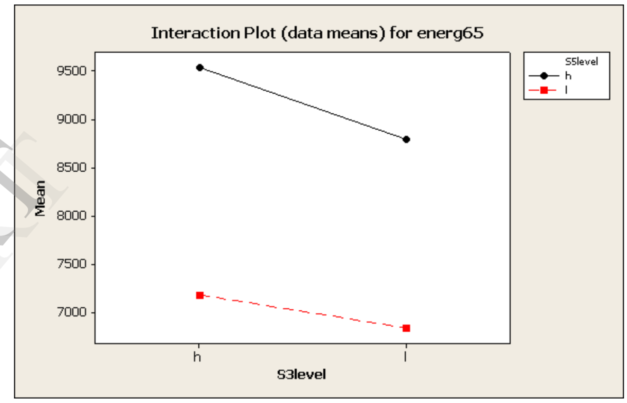

Figure 3.15 Relationship between energy and S3

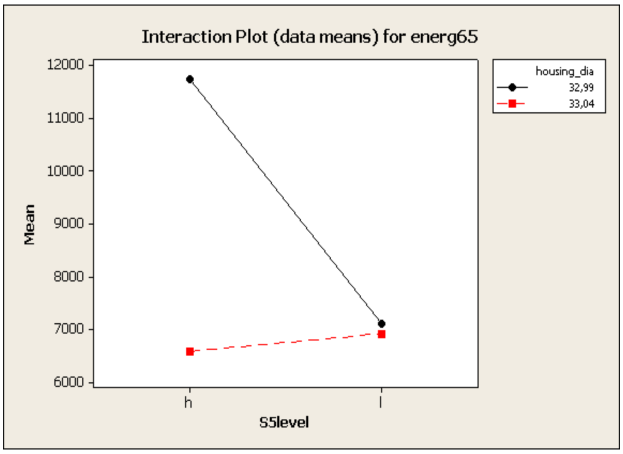

Figure 3.16 Relationship between energy and S5

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3.3.3. *Capability for S5 quote after mold change – Cavity 7*

As it was mentioned the first step of improvement was changing the mold of cavity 7 on the basis of the results mentioned in Analyze phase. After changing them it was time to calculate the process capability of S5 in terms of cavities 7 and 8.

The process capability was calculated .it is well known based on figure 3.17 the process had a Very high Capability, but off-center compared to the old specifications, as it was expected.

3.3.3.1.1. *Capability for S5 quote after mold change – Cavity 8*

The same happened for changing the mold of cavity 8.Very high Capability, but off-center compared to the old specifications was obtained (Figure 3.18).

3.3.3.1.2. *Cavities 7 and 8 validation*

Here some different experiments were done in order to validate the changing the mold of cavities 7 and 8.it is worth noting that all of these experiments resulted in positive results.

Internal control: the team decided to assemble 30 cars with bush from Figures 7 and 8.it was tried to trace the critical dimensions fully. It showed the positive result after a trial run (cycle hot and cold)

Reliability Growth: 7 cars assembled with bush from cavity 8 and 3 cars assembled with bush from cavity 7, and then positive results were obtained.5 cars assembled with used steering gear (10,000 cycles = 30,000 km), again all the results were positive.

Testing at the high temperature: 4 cars assembled: 2 with bush from cavity 7 and 2 with bush from cavity 8, positive results were obtained.

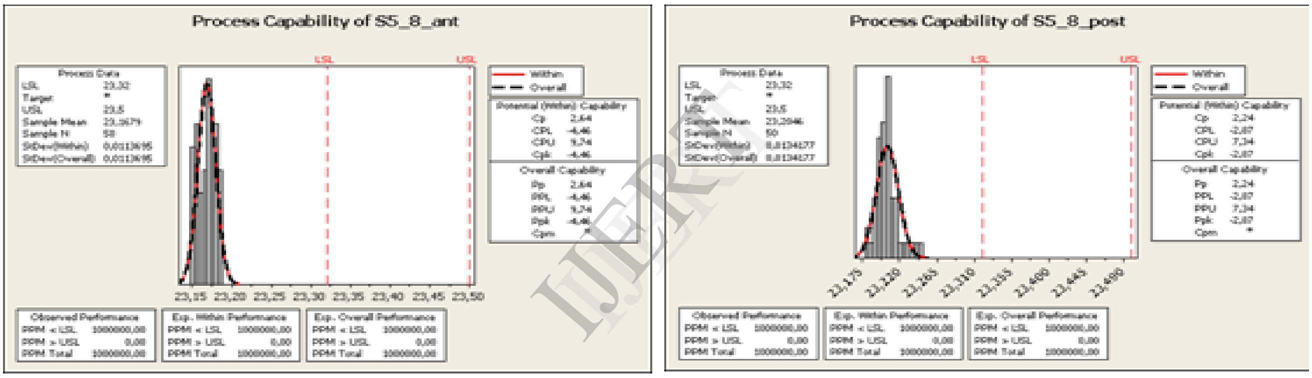

Figure 3.17 S5 process Capability-Cavity 7

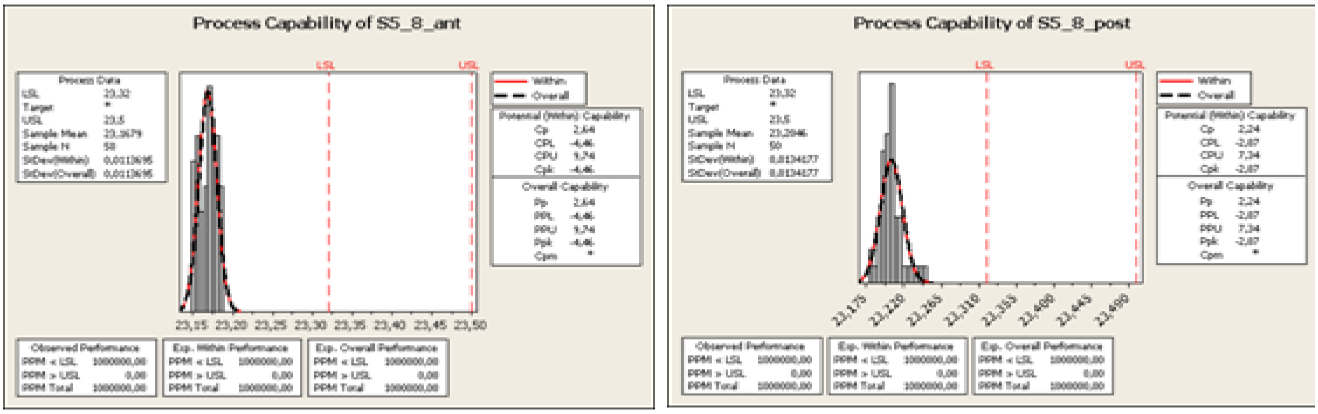

Figure 3.18 S5 process Capability-Cavity 8

3.3.3.1.3. *New specification definition*

Here the project team followed three main objectives: first new nominal values for S5 and S3 second new ranges and third different specs for S3 and S6. In table 3.6 these new dimensions are defined.

3.3.3.2. *Control*

The most critical purpose of such a phase is to ensure the quality and also the volume of the product. Finally the team came up with a control plan including the information in table 3.7 and also decided to enforce the control team to provide data every week.

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4. CONCLUSION

Although implementing DMAIC procedure under six-sigma concept would be costly and needs lots of efforts, training and also time, it brings about quality and customer satisfaction. In other words by doing so cost of poor quality such as refunds, rework or defective percentage, would be decreased. And it is important since poor quality directly affects the customers and may lead to loss of loyalty and reputation.

To sum up DMAIC is a managerial tool to improve the performance supported by quality techniques and relevant tools which have been thoroughly discussed in the paper. To summarize the cases, the table 4.1 represents the whole steps, tools and techniques taken and used in the defined cases.

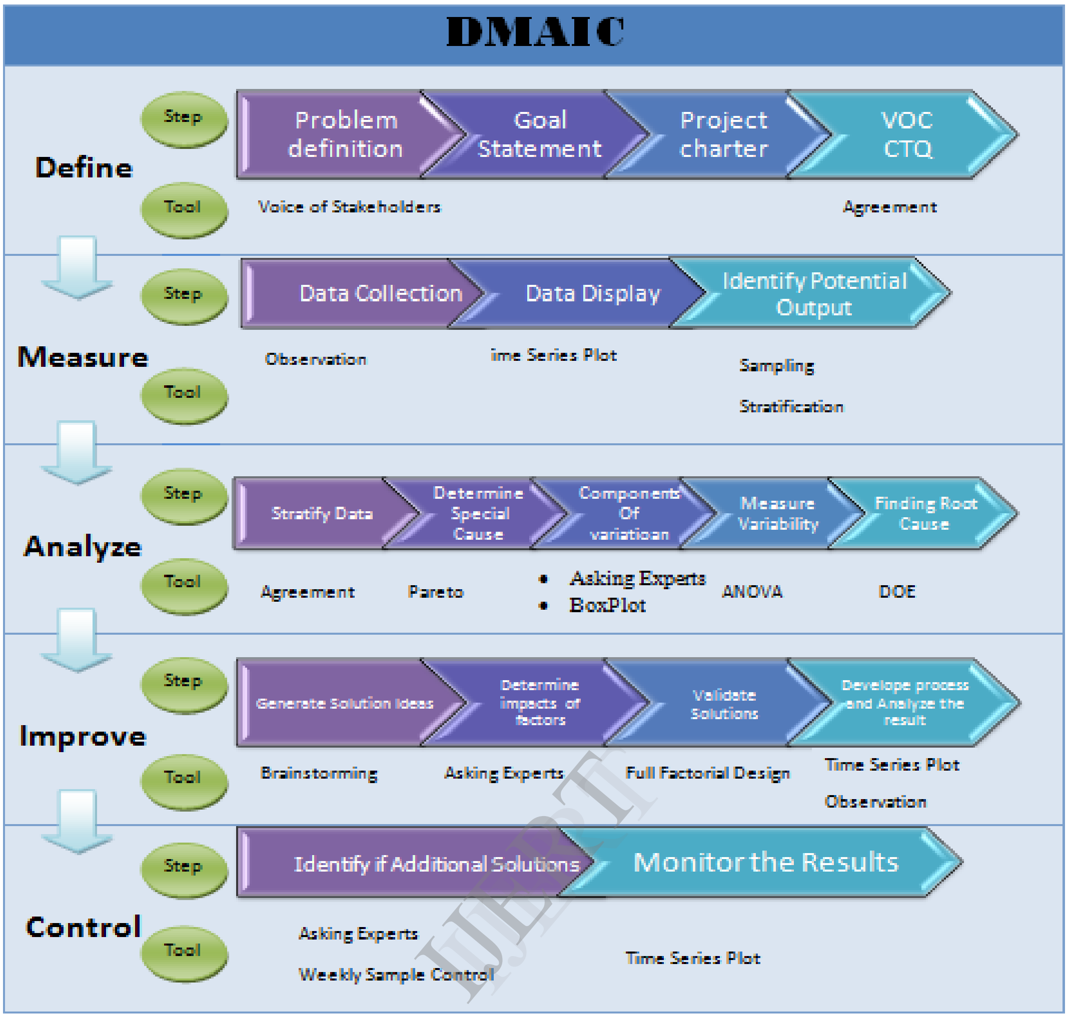
Table 3.6. new specifications

		old				new			
Caratteristica		nom	toll.	min	max	nom	toll.	min	max
S5		23,4	+/-0,05	23,35	23,45	23,18	+/-0,05	23,13	23,23
S4		4,48	+0,05	4,48	4,53	4,53	+0,05	4,53	4,58
S3	-15	33,53	+/-0,10	33,43	33,63	33,48	+/-0,05	33,43	33,53
	-6,5	33,53	+/-0,10	33,43	33,63	33,4	+/-0,05	33,35	33,45
S6	-15	4,45	0,05	4,45	4,5	4,47	+0,05	4,47	4,52
	-6,5	4,45	0,05	4,45	4,50	4,34	+0,05	4,34	4,39

Table 3.7. Control Plan

Dimensions and mechanical characteristics	
Sub-supplier	3 bushes every 20/30 pieces for all fundamental characteristics (S3, S4, S5, S6)
Supplier	• Ø housing → 3/100 • Ø Pinion → 2/3 every 20/30

Table 4.1 steps, tools and techniques used in the cases



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