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An application of Six Sigma to PPM reduction in the relationship with the external customer

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Abstract. Presently, companies from automotive industry adopt Six Sigma strategy to facilitate waste elimination and defect reduction. This paper discusses the successful implementation of Six Sigma DMAIC (Define–Measure–Analyse–Improve–Control) technique in an automotive part manufacturing company to PPM reduction in the relationship with the external customer. The main objective is to propose the solutions to improve the activity in the Cutting Bending, Prototype and Welding workshops to reduce the PPM value in these workshops, so that the PPM value of company will be reduce with a percent of minimum 70%, from 6000 to 2000 value. The DMAIC approach has had a significant financial impact on the profitability of the company in terms of reduction in scrap cost, man-hour saving on rework and increased output. A gain of approximately 389 k€ was reported from this project.

1. Introduction

Over the years, many quality tools and techniques were adopted in the automotive industry and advantages were also gained. Lean Manufacturing, Six Sigma, Lean Six Sigma is some of the techniques [1]. The Six Sigma, a well-structured methodology, was first launched at Motorola in1986 and is one of the most important and popular developments in the field of process improvement [2]. It has gone through a considerable evolution since the early exposition. Initially it was a quality improvement methodology based on statistical concepts. Then it transformed to a disciplined process improvement technique [3]. The methodology is focused on to improve the process by reducing the defects of products, minimizing the process variation and improving the capability of manufacturing processes [4-5]. The objective of Six Sigma is to enhance the Sigma level of "Critical to Quality'' (CtQ) variables that reflect the customer requirements through a dedicated set of tools and techniques. Statistical tools identify parts per million (PPM) of non-conforming products as the main quality for achieving Six Sigma [6-8]. Achieving a Six Sigma level means that having a process that generates an output with 3.4 defective PPM [6, 9, 11]. The introduction to Six Sigma is shown by a schematic diagram in figure 1 [2].

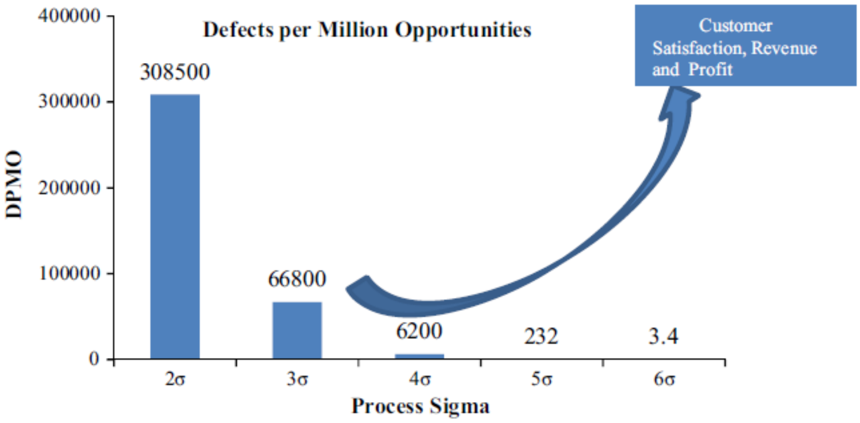

Figure 1. Introduction to Six Sigma.

Six Sigma methodology has two approaches: DMAIC (purpose of step (1)—Define—is to identify the CTQs (characteristics critical to quality) and the process to be improved; step (2) Measure—identify the potential sources of variation of the process and its current capacity; (3) Analyze—identify the sources of variation that significantly affect the process; (4) Improve—identify actions to increase the capacity and, in turn, (5) Control—are actions that help control the sources of variation to maintain the capacity of the process) which is applicable to an existing product or process to be improved, and DMADV (D - Define, M - Measure, A - Analyze, D - Design, V - Verify) which is applicable to new products or processes, to be designed and / or implemented in a manner that will provide a Six Sigma performance [12-13].

This paper deals with an application of Six Sigma define–measure–analyze–improve–control methodology in order to PPM reduction in the relationship with the external customer in automotive industry. The main objective is to propose the solutions to improve the activity in the Cutting Bending, Prototype and Welding workshops to reduce the PPM value in these workshops, so that the PPM value of company will be reduce with a percent of minimum 70%, from 6000 to 2000 value.

2. Problem. Definition

This phase of the DMAIC methodology is aimed at defining the scope and goals of the improvement project including project title, objective, scope, team composition, expected benefits and schedule for the project in terms of the customer requirements and developing a process that delivers these requirements [14]. For all the projects which use the Six Sigma methodology to solving any problem, the first step consists in creating a team of people associated with the process. For our study, the team includes the Quality Manager as the Black Belt (BB) and the other members of the team are Methods, Maintenance, Laser / Bending Manufacturing, Quality Control Senior Engineer, Welding Manufacturing and Warehouse Logistics. In this phase, the team developed a project charter, shown in table 1, with all necessary details of the project. This has helped the team members to clearly understand the project objective, project duration, resources available, roles and responsibilities of team members, project scope and boundaries, expected results from the project, schedule etc.

The team decided to consider the value 9000 of PPM (Parts Per Million) and the value 90% of FPY of First Pass Yield) as the Critical to Quality (CTQ) characteristic for this project. The target value was defined as the reduction of the PPM at 2000 value and for the FPY target value is 95%, which should result in large cost saving for the company in terms of reduction in rework and scrap cost, a 389 k€ value of company benefits.

In order to have a better understanding of the process because is a cross-functional team for executing this project it was necessary to perform a SIPOC (Supplier–Input–Process–Output–Customer) analysis.

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Table 1. Project Charter.

Project Title:	PPM reduction in the relationship with the external customer
Background and reasons for selecting the project:	The company has a high-volume production process utilising costly equipment and tools. The target value of PPM was established at 2500, but at the end of the year was 9000. The estimated financial loss was around 1.44 % rate of turnover.
Project Champion:	Quality
Project Leader:	Quality Control Senior Engineer
Team Members:	Methods, Maintenance, Laser / Bending Manufacturing, Quality Control Senior Engineer, Welding Manufacturing and Warehouse Logistics
Project's objectives	1. Reduction of the PPM value in the Cutting Bending workshop with 40% until June 2. Reduction of the PPM value in the Prototype workshop with 40% until June 3. Reduction of the PPM value in the Welding workshop with 40% until June
Performance Measurements for Improvement Assessment (Critical to Quality (CTQ) characteristic for this project):	9000 value of PPM 90% value of FPY (First Pass Yield)
Project boundary:	Improved processes: Manufacturing: Cutting Bending, Prototype, Welding; Included: Quality, Logistics, Methods, Commercial
Benefits of the project and connections to the company strategy (quantifiable):	389 k€
Benefits of the project and connections to the company strategy (non quantifiable):	Reduction the damage risk parts - through proper storage Work environment - productive and ergonomic - 5S, visual management Better use of the staff time - general rules in workshop, communication Better use of equipment - respect of the maintenance level 1 rules Eliminating the costs with unnecessary activities – standardization of the workstations Improvement of the flow - 5S, visual management, workstation standardization Increased of the equipment availability - equipment availability
Schedule	Define: 2 Weeks, Measure: 2 weeks Analyze: 3 weeks, Improve: 4 weeks Control: 6 weeks.

SIPOC is a method similar to process mapping for defining and understanding process steps, process inputs and process outputs. The team with the involvement of people working with the process prepared a SIPOC mapping along with a basic flowchart of the process. This SIPOC has given a clear understanding of the process steps needed to create the output of the process. The team focused on the reduction of the PPM value in the Cutting Bending, Prototype and Welding workshops of the manufacturing process, which is defined as the scope of the project. The process mapping along with SIPOC is presented in table 2.

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Table 2. Process Mapping (SIPOC).

Suppliers	Input	Process	Output	Customers
Warehouse man	Labels	Storage of raw materials	Raw material stock	Warehouse man
Warehouse man	Manufacture order	Transfer to workshop Cutting - Bending	Raw material	Leader of the workshop Cutting - Bending
Programmer	Planes / Cutting program	*Realization of prototype parts*	Prototype part	External/Internal customer
Programmer	Planes / Cutting program	*Cutting - bending*	Finished/semifinished product	Manufacturing/ Bending workshop
Programmer	Planes / semifinished product	*Welding*	Finished product	External customer

The high-level process mapping prepared along with the SIPOC provides the boundaries (start and end points) of the process where improvement activities to be performed.

3. Measure phase

The Measure phase in a Six Sigma project involves trying to collect data to evaluate the current performance level of the process, and provide information for analysis and improvement stages. This phase deals with the following:

- Validation of measurement system.
- Data collection plan and preliminary analysis of the data.

3.1. Validation of measurement system

The team decided to conduct a measurement system analysis to validate the measurement system. The samples used for study (30 parts) are not randomly chosen. They are chosen by specialized staff and must be determined to be either conforming or non-conforming (their status is known only by one person). Conforming parts were marked "OK" and nonconforming parts with "NOK". The parts are measured twice by two different evaluators (independently of each other). The results of the measurements are also shown in the figure 2.

Part #	Reference	Operator 1		Operator 2		Cote 416.3+/-1	Cote 272+/-1	Cote 54+/-1	// 0.5/A
		Rep 1	Rep 2	Rep 1	Rep 2				
1	A	A	A	A	A	416.582	271.85	53.51	0.49
2	A	A	A	A	A	416.85	271.17	53.48	0.33
3	A	A	A	A	A	416.453	272.05	53.33	0.055
4	A	A	A	A	A	416.21	271.08	53.85	0.159
5	A	A	A	A	A	415.38	271.41	53.21	0.423
6	A	A	A	A	A	415.72	271.14	53.15	0.37
7	R	R	R	R	R	414.43	271.84	53.26	0.21
8	A	A	A	A	A	417.03	271.02	53.45	0.45
9	A	A	A	A	A	415.41	271.88	54.38	0.41
10	A	A	A	A	A	416.95	271.45	54.17	0.35
11	A	A	A	A	A	417.25	271.24	54.15	0.34
12	A	A	A	A	A	417.11	271.05	54.53	0.25
13	A	A	A	A	A	416.85	271.43	53.77	0.44
14	A	A	A	A	A	417.3	271.32	53.09	0.451
15	A	A	A	A	A	416.961	271.449	53.37	0.48
16	A	A	A	A	A	417.05	272.1	54.25	0.325
17	A	A	A	A	A	416.53	272.15	54.15	0.458
18	A	A	A	A	A	416.85	271.35	53.33	0.495
19	A	A	A	A	A	416.855	272.2	53.55	0.255
20	A	A	A	A	A	416.95	271.45	54.015	0.355
21	A	A	A	A	A	417.1	271.859	54.25	0.4
22	A	A	A	A	A	415.75	271.45	53.22	0.45
23	A	A	A	A	A	415.85	271.85	54.12	0.35
24	A	A	A	A	A	415.95	271.77	54.05	0.39
25	A	R	R	R	R	416.35	271.71	53.95	0.41
26	A	A	A	A	A	416.55	271.25	53.85	0.455
27	A	A	A	A	A	415.95	271.25	53.77	0.33
28	A	A	A	A	A	415.54	271.88	53.49	0.45
29	A	A	A	A	A	415.65	271.15	54.1	0.425
30	A	A	A	A	A	416.85	272.15	53.25	0.458

Figure 2. The measurements results.

The results are also shown in the figure 3.

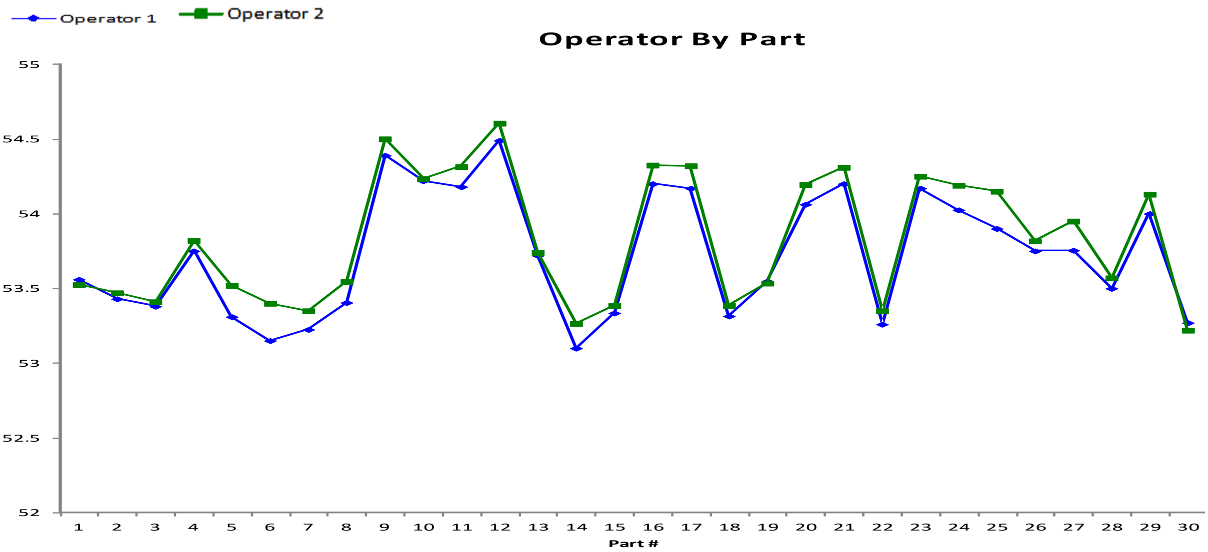


Figure 3. The measurements results – operator by part.

These data were analysed with the help of Minitab software. The total gauge repeatability and reproducibility (GR&R) values were found to be 2.40 % and 3.03 %. The Minitab software output of one of the GR&R study is presented in table 3. Since percentage GR&R values were less than 10 %, the team concluded that the current measurement system was adequate.

Table 3. Results of gauge R & R study (Minitab output).

Source	Standard deviation	% Study variation
Total Gauge R & R	0.100020665	5.45
Repeatability	0.066317796	2.40
Reproducibility	0.074873783	3.03
Operator	0.070318802	2.70
Operator – Part interaction	0.025716709	0.35
Product (Part-to-part)	0.416472059	94.55
Total variation	0.128311264	100.00

3.2. Data collection plan and preliminary analysis of the data

After the measurement system study, a data collection plan was prepared with all details of types of data required to be collected including sample size, frequency of sampling etc. During the defined period of data collection, 880 parts were rejected due to various defects. Each one of the rejected components was having one or more defects. The collected data shows that the rejection in the process was 9000 PPM.

Data analysis is performed using the variable control charts, figures 4 and 5. They are used when there are needed the information on the process centering (this is evaluated by mean or median) or its precision (evaluated by amplitude or mean square deviation).Thus, two parameters are investigated: the average of the characteristic values (which will provide information on centering process) and the amplitude of the R run of values (which will provide information on the accuracy of the process). In this project roughness of some types of parts was analysed. Analysing the graphs, it is observed that in the first part of the process it is an important variation of the roughness, this varying between the maximum rated value and the minimum (with the exceeding in some points). In the second part there is a grouping of values but this is done towards the minimum limit.

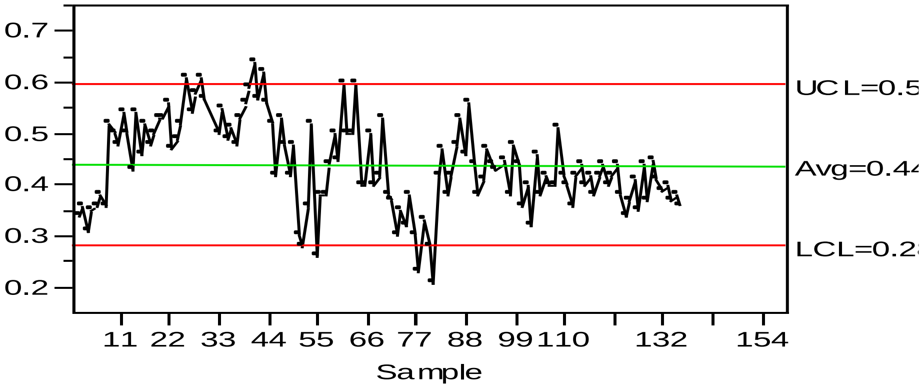


Figure 4. Control chart. Individual measurement of the roughness.

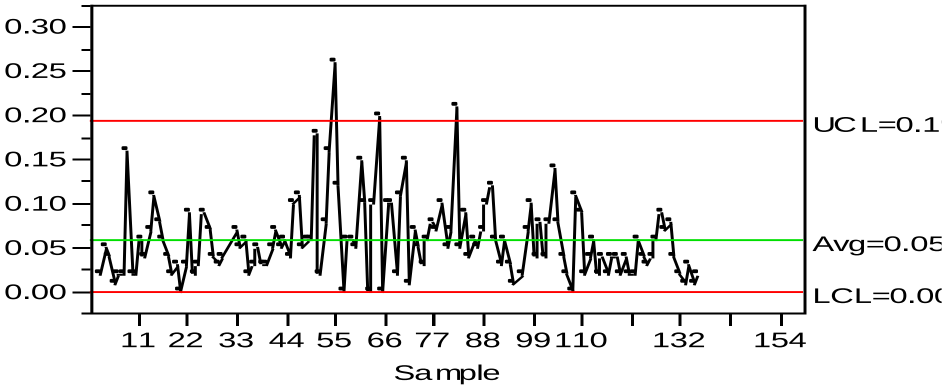


Figure 5. Control chart. Moving range of the roughness.

Further, the normality of the process is analysed. From the analysis of the histogram, figure 6 form but also using the "Henry test" it is observed that the process is statically stable (the values of the characteristics are distributed according to the normal distribution law).

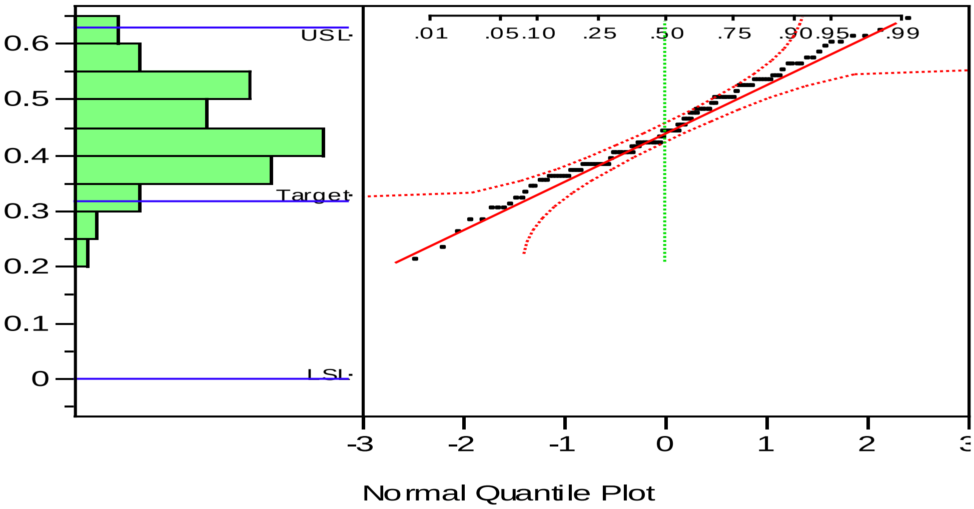


Figure 6. Distributions of the roughness

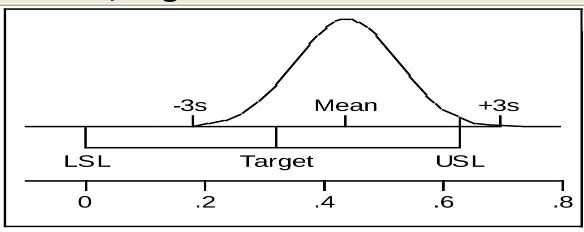
By analyzing the dynamic stability, figure 7, it is found that:

- the process is at the limit stable as precision (1.072 ≤ Cp ≤ 1.367);
- the process is not stable as adjustment (0,737 ≤ Cpk ≤ 0,843). In fact, this is observed by moving the distribution curve to the maximum value.

Capability Analysis

Specification	Value	Portion	% Actual
Lower Spec Limit	0	Below LSL	0.0000
Upper Spec Limit	0.63	Above USL	0.7576
Spec Target	0.32	Total Outside	0.7576

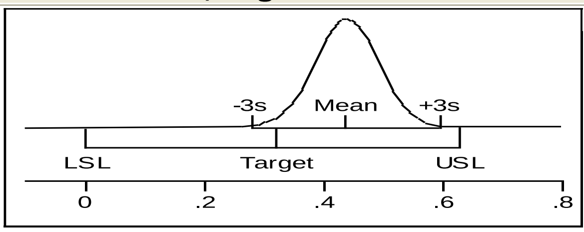
Overall, Sigma = 0.08612



Capability	Index	Lower CI	Upper CI
CP	1.219	1.072	1.367
CPK	0.737	0.631	0.843
CPM	0.701	0.630	0.773
CPL	1.702	1.488	1.915
CPU	0.737	0.631	0.842

Portion	Percent	PPM
Below LSL	0.0000	0.1654
Above USL	1.3527	13527.035
Total Outside	1.3527	13527.2

Control Chart, Sigma = 0.05263



Capability	Index	Lower CI	Upper CI
CP	1.995	1.754	2.236
CPK	1.206	1.049	1.362
CPM	0.791	0.712	0.870
CPL	2.784	2.442	3.125
CPU	1.206	1.049	1.362

Portion	Percent	PPM
Below LSL	0.0000	0.0000
Above USL	0.0149	148.9381
Total Outside	0.0149	148.9381

Figure 7. Control chart. Moving range of the roughness.

4. Analyse phase

In this phase the gap between actual and goal performance is identified, the causes of those gaps are determined. An Ishikawa diagram, figure 8, was prepared after conducting a brainstorming session with all the concerned people from the process.

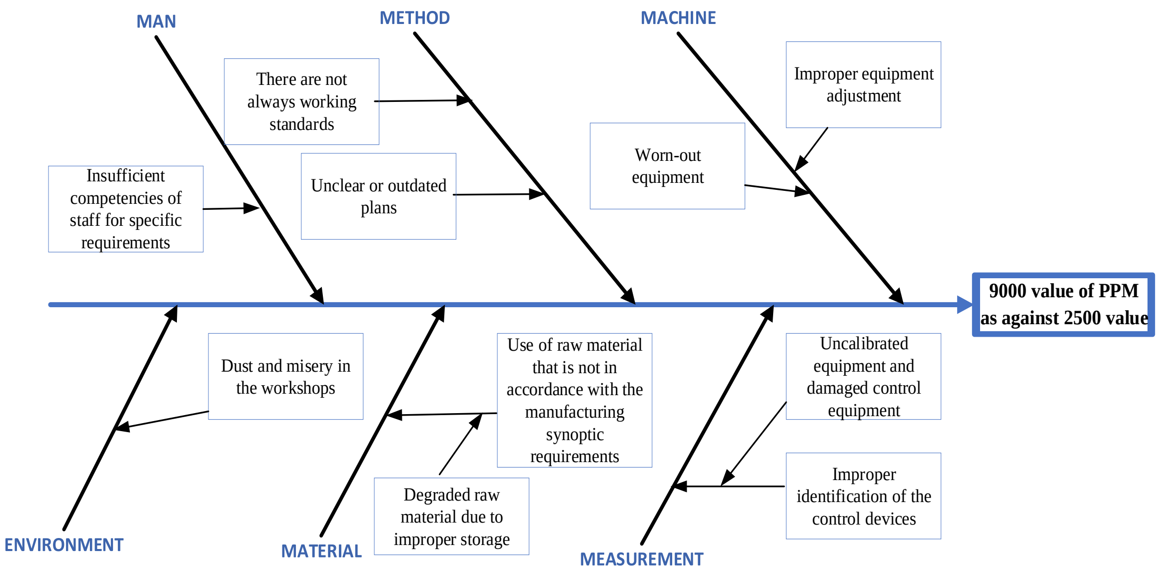


Figure 8. Ishikawa diagram for 9000 value of PPM as against 2500 value.

The results of Ishikawa diagram depend to a large extent on the quality and creativity of the session and the knowledge level of the team members.

5. Improve phase

This phase of the Six Sigma project is aimed at identifying solutions for all the potential causes identified during the Analyse phase, implementing them after studying the risk involved in implementation and observing the results. The risks analyses of our projects and the solutions for all the potential causes are presented in table 4 and 5.

Table 4. Project risks analyses.

Risks family	Potential failure mode	Risks	Potential effects	P	S	C	Recommended action	P	S	C
Customer contract	Erroneous data in PPM	Delayed transmission of the information from the customer on quality complaints.	Manufacturing processes that don't work according to the required objectives	3	4	12	Request the customer to send us the claims on the day of their issue	2	4	8
Technical	Incomplete standardization	Incomplete standardization and applied to certain areas of the process	unclear and incomplete rules	2	3	6	Clear requirements, working standards in all workshops. Displaying the documentation of the Integrated Management System on a web page accessible to all staff.	2	2	4

P –Probability, S- Severity, C =P x S

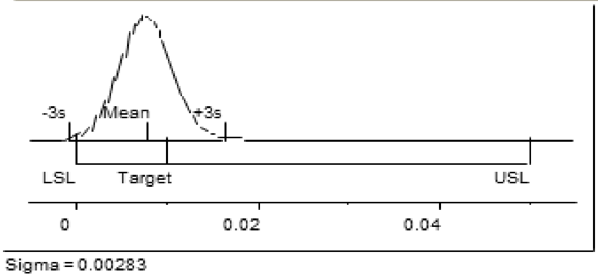
Table 5. Potential causes and proposed solution.

Potential causes	Solutions
Insufficient competencies of staff for specific requirements	Defining the workstation sheets, training after the validation of Initial Samples and during the life of the product, with operators and quality inspectors on customer requirements
There are not always working standards	Defining the instruction sheets for cutting – bending workshop Defining the instruction sheets for welding workshop
Use of raw material that is not in accordance with the manufacturing synoptic requirements	Labeling the raw material at the reception with the specification of the references for which it will be used
Degraded raw material due to improper storage	Purchasing of the additional racks for storage in the warehouse, warehouse reorganization Defining the conditioning sheet
Unclear or outdated plans	Realization of the bending instruction sheet Product audits
Worn-out equipment	Implementation of the maintenance level 1 for cutting, bending and welding equipment
Improperly equipment adjustment	Realization of the bending instruction sheet Realization of the instruction sheet for: description of welding operation mode
Uncalibrated equipment and damaged control equipment	Implementation of the management program for monitoring and measuring resources
Inadequate identification of control devices	Implementation of the management program for monitoring and measuring resources Metrology audits
Dust and misery in the workshops	Implementation 5S methodology in the workshops

6. Control phase

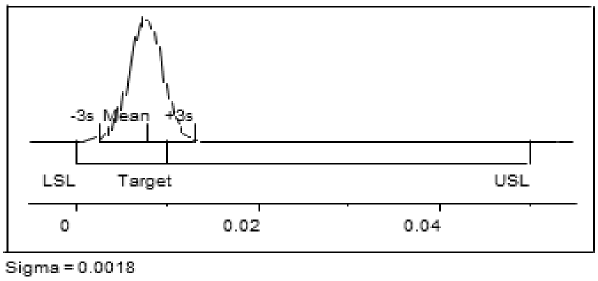
The purpose of this stage is to hold on to the improvement achieved from the last stage. After implementing the improvements presented in Improve phase there is a substantial improvement in process results, figure 9.

Long Term Sigma



Capability	Index	Lower CI	Upper CI
CP	2.940	2.096	3.782
CPK	0.916	0.619	1.212
CPM	0.927	0.696	1.158
CPL	0.916	0.619	1.208
CPU	4.964	3.532	6.392

Portion	Percent	PPM	Sigma Quality
Below LSL	0.3006	3005.9105	4.247
Above USL	0.0000	0.0000	
Total Outside	0.3006	3005.9105	4.247



Capability	Index	Lower CI	Upper CI
CP	4.641	3.309	5.971
CPK	1.446	1.007	1.884
CPM	1.170	0.889	1.450
CPL	1.446	1.008	1.880
CPU	7.836	5.582	10.086

Portion	Percent	
Below LSL	0.0007	7.2202
Above USL	0.0000	0.0000
Total Outside	0.0007	7.2202

Figure 9. Control chart. Moving range of the roughness.

It is observed, both an improvement of the centering as precision as well as adjustment. Also, after implementation the solutions the value PPM was reduced and during our project, the first 6 months of the next year, the average PPM was 1936 thus achieving the objective of the project.

7. Lessons learned

- Registering the values of the first part measured in the checklist (at the start of the project, the quality inspector validates without registering).
- Elaboration the materials and training rules for new employees.
- Accelerate implementation of the preventive maintenance.
- Process audits to evaluate how the rules and procedures are followed in the production workshops.
- Transfer of responsibility from the Quality Department to Production.

8. Conclusion

Six Sigma is perceived as a well-structured improvement approach with strong links to an organisation’s strategy, high level of management involvement, strong customer focus and strong links to financial results [15]. This paper presents the step-by-step application of the DMAIC approach of the Six Sigma methodology to PPM reduction in the relationship with the external customer for a company in automotive industry. After achieving the results and maintaining it for a period of 6 months, the team carried out a cost–benefit analysis of the whole project. A gain resulted from this project were estimated and found to be about of approximately 389 k€. The result should encourage the management and staff in the companies to work in Six Sigma projects.

Acknowledgments
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