SIX SIGMA METHODOLOGY IMPLEMENTED IN AUTOMOTIVE INDUSTRY

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A b s t r a c t : In present era of competition, Six Sigma has been considered as a powerful business strategy that employs a well structured continuous improvement methodology to reduce rejections within the manufacturing processes using effective application of statistical tools and techniques. This paper presents the implementation of Six-sigma methodology for reducing rejection of automobile part in an industry. The DMAIC (Define, Measure, Analyze, Improve and Control) methodology has been used to achieve quality level. During this process, data for all possible causes were collected, analyzed and thereby conclusions were drawn. Implementation of Six Sigma resulted in reduction of rejection and improvement of process capability and process performance. Finally, implementation of Six-sigma methodology has resulted in increase in quality level of assembly line and pre-assembly process in automobile company.

Key words: Six Sigma; Define; Measure; Analyze; Improve and Control (DMAIC); Lean Six Sigma (LSS);
Statistical process control (SPC); Measurement system analyze (MSA)

МЕТОДОЛОГИЈАТА ШЕСТ СИГМА ИМПЛЕМЕНТИРАНА ВО АВТОМОБИЛСКАТА ИНДУСТРИЈА

А п с т р а к т: Во денешната ера на конкуренција, „Шест Сигма“ се смета за моќна бизнис-стратегија што користи добро структурирана метологија за континуирано подобрување, со цел да ги намали дефектите во процесот на призводство применувајќи ефективни статистички алатки и техники. Во овој труд е прикажано имплементирањето на методологијата „Шест Сигма“ за намалување на дефекти во автомобилската индустрија. Се користи методологијата DMAIC (Дефинирај, Мери, Анализирај, Подобри и Контролирај) за да се постигне бараниот квалитет. За време на овој процес се собрани податоци за сите можни причинители на појавата на дефекти, и добиените податоци се анализирани и донесен е заклучок. Имплементирањето на „Шест Сигма“ во автомобилската компанија, што е предмет на ова истражување, резултира со намалување на стапката на дефекти. т.е подобрување на чподготбеноста перформансот на процесот. Заклучно, имплементирањето на методологијата „Шест Сигма“ резултира со зголемување на нивото на квалитетот на линијата за финално монтирање и на процесот на подготовка во производниот процес на автомобилската компанија што е предмет на истражувањето.

Клучни зборови: Шест Сигма; дефинирај, мери, анализирај, подобри и контролирај (DMAIC);
статистичка контрола на процес (SPC); анализа на мерните системи (MSA)

1. INTRODUCTION

For automotive industry to be globally competitive operational excellence is the basic success mantra. For global competiveness many technique such as Quality circles, Total quality management, ISO certifications are being tried. The automotive sector needs advance strategy which can have multidirectional benefit in shorter duration [1].

Six Sigma DMAIC is excellent methodology that is fully integrated into all aspects of the automotive manufacturing processes, and is now recognized worldwide as the standard of quality that must be used to be recognized as a world-class level manufacturing process [2].

Six Sigma DMAIC is designed to reduce process variation by defining, measuring, analyzing, improving and controlling processes [3].

The practitioners and researchers of Six Sigma have provided multiple dimensions and interpretations of this methodology. It is a business strategy to improve the effectiveness and efficiency of all the operations [4].

There are many frameworks proposed by different researcher in combination with other quality initiatives in disparate context. Some of them explores the study of the combination of two distinct strategies, Six Sigma and Theory of Constraints (TOC), for improving manufacturing system performance [5]. Some study also focus and introduce a conceptual framework that discuss the relationship between the two fields of the organizational discipline represented by Six Sigma and innovation from the perspective of the Absorptive Capacity Theory [6]. Increasingly, organizations that use Six Sigma are making an effort to integrate lean into their existing process improvement framework [7]. It is spotlighted on Six Sigma Process Improvement Model, where the goal of the process is to improve the overall quality of the system under development [8]. Studies also focus on the guiding principles of the Shainin tools [9] which are powerful, and at least, in combination, unique.

The approach that will be analyzed in this paper is integration of Lean Tool intelligent automation in improve phase of Six Sigma DMAIC (Define, Measure, Analyze, Improve and Control).

2. TEORETICAL PART – SIX SIGMA (DMAIC) METHODOLOGY

In the Table 1 are presented implementation phases of the Six Sigma (DMAIC) methodology [10].

When implementing the DMAIC method, a number of auxiliary quality improvement tools and methods are used. The improvement cycle using the DMAIC method consists of the following elements [11]:

Six Sigma (DMAIC) – Define phase: This phase will involves creating a project chapter, scope of the project and identifying projects critical to quality characteristics (CTQs). Select an opportunity for improvement and define the problem.

Six Sigma (DMAIC) – Measure phase: The major activity in measure phase is the project base lining. This includes identification of measurement factors, which need to improve the project Critical to Quality (CTQ) characteristics, developing "as is" process map, analyzing variations in the measurement system (MSA), preparing data collection plan,

and calculations of standard deviation σ [St Dev], Process Capability Index [Cpk] and Process Performance Index [Ppk].

T a b l e 1

Implementation phases of Six Sigma (DMAIC)

DEFINE	Charter	
	Scope of Project (Big Y)	Measureable
	Cost savings	
	Team members	
	Champion	
	Any other improvements?	Quick wins
MEASURE	Kickoff Meeting	
	High level process map	
	Low level process map	
	C&E matrix	Identify factors that impact the process Fishbone
	I-MR/Box plot	Identify qutliers
		How critical X is to Y
	FMEA	Identify most critical inputs
		Rate critical inputs base on SEV, DEC, OCC = RPN
	MSA	% R&R on Data
	Baseline capability	Data stable
		Data normal
		Determine the mean
		Cpk
		6-Pack
		IMR
		Histogram
		P-value (.05) P high keep
		Probability plot
		Normality test
	Lock chapter	No more changes to charter
ANALIZE	FMEA review update	
	Hypothesis testing	Ho vs. Ha
		Pareto analysis
		Define X/Y as descrete or continuous data
		t-test
		ANOVA
		Regression testing
		Reject or do NOT reject Ho
	Multi-variability study	Correlation hypothesis
		Main effect plot
		Interaction plot
		Fitted Line plot
		Six-pack
		Sources of variation
	Determine X's that have the	most impact on Y
IMPROVE	Confirmation run	Identify flaws in analysis
	Implementation plan	Establish actions
	Finalize FMEA	
	Change management	Track actions
		Capability 6-Pack
	Confirm things are okay	Regression testing model
CONTROL	Scorecard	
	Compare to charter	
	Metrics to measure effectiveness	
	Identify additional improvements	
	Continue monitoring/Cost avoidance	
	Project sign-off	

Measurement system analysis (MSA): MSA is defined as an experimental and mathematical method of determining the amount of variation that exists within a measurement process. Variation in the measurement process can directly contribute to our overall process variability. MSA is used to certify the measurement system for use by evaluating the system's accuracy, precision and stability [14].

Observed process variations is composed of true process variations and measurement system variations:

$$\sigma_{\text{opv}}^2 = \sigma_{\text{tpv}}^2 + \sigma_{\text{msv}}^2, \qquad [1]$$

where σ is normal distribution, σ_{opv} is observed process variations, σ_{tpv} is true process variations and σ_{mv} is measurement system variations.

In minitab software which we will use in experimental part of this paper for data analyses and statistical & process improvements, symbol for observed process variations (σ_{opv}) is TV-total variations, symbol for true process variations (σ_{tpv}) is PV – part-to part variations and symbol for measurement system variations (σ_{ms}) is Gage R&R or simply GRR (Gage repeatability & reproducibility):

$$TV^2 = PV^2 + GRR^2. \qquad [2]$$

In the further theoretical part of this paper we will use Minitab symbols in order to coincide with symbols in experimental part were we calculate baseline (MSA study and Statistical process control with control charts).

For validation of the measurement process is used Gage R&R or GRR study to assess the accuracy, precision and stability. Gage R&R study is a standard tool to assess and quantify the capability of a measurement system that generates continuous (variable) data on items that can be repeatedly measured. The key question that MSA seeks to answer is, can the data be trusted. Quality of the measurement system is characterized by statistical properties. For reliable Gage R&R study number of individual measurements should be: [S] × [O] × [T] > 30 (S – sample, O – operators, and T – trials). Samples for MSA study should span at least 80% of the full, typical range of the process in order to evaluate linearity, which is consistency of the measurement across the entire range of the measuring gage.

Components of variation graph in minitab: This is chart with various components of variation, based on % Contribution, % Study variation (or R&R% - ratio for reputability and reproducibility, see formula 8) and %Tolerance (or P/T% ratio of precision to tolerance, see formula 9). The different components of the graph are:

Repeatability. These are variations in the measurement system "within appraiser", that occurs between successive measurements of the same sample, same characteristic, by the same person using the same instrument. This variation is usually referred to as Equipment Variation (EV) in the Gage R&R study.

Equipment variations (EV) is calculated by multiplication of average ranges between appraisers $\bar{\bar{R}}$ and constant K_1 which depends upon number of trials used in Gage study (see Table A-2, Appendix):

$$EV = \bar{\bar{R}} \times K_1. \qquad [3]$$

Reproducibility. These are variations "between appraisers" or "appraiser variations AV", that occur when different conditions are used to make the measurements: different person, different set-up, different samples and different environmental conditions. Since the appraiser variation is contaminated by the equipment variation, it must be adjusted by subtracting a fraction of the equipment variation. Therefore, the appraiser variation (AV) is calculated by:

$$AV = \sqrt{(\bar{X}_{\text{DIFF}} \cdot K_2)^2 - \left(EV^2 / (nr)\right)} \qquad [4]$$

where K_2 is constant which depends upon number of appraisers, *n* is number of parts and *r* is number of trials (see Table A-2, Appendix):

$$\bar{X}_{DIFF} = [max\,\bar{X}] - [min\,\bar{X}], \qquad [5]$$

where: $\bar{X}_{\text{DIFF}}$ is subtracting max average of measurements by appraiser and min average of measurements by appraiser (see Table A-1 in Appendix).

Gage R&R (Gage repeatability and reproducibility). When Gage R&R <10 %, this shows that observed process variations are not due to measurement system variations but due to the true process variations (see formula 1). The measurement system variation for repeatability and reproducibility (GRR or σ_{ms}) is calculated by adding the square of the equipment variation and the square of the appraiser variation, and taking the square root as follows:

$$\sigma_{\text{ms}} \text{ (or } GRR) = \sqrt{(EV)^2 + (AV)^2}. \qquad (6)$$

Part-to-part variation. The variability in measurements across different part. Ideally this should be the highest graph for a very good GR&R

study. Part-to-part variation (PV) are true process variations (σ_{tpv}) without measurement system variations (GRR or σ_{ms}). PV is determined by multiplying the range of part averages (R_p) by a constant K_3. Constant K_3 depends upon the number of parts used in the GRR study and is the inverse of constant d_2^* [14].

$$PV = R_p \times K_3 \qquad (7)$$

• % R&R (ratio of repeatability & reproducibility) present measurement system variations compared with observed process variations:

$$\text{R\&R\%} = \frac{\sigma_{ms}}{\sigma_{opv}} \cdot 100\% = \frac{GRR}{TV} \cdot 100\%; \qquad (8)$$

where for GRR see formula 6, and for TV see formula 2.

• P/T% (ratio of precision to tolerance) – Measurement system variations compared with tolerance:

$$\text{P/T \%} = \frac{6 * \sigma_{ms}}{Tolerance} \cdot 100\% = \frac{6 * GRR}{USL - LSL} \cdot 100\%, \qquad (9)$$

where USL is upper specification limit and LSL is lower specification limit.

***Xbar chart by operators graph*:** This graph indicates out of control conditions. We wish to see the majority of the points on this chart outside the control limits. This indicates more sample-to-sample variability (true process variations), which is desired, compared to the variability within the measurement system. The pattern between operators should be similar, if the patterns are not similar, that probably indicates a reproducibility issue.

The R chart (range) by operators graph: The range chart should be in control if the operators measure consistently. Repeatability may be questioned if the range chart is out-of-control. If the ranges for all operators are out-of-control the system is likely sensitive to operator technique. The method should be investigated if the range for one operator is out-of-control and for the other operators is in control.

Measurement by operator's graph: Shows whether differences between operators are small compared to the differences between parts.

Part * operator interaction graph: Shows whether the lines that connect the measurements from each operator are similar or whether the line cross each other. Lines that are not parallel or that cross indicates that an operator's ability to measure a part consistently depends on which part is being measured. A line that is consistently higher or lower

than the others indicates that an operator adds bias to the measurement by consistently measuring high or low.

Validation of measurement system: Excellent measurement systems have both of ratios GRR (R&R % and P/T %) less then 10 %. In that case *observed process variations* are not caused by *measurement system variations,* they are result of *true process variations*.

Statistical process control (SPC): SPC is a procedure for open or closed loop control of manufacturing processes, based on statistical methods. Random samples of parts are taken from the manufacturing process according to process specific sampling rules [15]. Process characteristics are measured and entered in control charts. SPC and control charts are necessary tool in measurement phase of DMAIC to establish a process baseline [16]. The process baseline is an essential part of DMAIC, because this baseline is later compared to the improved process to demonstrate the project improvement results.

A variable control chart can explain process data in terms of its process variations, piece-to-piece variation, and its process average. Because of this, control charts for variables are usually prepared and analyzed in pairs.

An **individuals and moving range chart** (X-MR) is a pair of control charts for processes with a subgroup size of one. Used to determine if a process is stable and predictable, it creates a picture of how the system changes over time. The individual (X) chart displays individual measurements. The moving range (MR) chart shows variability between one data point and the next. Individuals and moving range charts are also used to monitor the effects of process improvement theories.

Individual control chart: Average of individual values of the measured samples:

$$\bar{X} = \frac{(X_1 + X_2 + \cdots + X_k)}{k}. \qquad (10)$$

Upper control limit of the iIndividual chart:

$$UCL_X = \bar{X} + E_2\bar{R}. \qquad (11)$$

where E_2 is constant, $\bar{R}$ is average range, $\bar{X}$ is average of individual measurements [15].

Lower control limit of the individual chart:

$$LCL_X = \bar{X} - E_2\bar{R}. \qquad (12)$$

Moving range control chart:

$$\overline{MR} = \frac{(MR_2 + MR_3 + \cdots + MR_k)}{k-1}. \qquad (13)$$

where MR is variability/range between one data point and next.

Upper control limit of the moving range control chart:

$$UCL_R = D_4 \bar{R}, \qquad (14)$$

where D_4 is constant, $\bar{R}$ is average range [15].

Lower control limit of the moving range chart:

$$LCL_R = D_3 \bar{R}, \qquad (15)$$

where D_3 is constant.

Process capability within subgroup variation (σ_c). This is the variation due only to the variation within the subgroups. If the process is in statistical control, this variation is a good estimate of the inherent process variation. It can be estimate from the standard deviation formula:

$$\hat{\sigma}c = \bar{R} / d_2. \qquad (16)$$

where d_2 is constant, $\bar{R}$ is average range from the individual measurements [15].

Process capability (Cp), it takes in consideration only process variations within subgroups. It compares the process capability to the maximum allowable variation as indicates by the tolerance. Cp is not impacted by the process location.

$$C_p = \frac{USL - LSL}{6\,\sigma_c} = \frac{USL - LSL}{6\left(\bar{R}/d_2\right)}. \qquad (17)$$

Cp_k (process capability index): It takes the process location as well as the capability into account. For bilateral tolerances Cp_k will always be less or equal to Cp.

$$Cp_k = \min\left\{\left(\frac{USL - \bar{\bar{X}}}{3\left(\bar{R}/d_2\right)}\right), \left(\frac{\bar{\bar{X}} - LSL}{3\left(\bar{R}/d_2\right)}\right)\right\}. \qquad ([18)$$

Cp_k and Cp should always be evaluated and analyzed together. A Cp value significantly greater than the corresponding Cp_k indicates an opportunity for improvement by centering the process.

Process performance

Total process variations. This is the variation due to both within subgroup variation and between subgroup variations. This variation may be estimated by s, the sample standard deviation:

$$s = \sqrt{\sum_i^n \frac{(X_i - \bar{X})^2}{n-1}}. \qquad (19)$$

Process performance (Pp): It takes in consideration total process variations. It compares the process performance to the maximum allowable variation as indicates by the tolerance. P_p is not impacted by the process location.

$$Pp = \frac{USL - LSL}{6\,s} = \frac{USL - LSL}{6\sqrt{\sum_i^n \frac{(X_i - \bar{X})^2}{n-1}}}. \qquad (20)$$

P_{pk} (process performance index): It takes the process location as well as the performance into account. For bilateral tolerances Pp_k will always be less or equal to Pp.

$$Pp_k = \min\left\{\left(\frac{USL - \bar{\bar{X}}}{3\sqrt{\sum_i^n \frac{(X_i - \bar{X})^2}{n-1}}}\right), \left(\frac{\bar{\bar{X}} - LSL}{3\sqrt{\sum_i^n \frac{(X_i - \bar{X})^2}{n-1}}}\right)\right\}. \qquad (21)$$

P_{pk} and P_p should always be evaluated and analyzed together. A P_p value significantly greater than the corresponding P_{pk} indicates an opportunity for improvement by centering the process.

Six Sigma (DMAIC) – Analyze phase: The analyze phase of DMAIC helps project teams identify problems in the production process that cause product defects. This phase of Six Sigma methodology is loaded with tools to help spot the problems in the production process and to determine if these problems are the root causes of defects [17, 18]. The tools that will be used are: Pareto chart, Cause & effect diagram, 5-why analysis, and PFMEA (process failure mode and effect analysis) [19].

Six Sigma (DMAIC) – Improve phase: The improving phase focuses on identification of the best solution to eliminate the root causes or minimize the effect of root causes [20]. Counter measure matrix will be prepared and check the effectiveness of the countermeasure actions.

Six Sigma (DMAIC) – Control phase: In the control phase, the process performance is evaluated after the implementation of the solutions, and compared with that at the start of the project. The achieved improvements are verified. The steps are taken to ensure that the improvements will be sustained in the process [21]. To ensure those activities following tools are used: PFMEA (Process failure mode and effect analysis), control plan, drafting process procedure, training, calculation of process capability and introducing SPC based on defined measuring method in control plan [22].

3. EXPERIMENTAL PART – SIX SIGMA IN AUTOMOTIVE COMPANY

Six Sigma (DMAIC) – Define phase:

Problem statement – Data collection in the period of September 2017 – September 2018 indicates that 6.400 ippm of the seat heaters are with failure resistance out of specification, generating annual scrap costs of 235.000 euro. Process capability index is $C_{pk} = 0.83$ (<1.33).

Six Sigma (DMAIC) – Measure phase:

Measurement system analysis (MSA): For the Gage R&R study were conducted 90 measurements: [S] × [O] × [T] = 90 (see Table A-1 in Appendix). Control charts for MSA study are presented in Figures 1 –5.

Components of variation graph: Measurement system variations compared with observed process variations are %R&R = 8.26% and measurement system variations compared with tolerances are %P/T = 4.22 %, which in both cases is less then 10 % (see Formulas 8 and 9). Part-to-part variations (true process variations) are the highest graph in components of variations control chart (Figure 1).
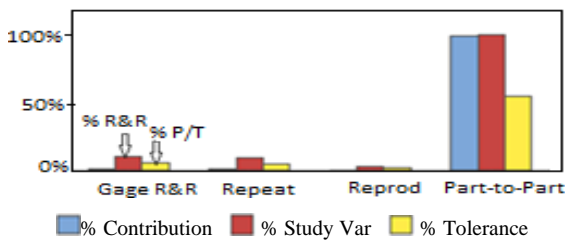

Fig. 1. Validation of measuring system
(Components of variation)

T a b l e 2

Gage evaluation table

Source	Std Var (SD)	Study Var (6 × SD)	%Study Var (%SV)	%Tolerancc (SV/Toler)
Total gage (R&R)	5,1996	31,198	8.26	4.22
Repeatability (EV)	4,8644	29,186	7.73	3.94
Reproducibility (AV)	1,8368	11,021	2.92	1.49
Part-to-part	62.7371	376.423	99.71	50.87
Total variation	62.9522	377.713	100	51.04

The conclusion of the conducted MSA study is that observed process variations are not caused by measurement system variations, they are result of true process variations. Further focus should be on process improvements in order to reduce process variations.

Xbar chart by operators: In this control chart majority of the points on the chart are outside the control limits, which indicates more sample to sample variations (true process variations), which is desired compared with measurement system variations. The patterns are similar, which indicates good reproducibility (AV) (Figure 2).
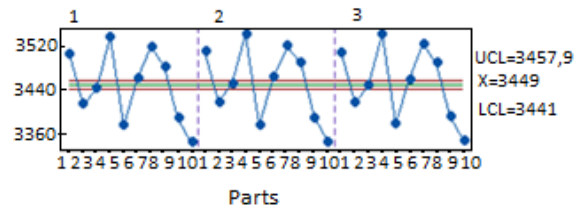

Fig. 2. Validation of measuring system
(Xbar chart by operators)

R chart (range) by operators: This control chart is in control which means repeatability or EV of the operators is good (Figure 3).
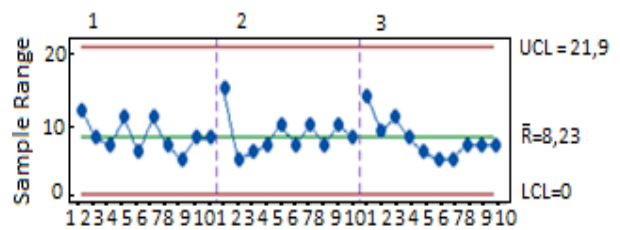

Fig. 3. Validation of measuring system
(R chart by operators)

Measurement by operators graph: This graph shows that differences between operators (AV) are small compared to the differences between parts (PV or true process variations) (Figure 4).
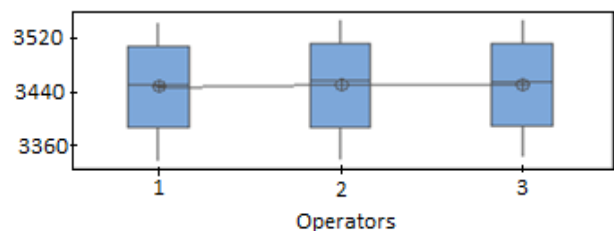

Fig . 4. Validation of measuring system
(Measurements by operators)

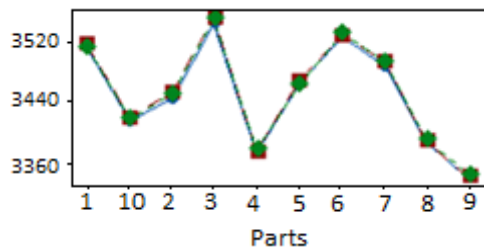Part * Operator interaction (see Figure 5):

Fig. 5. Validation of measuring system
(Part * Operators iInteraction)

In this graph lines coincident which indicates that the operators measure similarly. Operator does not add bias.

Statistical process control (SPC): In this paper subgroup size is one, which means that we will use individuals and moving range (X-MR) pair of control charts.

The individual (X) chart displays individual measurements. The moving range (MR) chart shows variability between one data point and the next (see Figures 6 – 9).
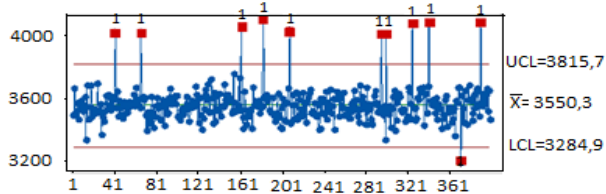

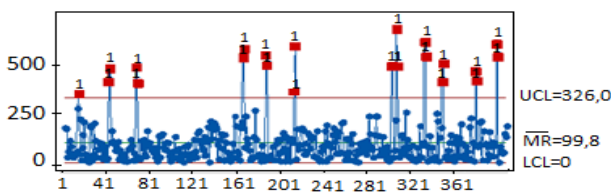**Fig. 6.** Process capability graph (current process):
I chart (individual value)

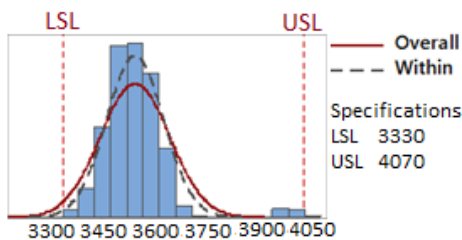**Fig. 7.** Process capability graph (current process):
Moving range chart

Fig. 8. Process capability graph (current process):
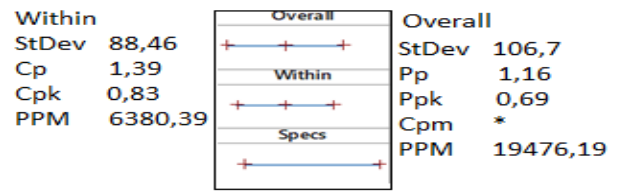Capability histogram

Fig. 9. Process capability graph (current process):
Apability plot

Process capability ratio is C_p = 1.39 (>1.33) which indicates that our process distribution is accurate, but process capability index is C_{pk} = 0.83 (<1.33) which means that process distribution is not precise (there is shifting of the normal distribution off-center).

Six Sigma (DMAIC) – Analyze phase: Cause & Effect matrix is shown in Table 3, with categorizing causes with the highest probability to turn into failure "Resistance out of spec".

T a b l e 3

Cause & Effect matrix

Rating of importance to customer >>		Resistance	Total
Process step	**Process inputs**		
Sewing process	Number of hit wire per meter by needle during sewing out of spec.	9	90
Sewing process	Operator handling NOK (wire/thread tension NOK, wrong parameter on feeding device).	9	90
Crimping process	Operator handling NOK (positioning I-Cu wire).	9	90
Welding	Missed welding process.	9	90
Incoming inspection	Nominal resistance per 1 meter of heating wire out of specification.	3	30
Incoming inspection	Condition of wire from supplier (Damaged wire).	3	30
Sewing process	Damaged heating wire during bobbin rewinding process before sewing.	3	30
Sewing process	Wrong product design (wrong length of wire in the design).	3	30
Pre-assembly	Operator handling (manual cut, pull out the wire).	3	30
Pre-assembly	Tools and working conditions NOK.	3	30
Pre-assembly	Storage condition of seat heater after sewing NOK.	3	30
Stripping proc.	Strip machine parameters.	3	30
Stripping process	Operator handling NOK (wire positioning).	3	30
Welding process	Operator handling NOK (positioning of the wire, supporting wire during welding).	3	30
Welding proc.	Welding machine parameters NOK	3	30
FA line	MSA of the EOL tester NOK.	3	30
FA line	Probe pins on EOLT worn-out.	3	30
Crimping proc.	Crimp tool worn-out.	1	10
Total		**76**	

Based on daily failure analyses conducted in period of 1 year, root causes of the failure are categorized: In 39% (from total 6.400 ippm), root cause is needle hit wire – sewing process.

1) In 28% (from total 6.400 ippm), root cause is deviation of wire consumption – sewing process.

2) In 16% (from total 6.400 ippm), root cause is wrong positioning of the heating wire & harness – crimp process.

3) In 9% (from total 6.400 ippm), root cause is skipped welding process – FA line.

4) In 8% other reasons are root cause of the failure.

Six Sigma (DMAIC) – Improve phase: As corrective action for the root causes of the failure resistance out of spec we have implemented inteligent automation. Intelligent automation introduce some supervisory functions rather than production functions of the machines.

1. Sewing process: **a)** Automated hit wire detection system. The system will implement 100% detection of the damaged wire, and will implement in station quality control. NOK parts will not proceed to the next process. Additionally, the system will stop the sewing machine and root cause analysis can be immediately carried out (wrong thread/wire tension, needle high miss adjustment etc.). Electrical scheme is presented in Figure 10. **b)** System for checking if the hit wire detection system is activated. When heating wire is not connected with the feeder system than hit wire detection system is not activated, and the failure will not be detected. PLC system was installed which will automatically check and validate the accuracy of the connection. **c)** Automated system for control the consumption of heating wire. On each feeder system was installed encoder, connected to the PLC which will measure wire consumption and compare with bill of material of that specific product. If wire consumption deviate from BOM, machine will stop and operator will investigate the root cause of the deviation.
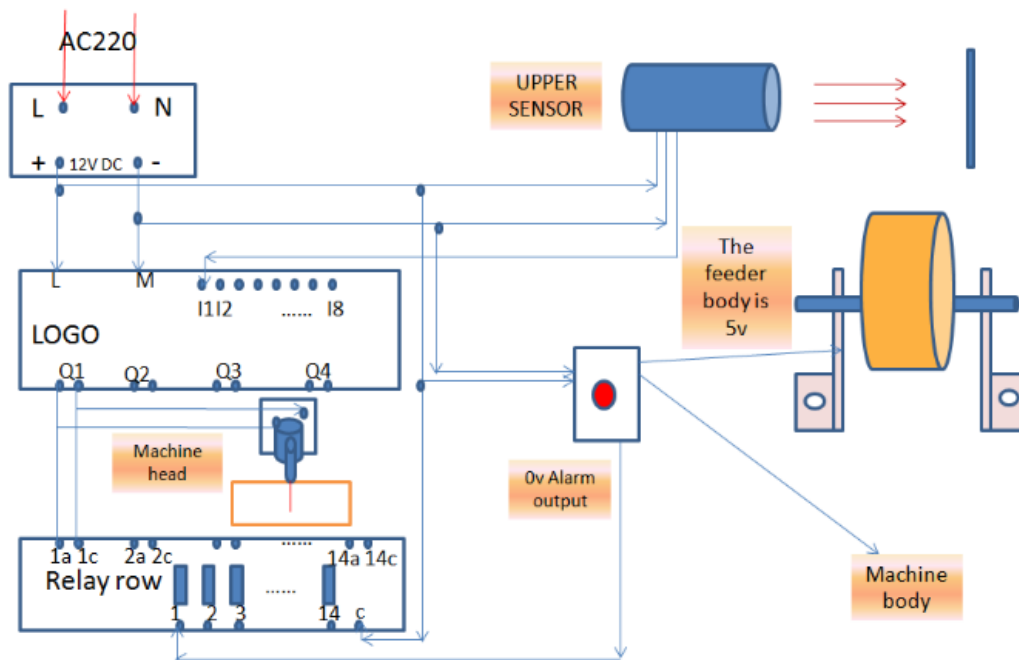

Fig. 10. Electrical wiring of the needle hit detection (System)

2) Crimping process – System for controlling heating wire position. Camera system was installed on crimping machine to monitor and control position of wire.

3) Final assembly line – System for controlling sequence of processes on FA line. Due to rotation mode and manual assembly process in the final assembly line, sometimes operatorss miss some of the assembly processes. PLC controller was installed to control the sequence of the assembly processses and avoids operator mistake.

Process capability study was performed after implementation of all process improvements. The study was carried out with 400 measured samples.

Six Sigma (DMAIC) – Control phase: For sustainability of achieved results were done following updates: PFMEA, control plan, drafting process procedure, training, calculation of process capability and control gate review.

4. The results and discussion – For validation effectiveness of the implemented Six Sigma DMAIC methodology we will compare individual chart I, moving range chart MR, process capability and process performance before and after implemented improvements (see Figure 9 vs. Figure 14). With eliminating special causes, *C* is almost identical to *P*.
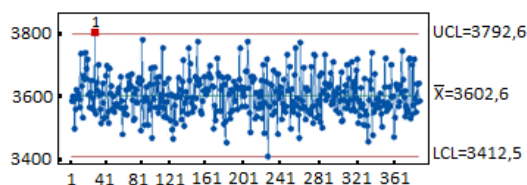

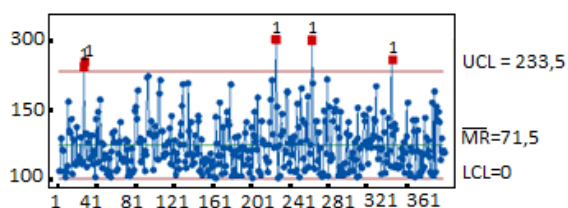**Fig. 11.** Process capability graph (after improvements): I chart (individual value)

Fig. 12. Process capability graph (after improvements): Moving range chart
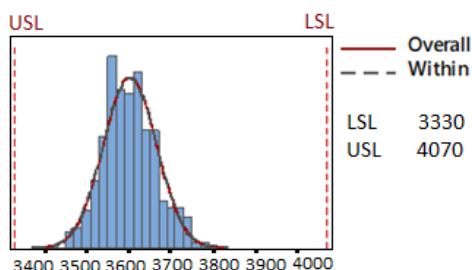

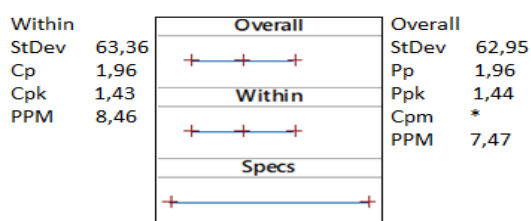**Fig. 13.** Process capability graph (after improvements): - Capability histogram

Fig. 14. Process capability graph (after improvements):- Capability plot

T a b l e 4

Process capability and performance before vs. after process improvements

	Before improvements in the process	After improvements in the process	Before vs. after (%)
$\dot{C}_p$	1.39	1.95	40
$\dot{C}_{P_k}$	0.83	1.43	72
$\dot{P}_p$	1.16	1.96	69
$\dot{P}_{p_k}$	0.69	1.44	109

This improvement of process capability is significant and it is validation of the successful implementation of Six Sigma project in automotive company for seat heaters production.

4. CONCLUSION

In the present work, initiative has been taken to apply Six Sigma in automobile sector manufacturing company to reduce the level of defects.

The application of Six Sigma DMAIC model helped in quick root cause analysis and reduction of rejection and improvement of process capability from $C_{P_k} = 0.83$ to $C_{P_k} = 1.43$, and 235,000 cost savings in period of 1 year.

Even though this is a small research work it can be certainly concluded that, Six Sigma is really a tool that can be used to obtain positive results in process improvements. If the methodology is applied through all the production lines, it would be very beneficial for the company as it would result in significant saving of resources.

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A P P E N D I X

Table A.1

Gage repeatability and reproducibility report sheet

	Appraises? Trails #		PART											AVERAGE	
			1	2	3	4	5	6	7	8	9	10			
1	A	1	3502	3441	3539	3369	3455	3517	3483	3382	3337	3409			3443,4
2		2	3514	3439	3533	3375	3466	3524	3482	3390	3345	3417			3448.5
3		3	3507	3446	3544	3374	3461	3522	3487	3389	3341	3415			3448.6
4	Average		**3508**	**3442**	**3539**	**3373**	**3461**	**3521**	**3484**	**3387**	**3341**	**3414**	$\overline{X_a}=$		**3447**
5	Range		**12**	**7**	**11**	**6**	**11**	**7**	**5**	**8**	**8**	**8**	$\overline{R_a}=$		**8300**
6	B	1	3519	3454	3548	3379	3468	3527	3494	3393	3347	3420			3454.9
7		2	3504	3451	3546	3369	3466	3517	3488	3383	3339	3418			3448.1
8		3	3512	3448	3541	3375	3461	3523	3487	3389	3341	3415			3449.2
9	Average		**3512**	**3451**	**3545**	**3374**	**3465**	**3522**	**3490**	**3388**	**3342**	**3418**	$\overline{X_b}=$		**3451**
10	Range		**15**	**6**	**7**	**10**	**7**	**10**	**7**	**10**	**8**	**5**	$\overline{R_b}=$		**8500**
11	C	1	3514	3444	3540	3376	3460	3523	3490	3387	3342	3421			3449.7
12		2	3500	3455	3548	3381	3457	3526	3494	3394	3347	3416			3451.8
13		3	3512	3448	3544	3375	3462	3528	3487	3390	3349	3412			3450.7
14	Average		**3509**	**3449**	**3544**	**3377**	**3460**	**3526**	**3490**	**3390**	**3346**	**3416**	$\overline{X_c}=$		**3451**
15	Range		**14**	**11**	**8**	**6**	**5**	**5**	**7**	**7**	**7**	**9**	$\overline{R_c}=$		**7900**
16	Part Average		**3509**	**3447**	**3543**	**3375**	**3462**	**3523**	**3488**	**3389**	**3343**	**3416**	$\overline{\overline{X}}=$		**3449**
													$R_p=$		199
17	$([\overline{R_a}=8.3]+[\overline{R_b}=8.5]+[\overline{R_c}=7.9]/[OFF\ APPRAISERS=3])=$												$\overline{\overline{R}}$a		**8.23**
18	$[Max\ \overline{X}=3.451]-[Min\ \overline{X}=3447]=\overline{X}_{DIFF}=0.004$														
19	$[\overline{\overline{R}}=8.23]X[D_4=2.58]=UCL_R=21.2$														
	$D_4=2.58$ for 3 trials. UCL$_R$ = represent the limit of individual R's														

T a b l e A.2

Gage repeatability and reproducibility report sheet

Gage Repeatibility and Reproducibility report			
Part No&Name:	Gage name:		Date:
Characteristics:	Gage No:		Performed by:
Specifications:	Gage Type:		
From data sheet $\bar{\bar{R}} = 8.23$	$\bar{X}_{DIFF} = 0.004$		$R_p= 199$
Measurement unit analysis			% Total Variations (TV)

Repeatability - Equipment Variations (EV)			% Total Variations (TV)
$EV = \bar{\bar{R}}\ K_1$			
$= 8.23\ 0.5908$			%EV = 100 [EV/TV]
$= 4.862$	Trails	K1	= 100 [4.862 / 62.79]
K_1 − depends number of trials used in Gage study	2	0,8862	= 7.74 %
	3	0,5908	

Reproducibility – appraiser variation (AV)			
$AV = \sqrt{(\bar{X}_{DIFF} \cdot K_2)^2 - \left(EV^2/(nr)\right)} =$			
$= \sqrt{(0.004\ 0.5231)^2 - \left(4,862^2/10 \times 3\right)} =$			
$= 1,8368$			%AV = 100 [AV/TV]
K_2 −depends upon number of appraisers			= 100 [0.887/ 62.79]
n = parts r = trials	Appreisers	2 | 3	=2.92 %
	K_2	0.7071 | 0.5231	

Repeatability & Reproducibility (GRR)			
$GRR = \sqrt{(EV^2 + AV^2)}$			%GRR = 100 [GRR/TV]
$= \sqrt{(4,862^2 + 1,8368^2)}$			= 100 [5,1996/ 62,79]
$=5,1996$	Parts	K_3	= 8,26 %
	2	0.7071	
	3	0.5231	

Part variation (PV)	4	0.4467	%PV = 100 [PV/TV]
$PV = R_p\ K_3$	5	0.403	= 100 [62,61/ 62,79]
$= 62,6054$	6	0.3742	= 99,71%

Total variation (TV)	7	0.3534	ndc= 1,41 [PV/GRR]
$TV = \sqrt{(GRR^2 + PV^2)}$	8	0.3375	= 1,41 [62,61/ 5,19]
$= \sqrt{(4.94^2 + 62.60^2)}$	9	0.3249	= 17,001~17
$= 62.79$	10	0.3146	