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Using Six Sigma Methodology to Improve the Assembly Process in an Automotive Company

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Abstract

The exigencies of the permanently evolving markets require continuous adaptation of company offers. The development and continuous improvement of the quality and environment management systems would be to anticipate these developments and therefore fully satisfy the needs and expectations of each partner (customers, staff and other stakeholders) and also maintain competitive advantage. One of the possibilities of gaining operational excellence is implementing different quality improvement initiatives like Total Quality Management, ISO certification, Agile & Lean manufacturing etc. Real life demonstrated that these initiatives are neither time efficient nor profitable in terms of quality. Therefore introducing and implementing the Six Sigma methodology was proven to provide breakthrough quality improvements in a reasonable short time. This paper presents a creative solution for improving an assembly process in an automotive company in Romania by using Statistical Thinking and DMAIC Six Sigma methodology.

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Keywords: Six Sigma; DMAIC; Xbar & R charts; AHP; Poka Yoke

1. Introduction

The desire to achieve business excellence in the Automotive Industry assumes the management commitment to develop and deliver perfect solutions, products or services, to promote the "Zero Defects" and first time right production philosophy, the integration of environmental protection in all its activities (design and production), as well as training, motivating and involving all staff in the effort towards excellence.

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Usualy, for an Automotive Company, policy is conducted mainly along the following lines: increase the quality of staff, steady decrease in non-quality costs, react better to meet customers requirements and to solve problems, regulatory compliance for the environment, optimizing natural resource consumption, better waste management, prevent any type of pollution, chronic or accidental.

In this context, it is considered that Six Sigma methodology is the best way for improving quality / reducing waste by helping organizations produce products and services better, faster, and cheaper (Pyzdek & Keller 2010). Tomkins (1997) defines Six Sigma to be "a program aimed at the near-elimination of defects from every product, process and transaction". Harry (1998) define Six Sigma to be "a strategic initiative to boost profitability, increase market share and improve customer satisfaction through statistical tools that can lead to breakthrough quantum gains in quality". Park, Lee & Chung (1999) believe that Six Sigma is a "new strategic paradigm of management innovation for company survival in this 21st century, which implies three things: statistical measurement, management strategy and quality culture". Pyzdek and Keller (2010) believe that Six Sigma is a "rigorous, focused, and highly effective implementation of proven quality principles and techniques. .. Six Sigma aims for virtually error-free business".

Six Sigma methodology has two approaches: DMAIC (D-Define, M-Measure, A-Analyze, I-Improve, C-Control).), 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.

Statistical thinking is a method used as part of Six Sigma methodology. Statistical thinking relates processes and statistics, and is based on the following ideas: action occurs in a system of interconnected processes, variation exists in all processes and is very important to understand and deal with it (reducing variation is the key to success), understand and use the appropriate statistical tools for a systematic approach to process improvement.

2. The DMAIC Six Sigma methodology applied to an assembly process

2.1. Define Phase

The analysis was focused on the production line providing a semi-finished product in "Horn Assembly" product, i.e. "Upper wire horn assembly".

On the production line, for this semi-product, are performed the following operations:

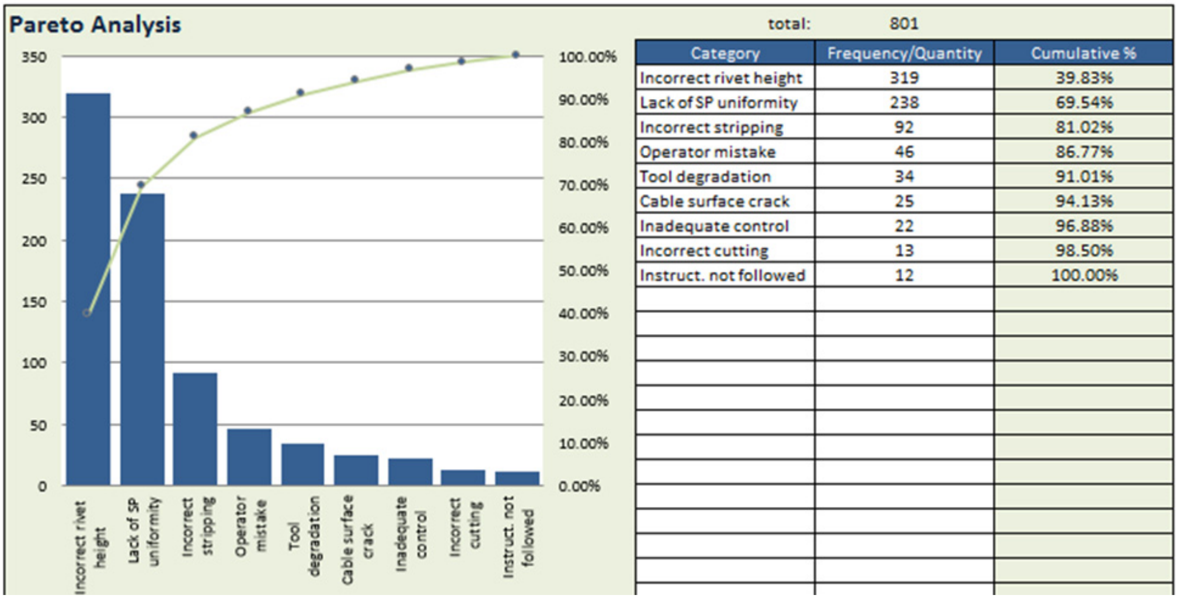
- Cutting and stripping cables
- Cables stripping and crimping terminal on the stripped cables
- Crimping terminal cables stripped from previous operations
- Riveting rivet

It was performed a SIPOC analysis and then a Flow Chart was drawn for the process. A Pareto analysis was performed on 10,000 semi-finished products from which 801 were defective, revealing that incorrect height of the rivet (319 defects) as the major defect (Fig. 1.).

2.2. Measure Phase

It has been decided to concentrate improvement efforts on riveting process which causes the highest number of defects. This process is done manually by inserting the horn upper plate and the cables in a holding device than applying a riveting force using a special hand operated tool. (Fig. 2.).

The measured characteristic (CTQ - Critical To Quality) is the "Rivet Height" which is very important for the next operation in the final assembly of the finished product "horn assembly". According to the technical drawing (Fig. 3.), the rivet height (assembled) dimension is 10.3 ± 0.035 mm. It has been decided to measure 20 samples of 5 semi-finished products each, during an 8 hour shift.



Category	Frequency/Quantity	Cumulative %
Incorrect rivet height	319	39.83%
Lack of SP uniformity	238	69.54%
Incorrect stripping	92	81.02%
Operator mistake	46	86.77%
Tool degradation	34	91.01%
Cable surface crack	25	94.13%
Inadequate control	22	96.88%
Incorrect cutting	13	98.50%
Instruct. not followed	12	100.00%

Fig. 1. Pareto analysis for upper wire horn assembly

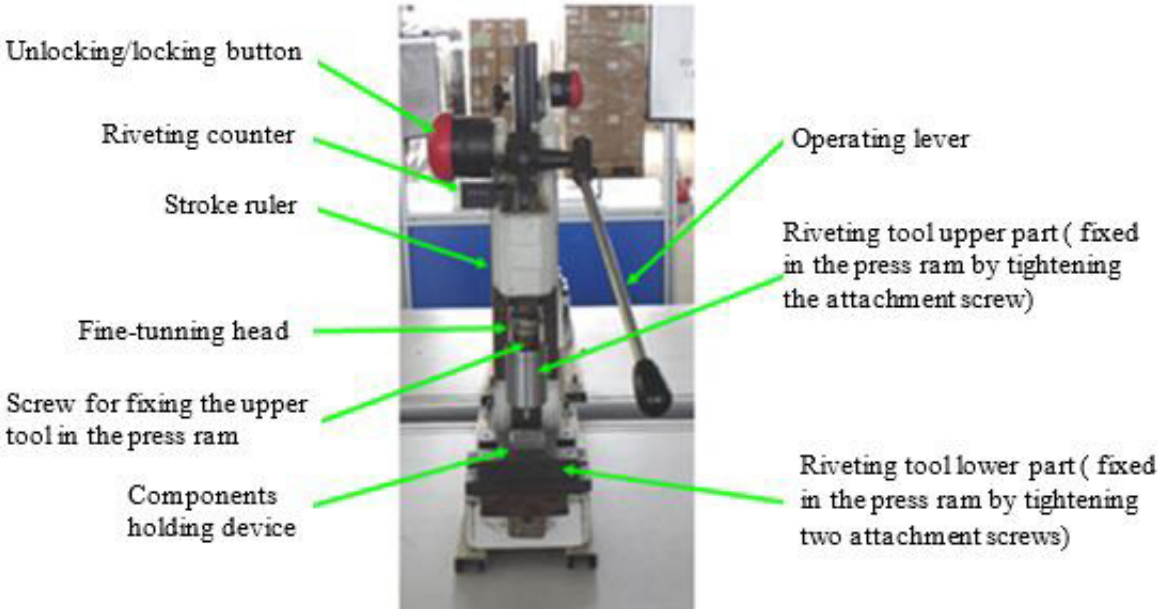


Fig. 2. Hand operated riveting tool

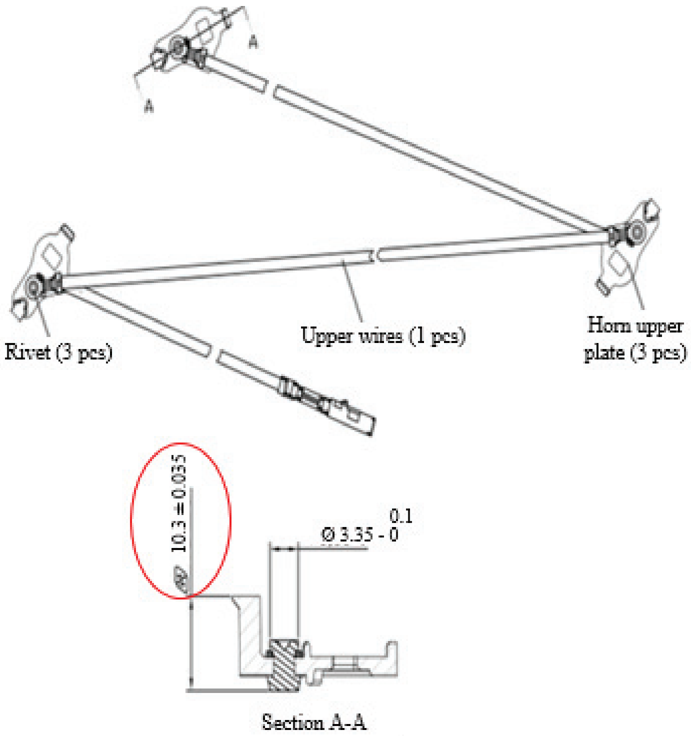


Fig. 3. Assembled rivet on upper wire horn assembly

There were performed tests to detect the random character of the sample data, tests to detect and remove outliers, has been assessed whether the data obtained through measurement came from a normal distribution (Table 1) and also were assessed indicators of process capability (Fig. 4.).

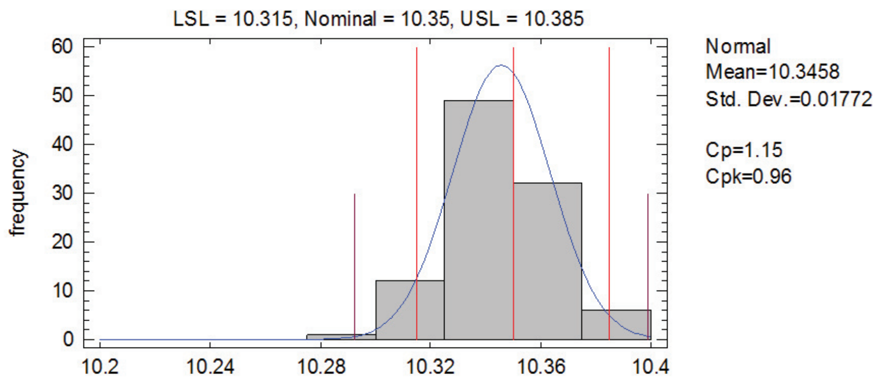


Fig. 4. Process capability for Rivet Height

Table 1 shows the results of chi-square test, which divides the amplitude data 24 and compares the number of observations of equiprobable classes of each class of the expected number, Shapiro-Wilk test which is based on a comparison of a normal distribution quintiles of the data and Kolmogorov-Smirnov test, which calculates the maximum distance between data probability function and probability function of a normal distribution, to determine whether the data can be modeled by a normal distribution. Since p-value of the three tests is ≥ 0.05, we can not reject the idea that the data come from a normal distribution with a probability of 95%.

Table 1. Statistical tests for normality

Test for normality	Test statistics	P - value	Distribution
Chi-square	30.08	0.0903922	Normal (p ≥ 0.05)
Kolmogorov-Smirnov	0.0552206	0.9205840	Normal (p ≥ 0.05)
Shapiro-Wilk	0.975131	0.2978780	Normal (p ≥ 0.05)

To asses if the process is in control or not, the 100 measurements were plotted on a Xbar & R charts, revealing that regarding R chart the process was in control (Fig. 5.) but regarding the Xbar chart the process was not in control (Fig. 6.).

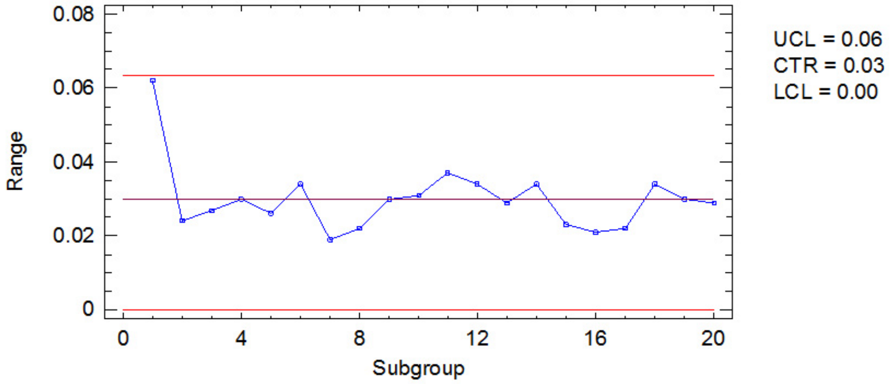


Fig. 5. R chart for Rivet Height

One can see that there are not only points which exceed the control limits, but also there is a clear tendency of increasing the rivet height as the time passes, definitely showing that there is a systematic problem which causes this situation. For C_{pk} = 0.96 resulting in Sigma Level short-term ≈ 2.9 respectively Sigma Level long-term ≈ 1.4 and therefore DPMO ≈ 81,000.

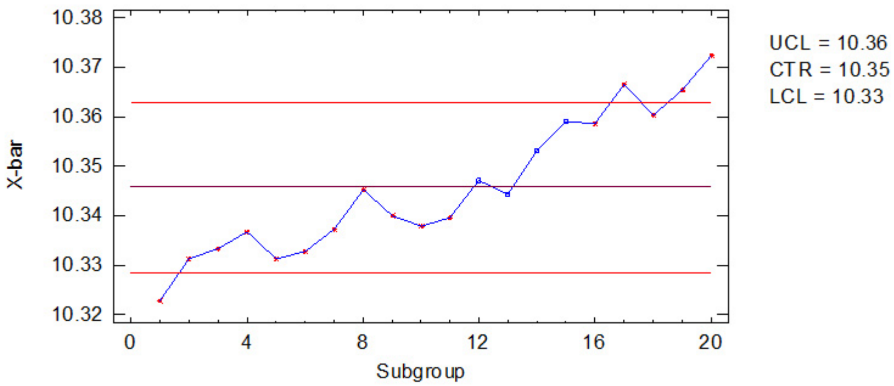


Fig. 6. Xbar chart for Rivet Height

After Measure Phase the following conclusions were drawn:

- Amplitude values are within control limits and therefore riveting process is stable as precision.
- Average values exceed control limits and therefore riveting process is unstable as adjustment (usually, adjustment instability may have as sources, failure to periodically check machine-tools, tool wear, improper machine adjustment to work dimension and inhomogeneous semi-finished products).
- There is an abnormality in the riveting process meaning there is a constant tendency of displacement to increasingly higher values of rivet height.
- The riveting process is not capable on short and long term.

2.3. Analyze Phase

Taking in account the conclusions drawn from Measure Phase it has been decided to address the following issues:

- Constant tendency of displacement to increasingly higher values of rivet height must thoroughly analyzed.
- The riveting process must be brought in control.
- Riveting process capability must be substantially improved on long term.

In the first instance, to analyze these issues, an Ishikawa diagram has been utilized. Ishikawa diagram or "Cause - Effect" diagram is a tool for analyzing and plotting the relationship between a given effect (e.g., variations of a quality characteristics) and its possible causes. By performing his analysis in conjunction with a “5 Whys – RCFA” analysis it has been determined that the root cause off rivet height noncompliance is the use of improper riveting force during work deployment due to the operator`s fatigue, as the eight as the eight-hour shift takes place (Fig. 7.).

It has been determined that at the beginning of the eight-hour shift the operator`s tendency is to apply a greater downforce than needed and as the shift deploys the downforce diminishes due to operator fatigue, which explain why there is a tendency of increasingly higher values of rivet height.

Also it has been performed a FMEA analysis. FMEA a considered a rational analysis technique for product reliability, process or machine (used in the process) by inventorying their possible modes of failure, of causes that could induce these failures, of failures effects on users, and as a result, a quantitative evaluation of damage probability to product / process / equipment functions.

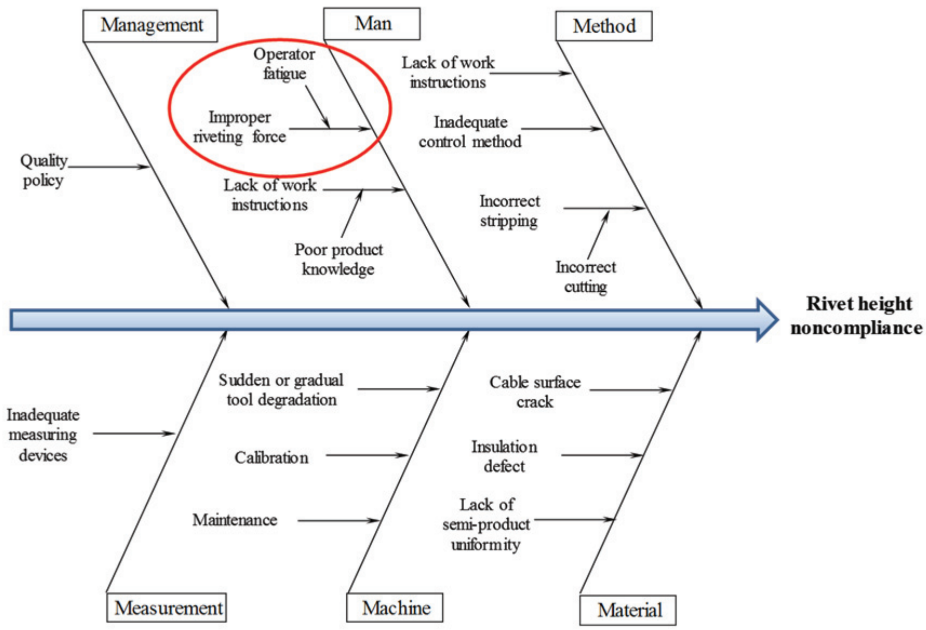


Fig. 7. Ishikawa diagram for Rivet Height noncompliance

It has been determined that at the beginning of the eight-hour shift the operator`s tendency is to apply a greater downforce than needed and as the shift deploys the downforce diminishes due to operator fatigue, which explain why there is a tendency of increasingly higher values of rivet height.

Also it has been performed a FMEA analysis. FMEA a considered a rational analysis technique for product reliability, process or machine (used in the process) by inventorying their possible modes of failure, of causes that could induce these failures, of failures effects on users, and as a result, a quantitative evaluation of damage probability to product / process / equipment functions. It has been determined (Fig. 8.) that the function affected is the contact from upper wire horn assembly and the rest of car electrical system. The potential failure mode was detected as the inadequate riveting force (resulted also from Ishikawa analysis) having as potential failure the inability to couple to other horn subassemblies. Definitely the current control, that is operator training, is ineffective. By taking into account the severity, occurrence and detection, a RPN of 162 was calculated. The recommended action by Six Sigma FMEA team was to install a device to properly control the riveting force. Also it has been recommended that the riveting hand-tool design to be improved, even if the necessary downforce is not high.

The Six Sigma team decide to tackle also the issue regarding the lack of semi-finished products inconsistency (generating 30.29% of total defects). It has been decided to use AHP (Analytic Hierarchy Process) to choose from 5 different suppliers of cables based on some important criteria.

2.4. Improve Phase

Based on the recommendations from Analyze Phase, there were implemented the following changes:

- Hand-tool design for riveting was improved by including a softer release spring.
- A Poka-Yoke device was installed.
- A supplier of cables was selected using AHP.

FMEA Template for AIAG and Six Sigma																
Prepared By:								FMEA No/Rev: 0000/01								
Date: 00/00/00								Process/Component:								
												Action Results				
Item	Function	Potential Failure Mode	Potential Effects or Failure	Svrty	Potential Causes of Failure	Ocrnc	Current Controls for Prevention/Detection	Dtctn	RPN	Recommended Action	Responsibility and Target Completion Date	Action Taken	Svrty	Ocrnc	Dtctn	RPN
1	Contact between the horn cables and the car electrical system	Inadequate riveting force	Unable to couple to other horn subassemblies	9	One can not control downforce	6	Operator training	3	162	Installing a device to control the riveting downforce	Process Engineering					

Fig. 8. FMEA for Rivet Height noncompliance

To improve the riveting process it has been decided to use a contact sensor with warning (Poka-Yoke device). After analyzing four alternatives, an Allen-Bradley Rockwell Automation limiter was chosen. This version is more compact and has a small size, most suitable for the riveting hand-tool. When the operator applies the downforce, the limiter gives visual and acoustic signals when the necessary force has beet reached, meaning that the proper rivet height is attained.

There were selected 5 potential cables suppliers (denoted from A to E), using 6 decision criteria, namely Experience (EXP), Financial Stability (FS), Quality Performance (QP), Human resources (HR), Technological Resources (TR) and Current workload (CW). Priorities matrix, Criteria weights and Priority vector for the 5 potential cables suppliers are presented in Table 2. Therefore, according to Priority vector, supplier C was chosen.

Table 2. AHP for selecting the most suitable supplier

	EXP (0.188)	FS (0.122)	QP (0.308)	HR (0.270)	TR (0.082)	CW (0.085)	Priority vector
A	0.162	0.26	0.30	0.24	0.34	0.117	0.24
B	0.204	0.11	0.10	0.19	0.17	0.402	0.30
C	0.172	0.21	0.39	0.39	0.74	0.159	0.35
D	0.364	0.35	0.13	0.11	0.06	0.224	0.18
E	0.080	0.08	0.05	0.08	0.04	0.150	0.07

2.5. Control Phase

After implementing the improvements presented in Improve Phase, there were measured 20 samples of 5 semi-finished products each, during an 8 hour shift. There were performed tests to detect the random character of the sample data, tests to detect and remove outliers, has been assessed whether the data obtained through measurement came from a normal distribution and also were assessed indicators of process capability (Fig. 9.).To asses if the improved process is in control or not, the 100 measurements were plotted on a Xbar & R charts, revealing that regarding both Xbar & R charts the process was in control (Fig. 10 and Fig. 11.). For C_{pk} = 1.72 resulting in Sigma Level short-term ≈ 5.2 respectively Sigma Level long-term ≈ 3.7 and therefore DPMO ≈ 108.

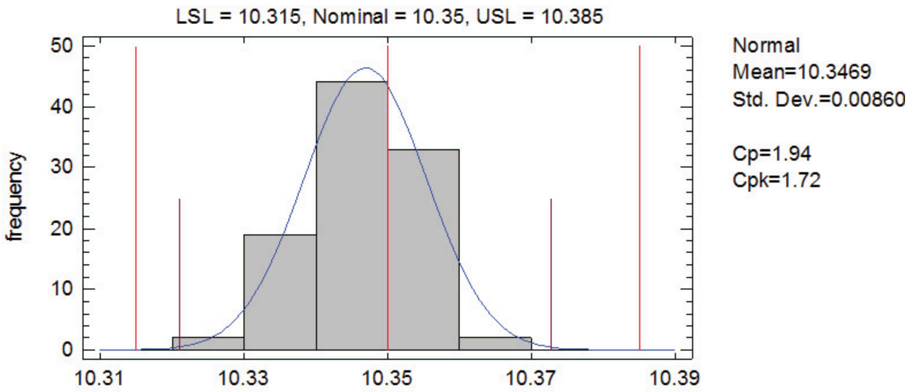


Fig. 9. Process capability for Rivet Height (improved process)

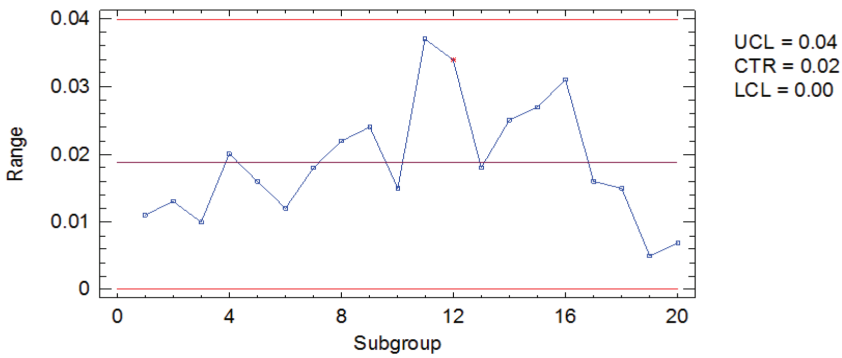


Fig. 10. R chart for Rivet Height (improved process)

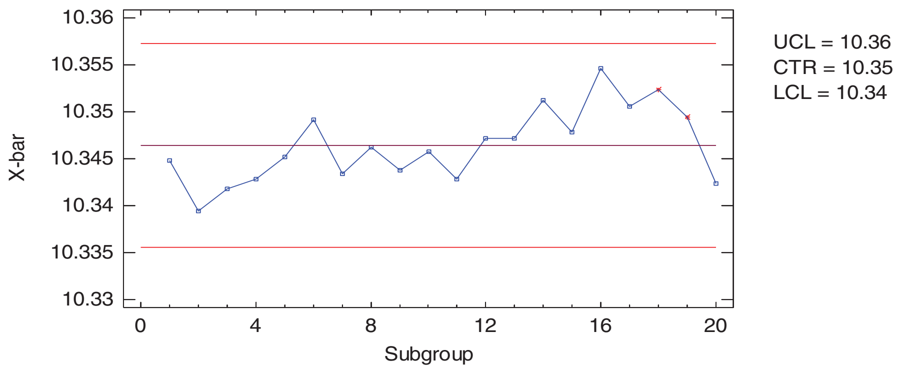


Fig. 11. Xbar chart for Rivet Height (improved process)

After implementing the recommended action by Six Sigma FMEA to install a device to properly control the riveting force, the updated FMEA is presented in figure 12, showing a much lower RPN of 32.

FMEA Template for AIAG and Six Sigma																
Prepared By:									FMEA No/Rev: 0000/01							
Date: 00/00/00									Process/Component							
												Action Results				
Item	Function	Potential Failure Mode	Potential Effects or Failure	Svrty	Potential Causes of Failure	Ocrnc	Current Controls for Prevention/Detection	Dtctn	RPN	Recommended Action	Responsibility and Target Completion Date	Action Taken	Svrty	Ocrnc	Dtctn	RPN
1	Contact between the horn cables and the car electrical system	Inadequate riveting force	Unable to couple to other horn subassemblies	9	One can not control downforce	6	Operator training	3	162	Installing a device to control the riveting downforce	Process Engineering	Device installed on 01.04.2015	9	1	2	18

Fig. 12. Updated FMEA for Rivet Height noncompliance

3. Conclusions

By applying Statistical Thinking and DMAIC Six Sigma methodology to the riveting process the following conclusions were drawn: the riveting hand tool design was improved allowing a smoother handling, a Poka-Yoke device was installed signaling acoustically and visually when the necessary downforce was attained, the riveting process was brought in-control, the riveting process capability was substantially improved on short and long term, C_{pk} increased from 0.96 to 1.72, Sigma Level short-term increased from 2.9 to 5.2, Sigma Level long-term increased from 1.4 to 3.7, DPMO were reduced from 81,000 to 108, improving the riveting process led to ≈ 40% defect reduction, choosing the most suitable supplier led to ≈ 30% defect reduction.

It was decided to continue the improvement process by tackling the next nonconformities from Pareto chart and also to attempt riveting process automation, in order to eliminate possible human errors.

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