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Using Six Sigma to Improve the Quality Rate of a Display Production Line in the Automotive Industry

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Abstract – The Six Sigma methodology has been developed to identify, measure, analyse, optimize, and control process variation. It provides companies with a mentality focused on continuous improvement and a common language for efficiency. Nevertheless, there are still few scientific papers which present the methodology in practical case studies. By using the DMAIC model and a set of well-known quality tools, the present paper aims to exhibit a successful implementation of the methodology in the automotive industry, more specifically on improving the quality rate of a display production line. Thus, it proofs that small process improvements based on a solid methodology can drive competitiveness.

Keywords DMAIC model, Ishikawa diagram, SIPOC diagram, Capability analysis

I. INTRODUCTION

Six Sigma is a scientific methodology based on statistics [1], allowing companies to determine improvements on different kind of processes leading to major savings [2], not only in production but also in various fields such as finance [3], healthcare logistics [4], and others. But the most successful implementations remain in production, where the complexity of processes requires engineers to use specific quality tools and respect the DMAIC (Define Measure Analyse Improve Control) approach [5].

The automotive industry has developed extremely complex production processes of different parts in parallel for diverse clients. This situation determines chain reactions. If one process has high variability, the whole production may be jeopardized. Therefore, automotive companies require a proven methodology to control their processes and strive for competitive advantages. Six Sigma has been used in this industry to reduce nonconformities [6], scrap formation [7], or capacity waste in centreless grinding [8], but also for several improvements of industrial processes like the extrusion process in tire production [9], grinding processes [10], waste gate actuator [11], and so on. The achievements of using Six Sigma in automotive parts production are reduction of tools expenses, cost of poor quality and labour expenses [12] with significant financial positive impact.

Therefore, Six Sigma with its DMAIC model will be used in this project to identify and reduce the weak spots of a screwing unit in an automotive company from the Western part of Romania.

II. MPROVEMENT OF THE QUALITY RATE OF A DISPLAY PRODUCTION LINE

For the case study, we have chosen to analyse the manufacturing system of an automotive company situated in the Eastern part of Europe. More specifically, the scope of the present paper has been to apply the Six Sigma methodology to improve the final assembly line of their display. The screwing unit is represented by six key machines (WP7, 9, 10, 10.1, 11 & 12) and it is of high importance for the company because it affects the whole quality of the finished products.

The analysed production unit is mainly working with robots and consequently, the human interventions are reduced to the minimum. It is assembling the PCB (Process Control Board) to the displays with screws. To reach the best quality of the final product, the process must match predefined torque, angle criteria, etc. and must prevent dust and other particles to reach it during the operations.

For a Six Sigma approach to be successful, the selected project must firstly be a suitable DMAIC project and secondly, the different steps must be prioritized so that resources are allocated appropriately. A procedure that standardizes the selection of appropriate DMAIC projects uses a matrix of selection criteria. To select DMAIC projects, 15 criteria must be considered [13], according to which the project viability matrix is elaborated to determine which DMAIC approach is suitable to solve the problem. The viability matrix of the project is presented in Fig. 1.

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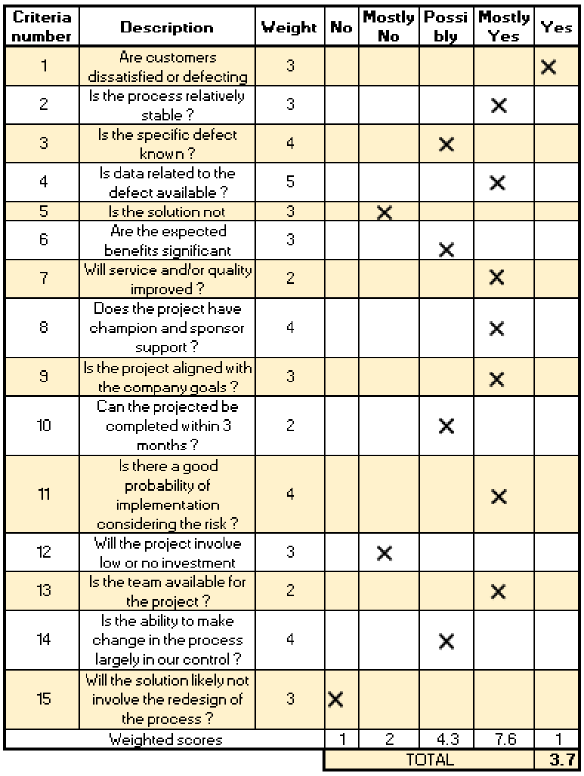

Criteria number	Description	Weight	No	Mostly No	Possibly	Mostly Yes	Yes
1	Are customers dissatisfied or defecting	3					X
2	Is the process relatively stable ?	3				X	
3	Is the specific defect known ?	4			X		
4	Is data related to the defect available ?	5				X	
5	Is the solution not	3		X			
6	Are the expected benefits significant	3			X		
7	Will service and/or quality improved ?	2				X	
8	Does the project have champion and sponsor support ?	4				X	
9	Is the project aligned with the company goals ?	3				X	
10	Can the projected be completed within 3 months ?	2			X		
11	Is there a good probability of implementation considering the risk ?	4				X	
12	Will the project involve low or no investment	3		X			
13	Is the team available for the project ?	2				X	
14	Is the ability to make change in the process largely in our control ?	4			X		
15	Will the solution likely not involve the redesign of the process ?	3	X				
Weighted scores			1	2	4.3	7.6	1
			TOTAL				3.7

Fig. 1. Project viability matrix

Next to each criterion there is a "weight" column, for establishing the importance of each criterion (the weight scale varies from "1 = least important" to "5 = most important"). After assigning a weight to each criterion, an answer must be given to each question about the project (between "1 = definite no" and "5 = definite yes"). To determine the scores of individual weights the Six Sigma team needs to divide each weight by 3, multiply each X-mark by its weight and summarize all X-mark values for each evaluation column. To determine the total score, they must multiply each weighted score by the value of its evaluation and add these products, divide the sum of these products by the sum of the weighted scores. For the last step, the team evaluates the total score to establish the viability of the project. There are three different situations the project can find itself in: not viable (score < 2.0), a possible (score between 2 and 3) and a viable DMAIC project (score >3).

In the analysed case, the total score of the project is 3.7, which qualifies it as a viable DMAIC project. In the following, the five steps of the DMAIC method are underlined with their respective results.

A. *Define*

The Define phase (DMAIC) is the first step of the Six sigma improvement process and a critical one to the project success. It consists of the project description and lists encountered problems by a previously selected team. During the studied process, a PCB is fixed on a display with screwing robots. Process maps and a SIPOC (Supplier, Input, Process, Output, and Customer) diagram that can be seen in Table 1 are usually created to help the team to understand the process.

Aiming to define the whole steps of the process, a detailed flowchart of the assembly unit has been built (Fig. 2). To obtain the most accurate flowchart possible, the authors have been working with an automation engineer and translated the program into the different steps of the process. The screwing unit is composed of six automated stations where there is a lack of torque repeatability for the screwing process of the PCBs on the display's support and a lack of control of the distance between the screw head and the PCB. To understand the screwing process, a low-end flowchart has also been built for the specific step of the process and it can be seen in Fig. 3.

Table 1. The SIPOC diagram for the process

SUPPLIER	**INPUT**	**PROCESS**	**OUTPUT**	**CUSTOMER**
Company A	PCB; Camera	Final assembly line	Display ready	Final customer
Company B	Electronic components			
Company C	Display's Support & Screen			
Company D	Screws			
Company E	Robots; Carriers			
Logistics department	Production Planning		Production Reports	Management, Engineers & Interns
				Quality Department

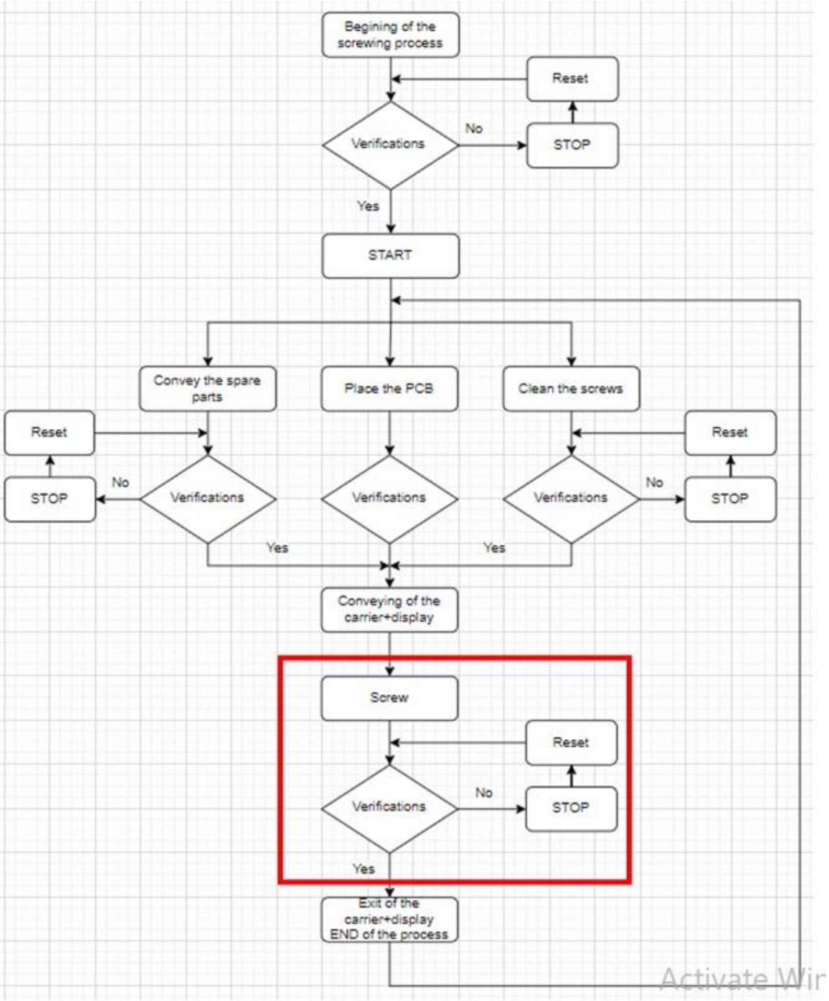

Fig. 2. High-end flowchart of the process

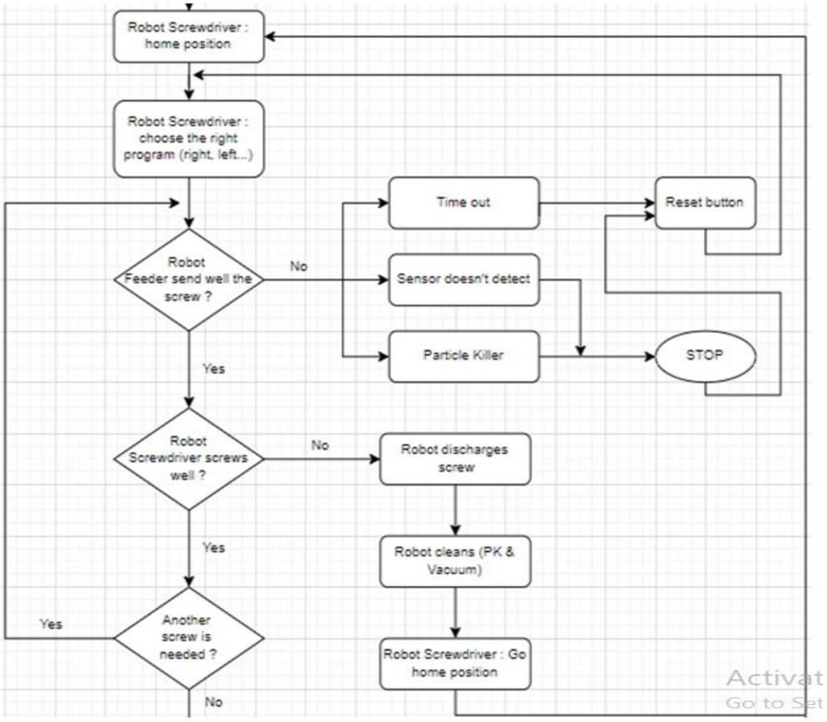

Fig. 3. Low-end flowchart of the screwing process

Table 2. Screwing problems encountered on each machine

Machine	Absence of PCB	Low Torque	Over torque	Screw angle
WP7	88	63	1	8
WP9	0	730	38	26
WP10	29	320	7	33
WP10.1	89	286	6	5
WP11	0	332	0	12
WP12	0	539	1	27
Total	206	2270	53	111

B. Measure

After the define stage of the project where the team has mapped the process and built a SIPOC diagram, in the measure stage it is necessary to collect data and therefore to improve the understanding of the failures that are occurring during the assembly process. The data extraction revealed different types of problems for the screwing process like wrong screw position, wrong PCB or display position, sensor defects as can be understood from Table 2.

A Pareto diagram has been created for more than 2650 defective parts and it is represented in Fig. 4. Pareto chart is sorting the problems by their frequency of occurrence. Thus, we can see which types of problems need to be addressed in the first instance to optimize the results.

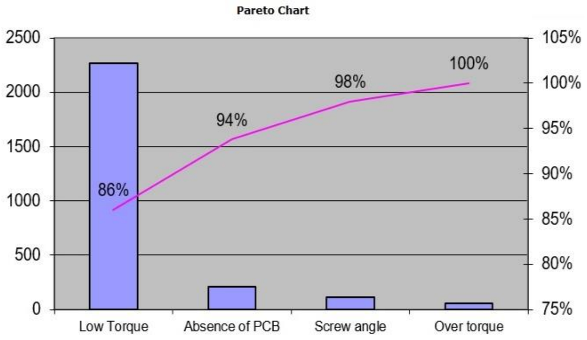

Fig. 4. Pareto chart of error types

The most representative defect the Six Sigma team had to focus upon was the screws’ low torque problem.

Also, to statistically validate the problem, a capability analysis of the process has been realized for the machine WP9 that offered the most relevant data.

To calculate the C_p, we applied the formula (1):

$$Cp = (USL - LSL)/6\sigma \qquad (1)$$

Because the C_{pk} coefficient considers possible decentering, the authors have also computed this coefficient by applying the formula (2):

$$Cpk = min\left(\frac{USL-\mu}{3\sigma}\ ;\frac{\mu-LSL}{3\sigma}\right) \qquad (2)$$

In Table 3, the main results have been outlined.

Table 3. Screwing problems encountered on machine WP9

Column 1	Column 2
LSL	0.23
USL	0.27
Mean	0.2399251
σ	0.0469365
Cp	0.142036
Cpk	0.0704862
Cpm	0.1388727
Z	3
e	0.0014563

We can see that Cp = 3σ, Cp = 2 Cpk, Cpm ≈ Cp. The dispersion of the measured torques for further information has also been detailed in Fig. 5.

The analysis reveals that the distribution is normal. Most of the defects are between 0 and 0.1 in the scatter plot.

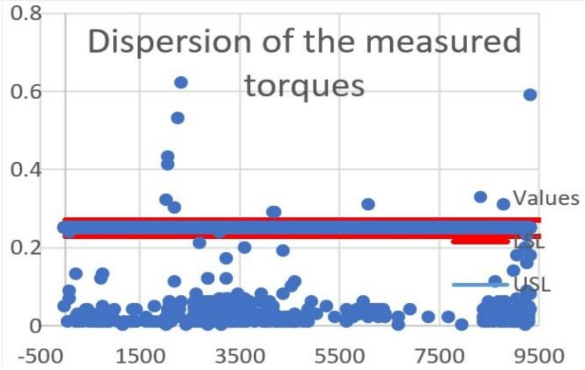

Fig. 5. Dispersion of the measured torques

This information is made clear by the capability analysis in Fig.6, where the defects are between 0 and 0.04 (which is circled in red on the graph) and shows that there is room for improvement.

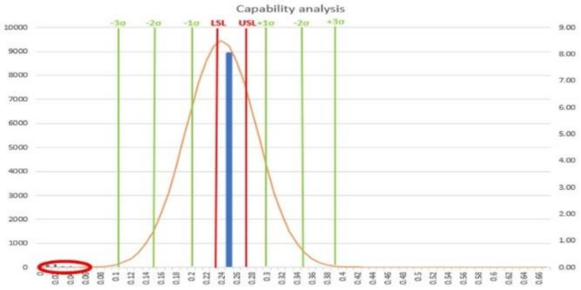

Fig. 6. The capability analysis of the screwing process in machine WP9

To improve the process, it is necessary to revise the torque to the middle of the tolerance interval and eliminate the outliers.

According to the data collected on machine WP9 (the machine that produces the most non-conforming products on the production line), and knowing that there are five criteria for non-compliance, we obtain a DPMO of 16,982.1 and a conformity rate of 98.30%. We know that this corresponds to a quality level of 3.6 sigma. This situation is not acceptable for the company whose goal is to reach Six sigma. This problem needs further analysis to determine the different root causes.

C. Analyze

The usual tools for the analysis phase of a DMAIC are the Ishikawa diagram, also known as the cause-and-effect diagram, and the 5 Whys method. The Ishikawa diagram is a tool developed by Kaoru Ishikawa in 1962 and used in quality management. It is a graphical representation of the causes leading to an effect. It can be used as a tool for moderating a brainstorming session and as a tool for summarizing and communicating the causes identified. It is often used in the context of problem solving or risk identification and management.

We have drawn an Ishikawa diagram (Fig. 7) in which we can easily see that the most important causes that trigger the problem come from the "Machine" and from the “Material” branch. For a deeper understanding of the root causes in the screwing station determined by the cause-and-effect diagram, the 5 Whys method was used (Table 4).

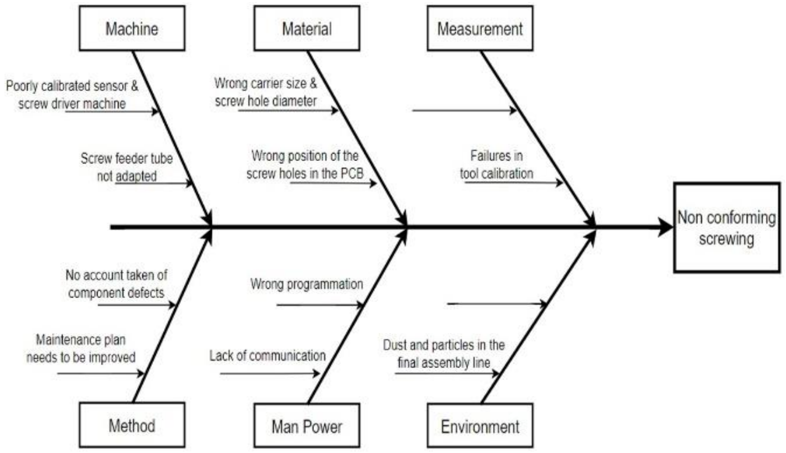

Fig. 7. The Ishikawa diagram for the nonconforming screwing process

Table 4. The 5 whys table for the three potential root causes of the nonconforming screwing process

Possible causes	**Too low torque**		**Absence of PCB**	**Screw angle too high**	
1st why?	Wrong screw position	No screw in the screwdriver	Sensor does not detect the PCB	Screw turns in air	Screw breaks the support
2nd why?	Incorrect X and Y position/Problem with the position of the display on the carrier	Screw stuck in the supply tube	Sensor is misadjusted	Wrong screw position	Support is weakened
3rd why?	Absence of dynamic position correction/not the same display support on all carriers	Screw askew in the tube	Incorrect programming and maintenance need to be improved	Incorrect X and Y position	
4th why?	Incorrect programming	Supply tube is too large		Absence of dynamic position correction	
5th why?		Wrong conception		Incorrect programming	
Correct. actions	Improve the program/ensure a unique position on the carrier	Change the size of the supply tube	Improve the sensor programming and the maintenance plan	Improve the program	Not relevant for the company (too rare)

In Table 4, three main potential causes from the PARETO chart for the high number of rejects at the screwing station were analyzed. For the three main causes of the high number of rejects, we have a technical root cause, i.e., the incorrect programming of the machines and a material root cause, i.e., using a poka-yoke to ensure a unique position and change the screws supply tube for a smaller size.

Despite a fully automated assembly line, problems of non-conformity can occur if all the factors responsible for product conformity have not been studied in advance. Therefore, we will focus on a few corrective actions mentioned above in the improvement phase, to achieve the percentage of compliance expected by the company.

D. Improve

To find solutions to the reported problems, after several meetings and brainstorming with the team, the following actions were chosen and implemented:

- Putting the carriers in a unique position thanks to a poka-yoke, exchanging with the supplier to follow up this modification.
- Modify the program that runs the screwdriver to consider the positions of the screw holes.
- Adjust the position of each screw hole in the display, to reduce the process variation from one display to another.
- Change the diameter of the screw feed tube of the machine.
- Improve the PCB sensor program and increase the frequency of the sensor check.

E. Control

After the implementation of the actions defined in the improvement phase, the team considers as necessary to analyse the process again for control and continuous improvement (Table 5). For this reason, a new production was analysed.

Table 5. Capacity coefficients after improvement

Column 1	Column 2
LSL	0.23
USL	0.27
Mean	0.2489514
σ	0.0152434
Cp	0.437349
Cpk	0.4144198
Cpm	0.4363179
Z	4.3
e	0.0008601

Out of the 5808 products that the WP9 machine assembled, only 80 products were found to be non-conforming. Given that there are five non-conformity criteria, using the DPMO calculation method, we obtain a DPMO of 2,754.3 and a quality level of 99.72%, which corresponds to a 4.3 sigma level. This is an improvement on the 3.6 sigma achieved prior to the improvement project but is still below the 6-sigma expected by the company. The continuous improvement implemented must be sustained over time to achieve the expected objectives.

III. DISCUSSIONS AND CONCLUSIONS

By applying the Six Sigma methodology, we can better understand the processes, identify the root causes of the problems, think about the most appropriate solutions, plan their implementation and follow-up to avoid errors and their consequences. The DMAIC way of working provides all the tools and logical steps necessary for process improvements and more informed decision making.

This scientific paper has verified the benefits of a DMAIC project in the automotive industry by going through the five phases of DMAIC and using well-known statistics and brainstorming tools.

The problem of the high number of rejects from the screwing station of the PCB-Display assembly line was analysed to determine whether it represents a viable DMAIC project.

After confirming the viability of the project, the process was mapped and an analysis of over 81,000 parts was carried out to determine the most common defect types. The data from the non-conforming parts was analysed to determine if the process was in statistical control and to visualize the process capability.

As the process had a Sigma level of less than 3.6, further analysis and improvement was required. After an Ishikawa diagram and a 5-Why table, a technical and material root cause was identified.

In the improvement phase, five corrective and preventive actions at the screwing station were proposed. In the control phase, the process capacity was continuously monitored. The Sigma level was 4.3 with a quality rate of over 99.72%, which is an excellent result for most of the companies.

But, even if a quality level of over 99.72% has been achieved, for an automotive company that produces hundreds of thousands of parts per year, non-conformities result in additional costs that could be avoided. For this reason, it is necessary to continue to work with a view to continuous improvement of the process. Continuous monitoring of quality indicators of the process, weekly meetings to decide, solve problems in production, all this is what it needs to reach the Six sigma quality level.

Decision-making was based on rigorous statistical measurement and analysis, which resulted in a high level of performance.

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