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IMPROVING THE FUNCTIONAL TESTING PROCESS BY APPLYING THE 6 SIGMA METHODOLOGY IN THE AUTOMOTIVE FIELD

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Abstract: *The article describes the benefits of using the Six Sigma DMAIC cycle to enhance delivery timing to clients in the automotive industry. The DMAIC cycle tools were used at each stage, and each consecutive step was built on the results of the preceding one, with the goal of achieving a long-term solution to the examined issue through the deployment of corrective actions. The use of corrective actions resulted in improvements, eliminating the waste in the assessed organization. The root cause was a lack of information between the teams, which resulted in waste. The solution for this challenge was to strengthen collaboration with other teams while creating papers for upcoming tests based on their duration and difficulty.*
Keywords: *Six Sigma, DMPO, automotive, lean, Ishikawa, manufacturing, waste.*

1. INTRODUCTION

The main goal of the Six Sigma strategy is to achieve a degree of quality and reliability that will satisfy, if not exceed, the demands and expectations of today's consumers. The phrase "sigma quality level" refers to a process's level of excellence. While a lower Sigma quality level suggests a greater likelihood of defective products, a higher Sigma quality level indicates a lesser likelihood of defective products within the process [1].

There is a 3.4 parts per million possibility of damaged items if the Sigma quality level is 6. Leadership, infrastructure, and the right tools and techniques are all necessary to reach the Six Sigma quality level, and corporate business plans must incorporate quality [2].

Table 1

Sigma levels and DPMO[2].

Process Capability	DPMO	Performance	Cost of Quality %
2	308537	69,10%	> 30
3	66807	93,30%	15 - 25
4	6210	99,40%	10 - 15
5	233	99,70%	5 - 10
6	3,4	99997%	< 5

The Six Sigma approach and tools address the total costs of quality, including both tangible and intangible components, and aim to reduce them while simultaneously raising the overall quality level, which promotes business development**.**

2. LITERATURE REVIEW

There is a continuous push to enhance current procedures to better serve current clients and a desire to create new procedures to meet the needs of future clients in this dynamic environment of shifting consumer demands, new markets, innovation, and societal change.

Six Sigma is a methodology that focuses on customer expectations and satisfaction, the result of their application to achieve process or product quality by reducing the defect rate [3]. The main approach of Six Sigma consists of following the 5 stages of its application, DMAIC (Define, Measure, Analyze, Improve, and Control) [4].

The methodology has been applied in many studies for various purposes and targets in the engineering area, especially in the automotive field [5].

Because the automotive industry is a competitive one with high standards for quality and safety, attempts have been made to implement Six Sigma in this sector [6].

Nowadays, Six Sigma is applied in a variety of industries, including automotive, electronics, energy, logistics, and others, and these sectors have seen success in their endeavors with regard to both financial advantages and product quality [7].

The results of a study that collected various articles published between 2005 and 2019 about the application of Six Sigma in various industries showed that most organizations saw improvements in process, rework, waste, and defect reduction as well as a significant improvement in financial performance following the implementation of this methodology [8].

Jou et al. applied the Six Sigma method to develop the manufacturing process related to brushless motor products. Following the application of Six Sigma-DMAIC, several improvement solutions were implemented with root cause identification by customer complaints [9].

Smetkowska et al. applied Six Sigma DMAIC to improve the manufacturing process by reducing the number of defects per product [10]. Also, the Six Sigma methodology was applied in order to eliminate waste during tire production, obtaining optimal solutions to improve the manufacturing process [11].

In a case study of the application of Six Sigma to improve logistics services at a consumer electronics company is presented. It identifies possibilities for further improvement, as well as the potential of logistics services using the DMAIC approach [12].

Because of this, the main goals of current scientific research on improving the quality of some entities (processes, resources, products, services, etc.) using the statistical approach known as "Six Sigma" are to achieve three main outcomes: a reduction in dead time, an increase in organizational satisfaction, and an improvement in departmental collaboration. Sigma (σ) is derived from the Greek letters and is used to assess process modifications in terms of quality [13].

Numerous works and studies about the application of research and investigation techniques for quality improvement using the approach provided by the "Six Sigma" concept can be found in the specialized literature [14].

The majority of the literature's studies concentrate on reducing and/or improving the hardening process's nominal cycle time. By analyzing each internal loss, the current method seeks to reduce and eliminate internal process time, hence improving productivity and product quality [15].

By using the current Six Sigma-DMAIC approach, this work takes a fresh approach to the optimization of the time lost during the Functional Build process as a result of the various errors that occurred in the process, intending to improve the quality of functional testing processes in the automotive industry [16].

This is accomplished by tracking every factor that could lengthen the delivery time to the subsequent internal customer and implementing corrective actions as needed to meet the target demand [17].

3. EXPERIMENTAL PROCEDURE

The functional testing process is the process by which production parts are validated on the assembly line, after they have undergone engineering changes or improvements. These changes are required or determined by the following factors: Customer feedback; Updates of legislation or of European or national norms; Design or software changes; Cost reductions through changes in materials, structural or construction technologies; Improvement of quality aspects reported by employees, technological engineers, and process engineers, respectively quality auditors.

After validating and obtaining agreement on compliance with customer requirements, a report called Functional Build Report is raised, which is sent to all those involved in the implementation of the new or modified benchmark. The results of this report can be: OK / OK-But / NOK.

Following the complaints received from the participants in the functional testing process regarding the delays and disruption of their activity, a Six Sigma improvement project was initiated.

3.1 Define

Teamwork is considered one of the most effective strategies to accomplish objectives in any field, profession, or activity. Since it promotes information sharing, issue solving, and more employee responsibility, it is among the most crucial components of continuous improvement systems [18].

As presented in Figure 1, one of the tools used in the Define phase for separating the "vital few" variables X that affect Y, from the "trivial many" is the Pareto diagram [19].

Only a small number of the X multiples influencing the process can be deemed essential; they were found by ranking them according to their percentage influence on the process:

- Information for Quality Check (QC) - 40%;
- Vehicle Personalization processing - 28%;
- Other (multiple) reasons - 18.7%;
- Quality Check activity overload.

An important element of Six Sigma is understanding the customer, this is called Voice of the Customer (VOC), and this allows finding all the necessary information that is relevant between the product/process and the customer, better known as CTQ (Quality Critical) [20].

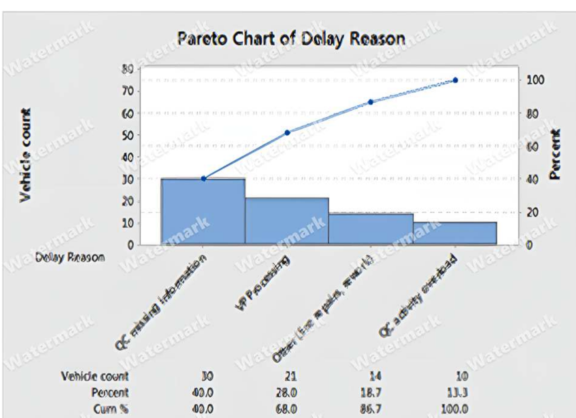

Fig. 1. Pareto analysis diagram

Every process has a result. The person or entity receiving this result is a customer. There are two different types of customers: external and internal, and people generally forget about domestic customers, although they are just as important as the customers who buy the product [21].

Within the project, the VOC is the following statement:

- The customer wants to have the completed vehicles available to deliver them in a timely manner. The validated CTQs are:
- Vehicles must be available for Quality Check shortly after completion;
- The required tests must be clearly expressed and submitted to Quality Check;
- Agreeing with Quality Check on the amount of daily tests required to avoid overloading the workload.

Definition Defect for Y - or what affects the customer (in this project an internal customer) - Material Planning & Logistics Team cannot send vehicles to customers because they are locked in the associated Functional Build Quality Leadership System (QLS) campaigns.

There are four elements that make up the COPQ: external costs, internal costs, prevention costs, and evaluation costs [22].

The process map is the most important and powerful tool you will use to improve the effectiveness and efficiency of a process.

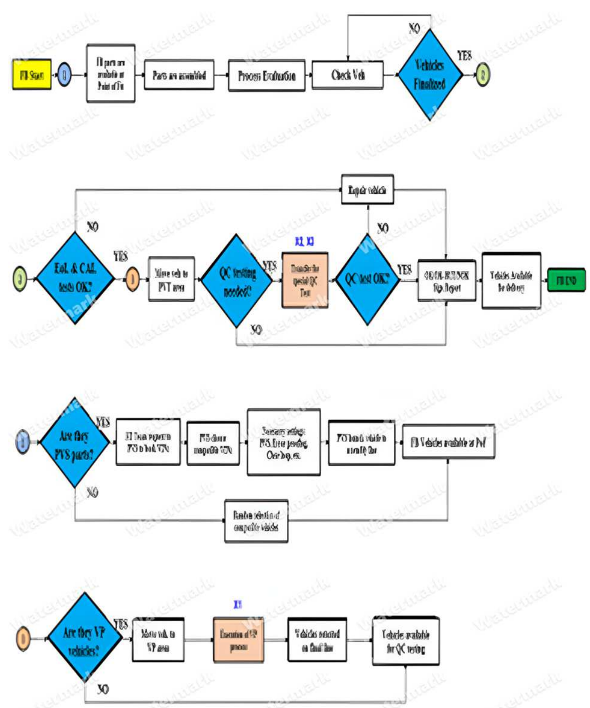

Fig. 2. Flowchart.

According to Figure 2 by drawing up the Functional Testing Process Map, the steps and activities within the process in which the influencing factors X act were highlighted.

3.2 Measure

In the measurement phase, it was necessary to determine the basic process capability and analyze the MSA, measurement system analysis.

To determine the Basic Capability of the process, we used the Defects Per Million Opportunities indicator, and the determined DPMO was 97025.

Table 2

Assessment method/tool used in accordance with Functional Build procedures - Assessment criteria.

2 Points	1 Point	0 Points
All of the following conditions are missing: -QC testing – full details on the "Campaign Opening Form", -VP vehicle avoided, -QC capability checked	1 or 2 of the following conditions are missing: -QC testing – full details on the "Campaign Opening Form", -VP vehicle avoided, -QC capability checked	All of the following conditions are missing: -QC testing – full details on the "Campaign Opening Form", -VP vehicle avoided, -QC capability checked

For this, in Table 3, 31 functional testing processes were evaluated, by 2 different operators, who scored them based on specified requirements. The responses to the evaluations were analyzed using the application Minitab 17, the answer being the Kappa indicator.

Table. 3

Minitab Data.

FB Process	Score Operator 1	Score Operator 2
1	1	1
2	2	2
…	…	…
30	1	1
31	1	1
Sum	34	35
Average	1.10	1.13

The purpose of Measure System Analysis is to evaluate errors due to measurement systems.

Given that Reproducibility and Repeatability are important types of error, they are the subject of a specific study called Gage R&R (Rage R&R).

Kappa from Figure 3 indicates the degree of consistency of the nominal or ordinary evaluations carried out by several evaluators in the evaluation of the same samples. Kappa statistics are commonly used in crosstab applications and attribute agreement (R&R) analysis.

Kappa values range from -1 to +1. The higher the kappa value, the stronger the agreement. Typically, a kappa value of at least 0.70 is required, but kappa values close to 0.90 are preferred.

In our case, the Kappa value obtained was 0.826, which denotes a strong agreement between the two evaluators, leading to the conclusion that the measurement/evaluation system has no error.

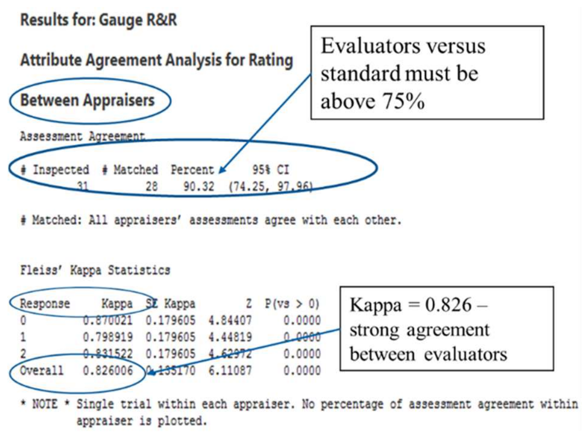

Fig. 3. Gauge R&R Results.

This diagram presented in Figure 4, often known as the Ishikawa or Fishbone Diagram, is used to connect multiple possible inputs to a single output.

Finally, it is determined whether each cause is a control factor or a noise factor. This is a requirement for process characterization. Then, we will explain the meaning and methods of using common categories.

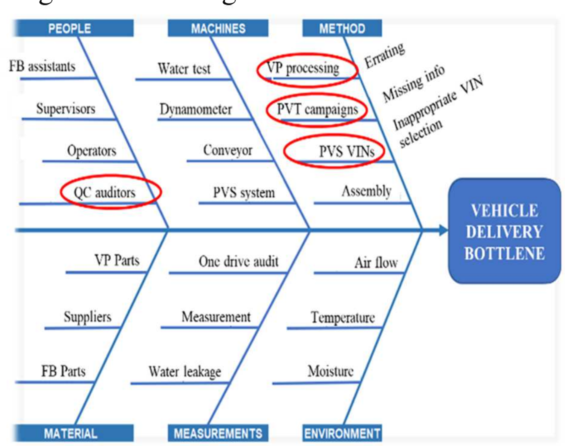

Fig. 4. Fishbone Diagram.

Following the analysis and classification of the influencing factors (X) into controllable, procedural or noise, the following key contributors were identified:

- Missing information on the Functional Build campaign opening form;
- Inadequate selection of VINs;
- Specific Quality Check testing capacity;

In order to make an analysis for the main contributors, the time spent by Functional Build vehicles during each stage was monitored and is presented in Figure 5. Thus, the standard average times allocated to each stage were highlighted, compared with the actual times achieved.

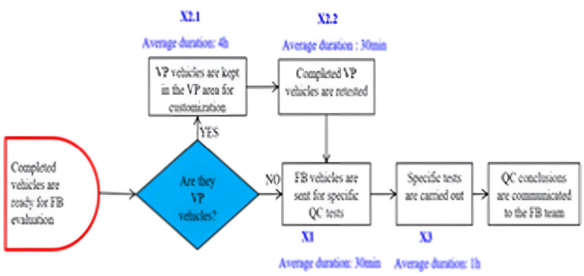

Fig. 5. Delayed Units - Simplified Process Flow.

X1–Transfer time of vehicles to Quality Check and testing planning:
Tmin = 20min; Tmax = 30min.
X2.1-Time to complete the customization process: Tmin = 1h; Tmax = 7h.
X2.2–Time for retesting PV vehicles: Average duration = 30min.
X3–Time to perform Quality Check tests:
Tmin = 15 min; Tmax = 4h.

3.3 Analyze

In the Analysis phase, Hypothesis Testing was used for the main contributors.

Hypothesis testing can help avoid the high costs of experimental efforts by using existing data, but the probability of occurrence is based on pre-established statistical confidence.

A hypothesis test converts the practical problem into a statistical problem.

Using the Hypothesis Testing by the "1 sample t test" method in the Minitab 17 application, within a 95% confidence interval of the tested statistical solutions (H0 and H1), the practical solution is chosen/confirmed: "the number of delayed Functional Build vehicles are different from 0 for any hypothesis". Therefore, these factors influence the results/outputs of the Functional Build process. The results are presented in the following figures.

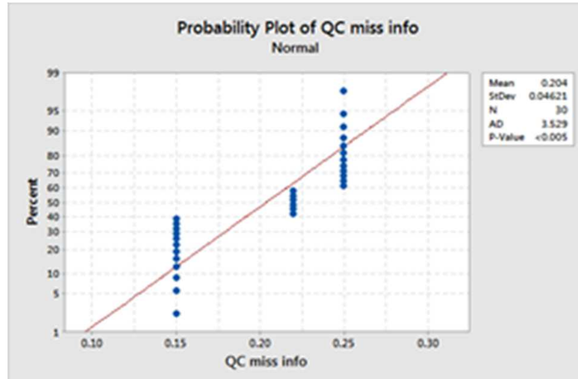

Fig. 6. Probability Plot 1.

One-Sample T: QC miss info

Test of μ = 0 vs ≠ 0

Variable	N	Mean	StDev	SE Mean	95% CI	T	P
QC miss info	30	0.20400	0.04621	0.00844	(0.18675, 0.22125)	24.18	**0.000**

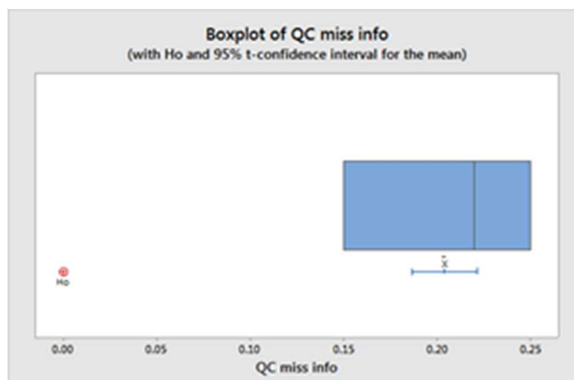

Fig. 7. Box Plot 1.

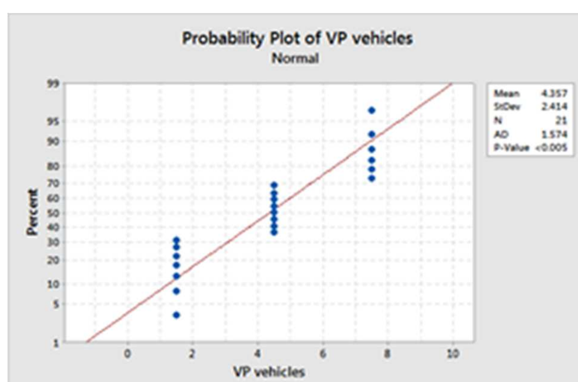

Fig. 8. Probability Plot 2.

One-Sample T: VP vehicles

Test of μ = 0 vs ≠ 0

Variable	N	Mean	StDev	SE Mean	95% CI	T	P
VP vehicles	21	4.357	2.414	0.527	(3.258, 5.456)	8.27	**0.000**

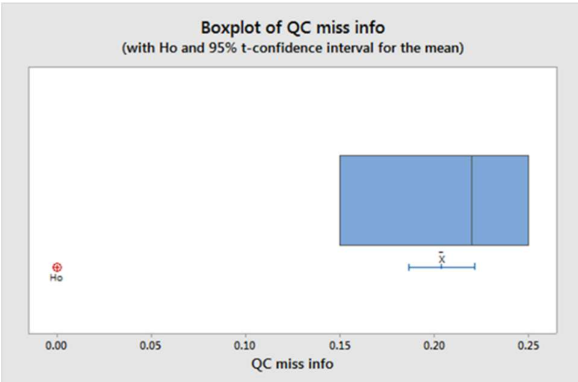

Fig. 9. Box Plot 2.

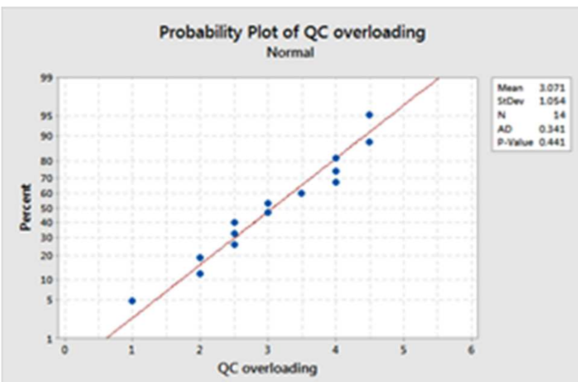

Fig. 10. Probability Plot 3.

One-Sample T: QC Overloading

Test of μ = 0 vs ≠ 0

Variable	N	Mean	StDev	SE Mean	95% CI	T	P
QC overloading	14	3.071	1.054	0.282	(2.463, 3.680)	10.91	**0.000**

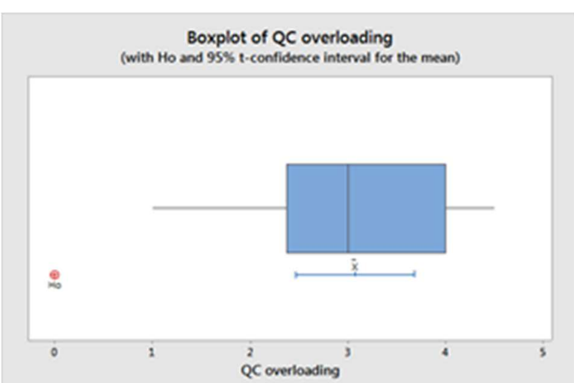

Fig. 11. Box Plot 3.

From the factors influencing the process considered, those with significant influence and on which action can be taken for improvement must be selected.

An X-Y Matrix or Prioritization Matrix is used for this as evidenced in Figure 12.

To summarize, the X-Y matrix is a team-based prioritization tool for potential X. To complete it, the data obtained in the Cause and Effect diagram (Fishbone) is used, which is entered in the "Entries" section.

The main values and any other secondary values are then entered in the columns numbered from 1 to 10 (output Variables Y).

These output variables (Y) are rated on a scale of 1 to 10, even if some have the same weight, which is fine.

For each X listed on the left, its effect on each corresponding item is evaluated based on a scale of 0, 1, 3 or 9.

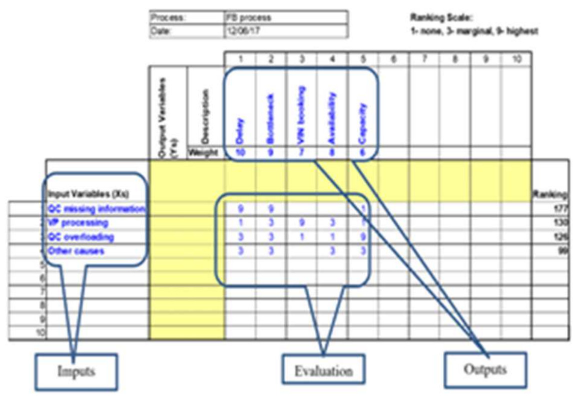

Fig. 12. X-Y Matrix Evaluation.

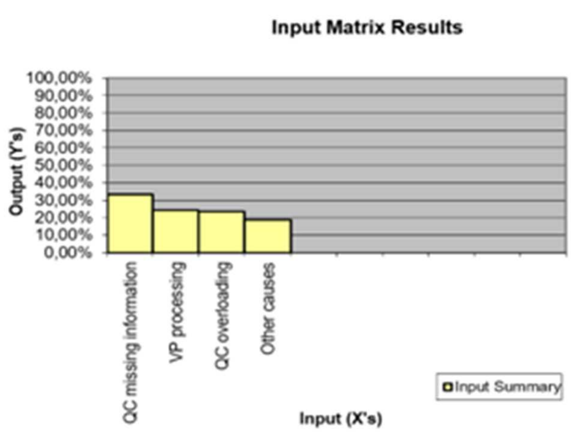

Fig. 13. Inputs matrix results.

Based on the ranking obtained after completing the X-Y Prioritization Matrix, the factors influencing the Functional Build process were identified in the following order, as seen in figure 13:

X1 – Missing information for Quality Check;
X2 – VP processing;
X3 – Quality Check Overload.

Table 4

XY Matrix Summary

Process:	FB process
Date:	30/08/2016

Output Variables	
Description	Weight
Delay	10
Bottleneck	9
Availability	8
VIN booking	7
Capacity	6

Input Variables		
Description	Ranking	Rank %
QC missing information	177	33.27%
VP processing	130	24.44%
QC overloading	126	23.68%
Other causes	99	18.61%
		0.00%

3.4 Improve

Below are the actions in the Improvement phase, including the measures taken to eliminate the loss of time in the Functional Testing Process, caused by the three influencing factors.

1. Providing all the necessary information for quality auditors on the FB campaign opening form, thus avoiding wasting time to obtain them;
Before improvement: auditors call PVT by phone to find out the details of the requested tests (waste of time).
After improvement: auditors find all the necessary information on the open FB campaign form.

2. Elimination of vehicles that require VP equipment, when in the FB process no specific tests are required for this area, by the specific request sent to the PVS team;
Before improvement: auditors call PVT by phone to find out the test details (waste of time).
After improvement: auditors find all the necessary information on the open form of the FB campaign.

3. Calibration of the tests required in the FB process, depending on their standard duration and the capacity of the QC auditor team.
Before improvement: The FB assistant informs the quality auditors to carry out the tests required by the PVT and the process engineers, without taking into account the working capacity of the quality department.

After improvement: The FB assistant informs the quality auditors to carry out the tests required by the PVT and the process engineers, taking into account the duration of the tests and the working capacity of the quality team, such as:

- One drive dynamic - 1.44h / vehicle;
- One drive static - 50min / vehicle;
- Key Off Load - 3h / vehicle;
- Wheel alignment - 1.08h / vehicle;
- Water test - 20min / vehicle;
- Audit specific - 15-20min / vehicle.

In the 3 figures below, the improvements were highlighted by eliminating the dead times from the selected influencing factors, thus leaving only the actual times allocated to the FB process.

X1- The FB assistant puts all the relevant details in the open form of the FB campaign

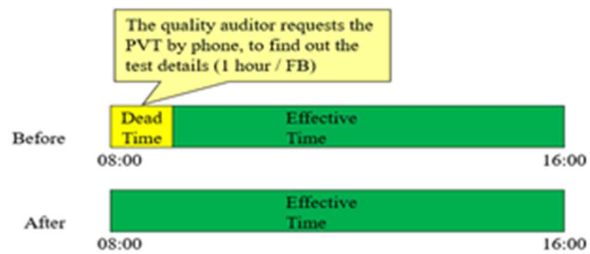

Fig. 14. X1 Results.

X2 – FB Assistant prompts for VIN selection, which should not include VP vehicles

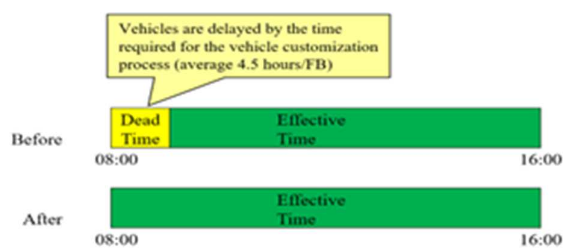

Fig. 15. X2 Results.

X3 – Better management of QC-specific tests

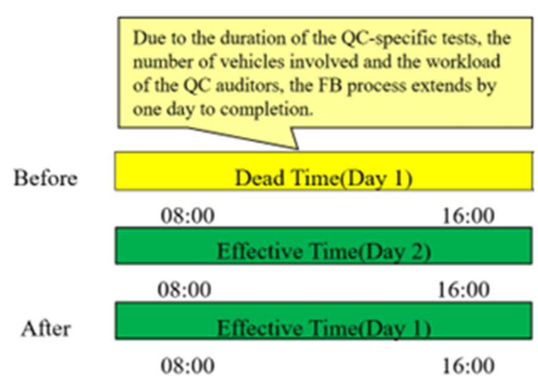

Fig. 16. X3 Results.

4. RESULTS AND DISCUSSIONS

4.1 Control

Following the application of the identified improvement measures, FB campaigns were monitored over two months and almost all delays were eliminated, and this result is illustrated in Figure 17.

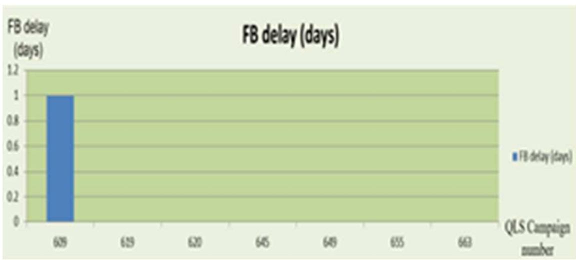

Fig. 17. Campaign monitoring FB-QLS.

Using the Hypothesis Testing by the "1 sample t test" method in the Minitab application17, after applying the improvement measures, within a 95% confidence interval, among the tested statistical solutions (H0 and H1), the practical solution is chosen/confirmed: "The number of vehicles delayed in FB campaigns does not differ from 0". As a result, the performance of process improvement is also statistically confirmed in the figures below.

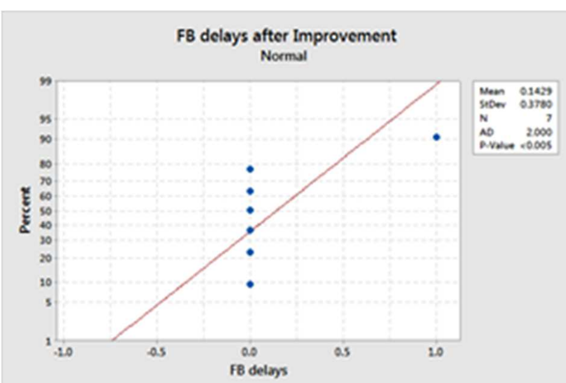

Fig. 18. FB Delays.

One-Sample T: FB delays

Test of μ = 0 vs ≠ 0

Variable	N	Mean	StDev	SE Mean	95% CI	T	P
FB delays	7	0.143	0.378	0.143	(-0.207, 0.492)	1.00	0.356

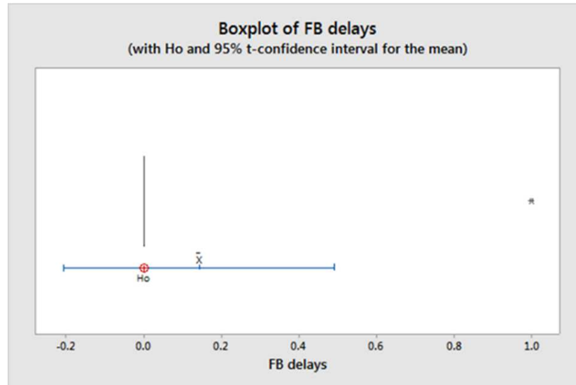

Fig. 19. FB Delays Box Plot.

Also, within the Control phase, the Basic Capability of the process - DPMO was recalculated, after the application of the improvement measures. The value obtained for the DPMO during the monitoring period was 20833.

DPMO (Ian–Mar) – DPMO (Apr–Mai) =
97025 – 20833 = 76192;
Improvement percentage =
76192 / 97025 * 100 = 78 %.

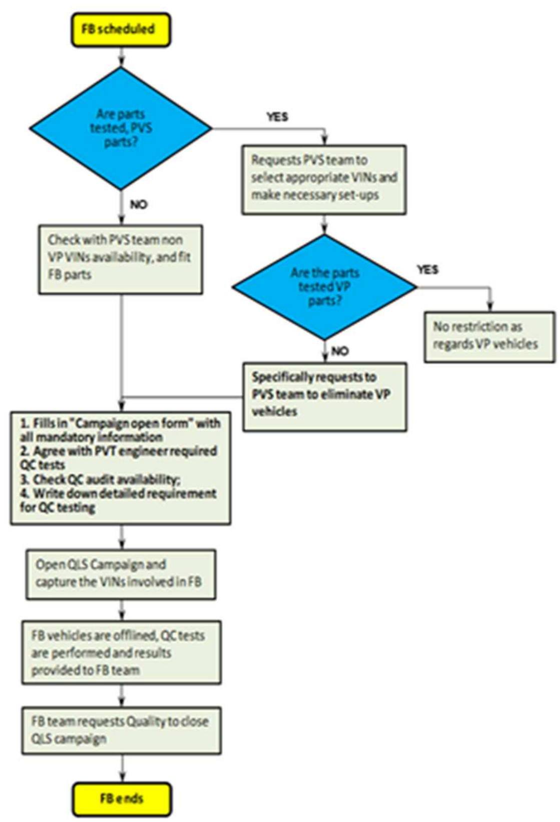

Fig. 20. Single Point Lesson.

Thus, through the improvements applied, a reduction of "defects"/delays of the vehicles involved in the FB process was achieved by 78%. The goal of the project was achieved, with a target of 70%.

At the same time, in order to keep the FB process under control after improvement and to prevent recurrence, an SPL (single point lesson) was drawn up, see Figure 20, which detailed the steps to be followed in the FB procedure in the programming phase to avoid the losses identified within the project.

5. CONCLUSIONS

A Six Sigma project is a well-defined effort that addresses a problem that affects key business and/or operational objectives in quantifiable terms and with known expectations for improvement [23].

Applying a Six Sigma improvement project for the Functional Testing Process in the automotive field was a fortunate choice, as it was possible to identify the main causes that caused delays in the delivery of vehicles to the next customer. In this way, losses, and unnecessary (dead) vehicle downtime in Quality Leadership System campaigns were eliminated, but at the same time, the flow of interdepartmental communications was simplified and improved, which greatly facilitated the upstream and downstream activities of the process.

The increase in quality was reflected in the reduction in the number of immobilized vehicles between the different phases of the Functional Testing Process, representing the essence of the "Lean Manufacturing" concept.

Although we might think that after so much time and so many improvements, all factories in all sectors have a Six Sigma level, this is not entirely true. Along with the development of the industry, problems also develop, always leaving space for the application of Lean Manufacturing.

And as directions for future studies, as before, we aim to analyze as many continuous improvement projects as possible from the specialized literature, and based on the lessons learned, to put into practice in the automotive field, as many improvements as possible with the aim of identifying various losses and eliminating them, using the Six Sigma methodology, its tools, and DMAIC steps.

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Îmbunătățirea procesului de testare funcțională prin aplicarea metodologiei 6 Sigma în domeniul auto

Articolul descrie beneficiile utilizării metodologia Six Sigma DMAIC pentru a îmbunătăți timpul de livrare către clienții din industria auto. Instrumentele ciclului DMAIC au fost utilizate în fiecare etapă și fiecare pas consecutiv a fost construit pe rezultatele celui precedent, cu scopul de a obține o soluție pe termen lung la problema examinată prin implementarea de acțiuni corective. Utilizarea acțiunilor corective a dus la îmbunătățiri, eliminând risipa în organizația evaluată. Cauza principală a fost lipsa de informații între echipe, ceea ce a dus la risipă. Soluția pentru această provocare a fost consolidarea colaborării cu alte echipe în timp ce se creau lucrări pentru testele viitoare în funcție de durata și dificultatea acestora.

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