

The elimination of the anti-coincidence colorimetry in the process of painting the shell of a vehicle by applying WCM

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ABSTRACT

This work presents the optimization of process of car shell painting in FCA Serbia Ltd. by using the world class manufacturing (WCM). In order to show the advanced Kaizen within the pillar "Focused improvement" we have taken an example of problems in the production of a passenger vehicle "Fiat 500L" which is reflected in an inadequate colour match during serial production. The anticoincidence in the process of painting the shell of a vehicle was eliminated by Kaizen method. The analysis of vehicle shell painting process improvement was carried out by DOE, the verification of the proposed activities was completed, the experiment factor was identified, a hypothesis testing was conducted, all results were viewed and the process of verification and optimization was completed.

KEYWORDS

World Class Manufacturing, The elimination of anticoincidence, The process of painting

1. INTRODUCTION

Most worldwide manufacturing industries due to the increasing market competency and economic crisis are seeking solutions to improve their performances. The two most significant strategies (models) which are used by companies are Lean Production and World Class Manufacturing. The similarities and differences between these two manufacturing strategies are described in details in this work [1]. At a very detailed level, the lean production practices include but not limited to practices such as cellular manufacturing, multifunctional workforce, lot size reduction, just-in-time (JIT), work delegation, total productive maintenance (TPM), set up time reduction, total quality management (TQM), continuous flow production, agile manufacturing strategies, safety improvement programs, process capability measurement and human resource management [2]. Of course, not all companies are ready to apply contemporary models, so in support to this, the authors in this work propose a model on assessing the maturity of the organizations when applying WCM system [3]. Various consultants have started implementing their own versions of Toyota's production system under Western names such as Continuous Flow Manufacturing, Inventory-free manufacturing, and World Class Manufacturing [4].

Model WCM (World class Manufacturing) world class production based on 10 interconnected technical pillars related to the production process and which, due to the easier understanding and monitoring, are presented and defined through seven steps. Beside technical, WCM consist of 10 managerial columns which are evaluated during the review as a subjective perception of the examiner. WCM was developed in the 1920s by Hausan, Schonberger and other authors. They determined that the measuring methods of the quality of manufacturing organizations at the time, especially those which carry out production by working orders, (MTO-Make to order) no longer gave good results and it was necessary to develop a new concept that, in addition to the more realistic description of the process, enables benchmarking on a global scale[5,6]. The management of the organization according to WCM principles is based on high-quality reliable methods and tools in the wide involvement of all employees and company management. The mere adoption of such an approach allows accomplishing high-quality and measurable savings in the production process [7]. In Serbia, this concept is most often used in foreign companies, with international or combined management, where changes in the competitiveness of any organization are monitored on a monthly basis. This work will show the optimization of the process of painting the shell of vehicles in FCA Serbia Ltd. by applying WCM governance model. Precisely, process optimization using WCM management model is the goal of the work, practical implementation and problem solving using the Kaizen approach and methodology is a possible contribution of the work.

2. BASICS OF THE WCM

The WCM principles are applied to all aspects of the organization, from quality systems to maintenance, from cost control to logistics to constant improvement. WCM system is based on the systematic reduction of all types of costs and losses through the benefits of all employees and with the precise use of the methods, standards and tools that world class production requires.

Each of the technical pillars must achieve a specific goal, which is supported by the managerial pillars. Managerial pillars are prescribed the requirements which are necessary in order to obtain better working conditions and improvement of technical pillars. Each technical pillar, following the prescribed standards must go through seven steps, where in each it is necessary to fulfill certain tasks in order for the pillar to move to the next level. Although this is about different pillars with different goals, they are closely related to each other and one without the other cannot manage. So, for example, the Safety pillar aims to eliminate accidents, the Cost Deployment pillar aims to identify problems related to the costs and points out where the major problems are, so that everyone can focus on eliminating them, the Focused Improvement pillar develops new insights and reduces the costs by using appropriate methods, the Workplace organization and Autonomous maintenance aims to increase the level of the competency of the people in the facility by organizing the workplace where the greatest costs are and where intensive work is needed, and by autonomous maintenance in parts with large investments in equipment. Thus, pillars are like the links of the chain, attach to each other and with their corporation provide support to the WCM temple. The ten management pillars form the foundation of the WCM:

Dedication – If the plans of the boards of directors are unaware or do not support management in order to achieve a level of world-class performance, company is doomed. 2) Involvement- All people in the company must be aware of the goals and tasks of the business. They must also be a key factor that will enable companies achieve their goals through their actions. 3) Communication- Before people can commit to this concept, they need to be informed about it in detail. People need to understand how and why WCM is important to the decisions of the company's goals. 4) Understanding – Understanding what and where the problems are is the starting point for making improvements. 5) Measurement – Measurement is the key in qualifying problems and determining their priorities, as well as determining the efficiency of the improvements achieved. It is necessary to perform a performance measurement before and after the changes and in that way determine whether and to what extent the changes of performances have improved. 6) Scheduling – Scheduling refers to how goals are converted to actions. 7) Application – Implementation of the right solutions to identified problems by applying strict principles with the help of trained people is essential for success. People can also learn and improve when implementing solutions. 8) Assessment – The assessment needs to be an integral part of the improvement process to see if the problem and solution have been solved. 9) Standardization – When the evaluation cycle is over, it is the time to standardize the method of process management, so that the obtained result is maintained after solving the problem, not that we have the same problem again. 10) Documentation – Documentation is created in order to accumulate the degree of knowledge and to use them in other areas in the future.

The quality pillar is responsible for carrying out quality studies. In the world class manufacturing model, the "Quality Control" (QC) pillar focuses on determining process conditions, maintaining predetermined conditions and ensuring production compliance to prevent nonconformities (Szewieczek, Roszak and Helizanowicz, 2008).

In WCM system, it is necessary to first identify the problems that will be considered, then determine the location and prioritize them by the cost analyses. After that, it is necessary to determine the right methods and evaluate how much the solution costs. It is necessary to implement solutions with accuracy and evaluate the achieved results in relation

to the original goal. To solve the problem WCM tools are used that can be divided into three groups: tools for describing the problems, tools for finding the root of the sample and tools for the standardization of the results.

When a problem arises, it is necessary to describe it with the use of appropriate tools. Using the tool 5W+1H we describe the problem by filling out a standardized form. After the description, it is moved to search for a sample problem with the help of a tool 4M (Men, Machine, Material, Method) that uses a herringbone diagram to show all possible causes of the problem, whereby the same is shared with those produced by man, machine, method and material. After generating all possible samples using no check list, the circle of possible causative agents is narrowed.

Finally, for the remaining possible samples, the depth of the problem is entered by using the tool 5W – question “Why?”, at least five times, we determine the actual cause of the problem [8].

3. FOCUS IMPROVEMENT

The purpose of the third technical pillar is to eliminate the main loss previously identified within the steps for the distribution and analysis of costs. In this way, organizations do not use resources for problematic issues of lower priority. Corrective actions are targeted and must lead to the final resolution of the problem and the renewal or introduction of a new specific standard. Focused on improvements make seven steps:

Step 1: Defining a model of a zone or machine within which continuous improvement will be carried out. Zones can be parts of production that are recognized as bottlenecks or zones that produce large losses.

Step 2: Stratification loss is carried out, and, that is, a breakdown is carried out into all types of losses.

Step 3: Choosing a project to be done and defining the activities of the project itself. When we talk about the tool that will be implemented in order to solve a particular problem, we use “Kaizen”.

An example of good practice of using the Lean-Kaizen concept is described by the authors in their work [9].

3.1. KAIZEN

Kaizen is a method of continuous improvement. A substantive translation would mean a change for the better that everyone is doing every day at all levels in one company. Kaizen comes from the best practice of Japanese management, it is dedicated to improving productivity, efficiency, quality and business excellence at all. Small improvements that apply to key processes, generate an increase in profits while gaining client loyalty. The purpose of this method is to exceed the stated goals of one company.

Step 4: Creating a team based on their competencies that will work on the project depending on the complexity of the problem.

Step 5: Defines the work on the implementation project in seven steps: Defining the problem. Classification of potential causes of the problem. Detecting the real or true causes of the problem. Establishing a definite solution to a given problem. Implementation of the solution. Verification of solutions and monitoring of the results. Standardization of a certified solution. Analysis of the cost-effectiveness of the project. Solution verification and horizontal expansion.

Step 6: Cost-benefit analysis of the project's profitability.

Step 7: Verification of the solution and its horizontal expansion [10, 11].

4. ELIMINATION OF ANTICOINCIDENCE IN COLORIMETRY IN THE PROCESS OF CAR SHELLPAINTING BY APPLYING ADVANCE KAIZEN

In order to display Advance Kaizen within the pillar “Focused Improvement”, an example of a problem has been taken within the production of a passenger vehicle “Fiat 500L” which is reflected in an inadequate color match during serial production. Due to the data protection in the continuation of the work, the color will be qualified as a “Specific color”. After the improvement of internal standards in the automotive industry, new methods have been defined about checking the harmonization of the color of the finished product. The method previously applied was based on the visual perception of the controller who was tasked with verifying the harmony of colors (compared to a master pattern) with reflection at the corner of 25°, 45° and 75°, that is, (Face, Flash, Flop) as shown in the figure 1 [12].

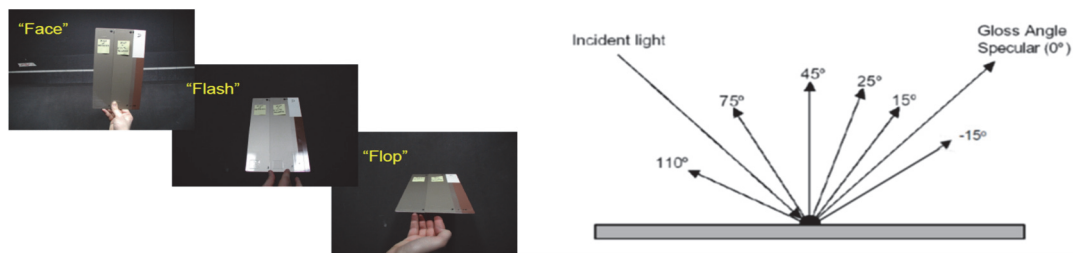


Figure 1: Previous method certification of color harmony on a vehicle.

The new method of checking the color alignment on the finished product is reflected in the measurement of the specific color using device "BTC MAC" which is pressed on the painted surface and by measuring it calculates the difference between the absolute value and the defined standard, figure 2.

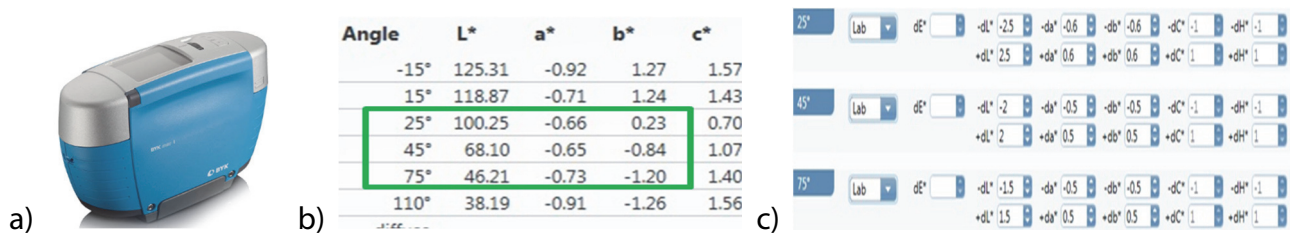


Figure 2: A new method certification of color harmony on a vehicle (a) - measuring device "BYC MAC", b) - measured values, c) - defined standards [12].

What was observed using the device is that the shell of the vehicle is darker than the bumpers of the vehicle, which were painted in an independent process in relation to the shell of the vehicle, figure 3.

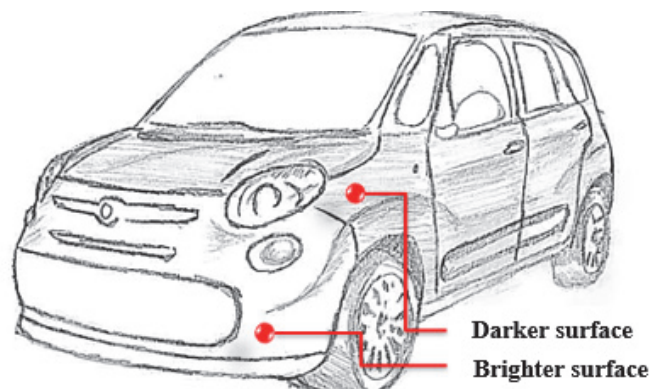


Figure 3: A sketched view of the vehicle effect.

Although the problem was related only to a "specific color", it occupied a high position in the classification of qualitative problems by using "Quality Assurance Matrix", shown in Table 1.

The Quality matrix is the main tool for establishing a quality control in WCM methodology. The purpose of the tool is to find correlation between the non-compliance of products from the process itself, as well to priorities the problems, that is, critical processes based on the criticality index.

The criticality index is calculated by multiplying four multipliers, which are defined by values from 1 to 5 for each individually:

- The frequency of occurrence, that is, the repetition of the problem.
- The cost of direct and indirect materials as well as working hours spent on troubleshooting.
- Detection problem, that is, the location where the defect was detected (if the defect is reported by the buyer, its severity is greater than the defect detected in the production process).
- Problem severity. If the problem affects the general security of the user or affects the ability to perform basic functions, the problem will carry more weight than if we talk about aesthetic problems [13].

$$\text{INDEX} = \text{FREQUENCY} \times \text{COSTS} \times \text{DETECTION} \times \text{SEVERITY}$$

Table 1: A view of problem classification and position within the "QA" Matrix.

#	Input	Source	Component	Anomaly	Frequency	Mat. Cost.	Cost.	Seventy	Detection	Priority Index	Responsibility
32	CPA	Internal	Paint Body Color	Color matchinging	2	2	2	4	4	40	PAINT

4.1. Analysis and corrective actions to improve the dyeing process of vehicle shells.

The defect is generated during the painting process "specific color" in the painting booth and it is detected at the final check in the paint shop during spectrophotometer measuring. The painting of outer surface of the vehicle is performed using a robot in the spray booth, through paint bells that are located in the processes of the basic color 1 and 2. (Base Coat 1 and Base Coat 2), so that there is no men's effect to generate problems. After measuring the colorimetry on the vehicle, it was observed that the parameters per L*axis deviate from the specification, that is, the shells of the vehicle tend towards a darker shade as in figure 4 (data is processed in the "Minitab") [13].

Silver_Metallik		dE*			L*			a*			b*			C*			h		
D65/10		25	45	75	25	45	75	25	45	75	25	45	75	25	45	75	25	45	75
Absolute Values					100.25	68.1	46.21	-0.66	-0.65	-0.73	0.23	-0.84	-1.2	0.7	1.07	1.4	160.48	232.2	238.63
Limit / Tol					2.5	2	1.5	0.6	0.5	0.5	0.6	0.5	0.5						
Limit / Tol					-2.5	-2	-1.5	-0.6	-0.5	-0.5	-0.6	-0.5	-0.5						
CheckZone	Status	dE*			dL*			da*			db*			dC*			dH*		
		25	45	75	25	45	75	25	45	75	25	45	75	25	45	75	25	45	75
Match to Std																			
Hauba_Centar	Fail	1.25	0.48	0.75	-2.63	-2.21	-1.72	-0.12	-0.19	-0.14	0.21	0.24	0.11	0.2	-0.03	-0.01	-0.14	-0.3	-0.17
Hauba_Desno	Fail	1.98	1.64	2.73	-2.78	-2.14	-1.68	0.04	-0.08	-0.06	-0.15	0.10	0.01	-0.07	-0.03	0.02	0.13	-0.13	-0.06
Hauba_Levo	Fail	0.28	1.29	1.03	-2.59	-2.15	-1.75	0.02	-0.06	-0.03	-0.12	0.05	0.03	-0.05	0	0	0.11	-0.08	-0.04
Krov_Desno_Nazad	Fail	2.22	1.39	1.63	-2.67	-2.18	-1.63	-0.15	-0.18	-0.14	0.42	0.37	0.14	0.33	-0.11	-0.03	-0.28	-0.39	-0.19
Krov_Levo_Napred	Fail	1.62	0.58	0.61	-2.80	-2.09	-1.66	-0.19	-0.27	-0.17	0.43	0.35	0.11	0.37	-0.02	0.01	-0.27	-0.43	-0.2
Poklopac_Rezervoara	Fail	2.75	2.02	1.99	-2.66	-2.13	-1.62	0.01	-0.08	-0.03	0.03	0.10	-0.05	0	-0.02	0.06	-0.03	-0.13	0
Pr_Desna_Vrata	Fail	0.68	1.22	0.87	-2.71	-2.12	-1.59	-0.09	-0.16	-0.10	0.26	0.27	0.12	0.2	-0.06	-0.05	-0.18	-0.3	-0.15
Pr_Desni_Blatobran	Fail	3.52	1.6	3.16	-3.58	-2.33	-1.82	-0.09	-0.15	-0.13	0.14	0.28	0.12	0.14	-0.08	-0.02	-0.1	-0.3	-0.17
Pr_Leva_Vrata	Fail	0.42	0.77	0.2	-2.81	-2.15	-1.67	-0.15	-0.18	-0.11	0.34	0.29	0.15	0.29	-0.06	-0.06	-0.22	-0.33	-0.17
Pr_Levi_Blatobran	Fail	3.12	1.7	2.82	-3.69	-2.38	-1.86	-0.04	-0.12	-0.08	0.07	0.21	0.04	0.06	-0.07	0.01	-0.05	-0.23	-0.09
V_Vrata_Desno	Fail	0.84	0.5	0.4	-2.61	-2.13	-1.71	0.01	-0.10	-0.08	-0.08	0.12	0.07	-0.03	-0.02	-0.01	0.08	-0.15	-0.11
V_Vrata_Levo	Fail	1.85	0.84	0.12	-2.58	-2.10	-1.73	0.18	0.02	0.02	-0.13	0.06	0.05	-0.21	-0.06	-0.05	0.07	-0.02	-0.01
Za_Desna_Vrata	Fail	0.84	1.37	1.22	-2.71	-2.18	-1.65	-0.15	-0.20	-0.12	0.29	0.30	0.16	0.25	-0.05	-0.06	-0.18	-0.35	-0.19
Za_Desni_Blatobran	Fail	0.31	1.21	0.55	-2.66	-2.17	-1.68	-0.06	-0.13	-0.05	0.17	0.17	0.05	0.13	-0.03	-0.02	-0.13	-0.21	-0.07
Za_Leva_Vrata	Fail	0.8	0.87	0.18	-2.74	-2.18	-1.71	-0.10	-0.16	-0.08	0.30	0.24	0.13	0.23	-0.06	-0.06	-0.21	-0.28	-0.14
Za_Levi_Blatobran	Fail	0.23	0.74	0.08	-2.65	-2.21	-1.66	-0.04	-0.11	-0.03	0.15	0.15	0.06	0.1	-0.04	-0.03	-0.12	-0.18	-0.06

Figure 4: The results of measurements of a non-compliant product.

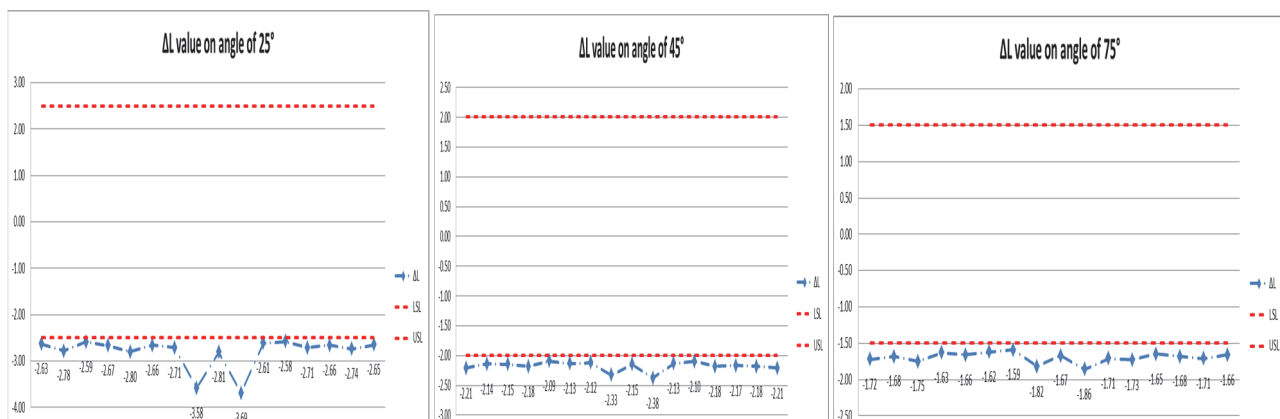


Figure 5: Distribution of measured values for the "specific color" L* characteristics for the angle of 25°, 45° and 75°.

Optional values indicate that the application of paint applications uniformed throughout the product, but that it is outside the set control limit (LSL - lower specific limit, USL - upper specific limit), (figure 5). Also, based on the collected data, it was found that the defect is chronic and is present only on the "specific color" of the vehicle, which accounts for 8,5 % of the total production (figure 6).

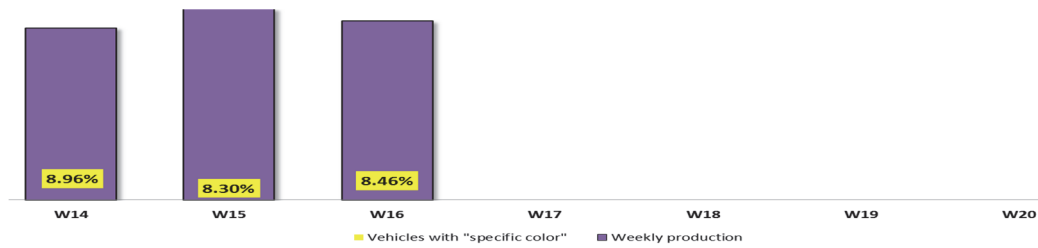


Figure 6: Percentage of product non-compliance in relation to production volume for 3 weeks is shown.

In the continuation of the analysis, the verification of all the basic elements related to the process of painting was carried out, taking into account the 4M analysis, that is, the causative agent of the problems associated with man, machine, method and material, what is shown in the chart.

Table 2: Verification of the basic elements of the process using 4M analysis.

4M	Activities	Status
MAN	Operator is following parameters of robots?	OK
	Operator is respecting AM cycle?	OK
	Operator checking parameters of spray booth?	OK
	Operator is checking parameters of BC and CC according to procedure?	OK
MACHINE	Robot bell?	OK
	Nozzles?	OK
	Shaping air ring?	OK
	Atomizer?	OK
	Dozing pump?	OK
	Pressure regulator?	OK
	Pump for mixing in preparation tank?	OK
	High tension controller?	OK
MATERIAL	Viscosity of material?	OK
	Expire data of material?	OK
	Temperature of material?	OK
	Spectrophotometry of material?	KO
METHOD	Paint preparation?	OK
	Tempering?	OK
	Application parameters?	OK
	Parameters of BC and CC booths?	OK
	Oven parameters?	OK
	Flash off BC1-BC2?	OK
	Method of measurement check?	OK

The discrepancy found during 4M verification was referred to direct material. When delivering paints for serial production, the supplier of materials performs the delivery of colored panels that are painted by simulating the industrial environment with the delivered color. Using "BYC MAC" four panels were measured for the last four deliveries for the specific parameters L , a , b where it was found that in the direct material there was a deviation from the specific parameters L^* and for the angles of 25° , 45° and 75° as shown in figure 7 (data is processed in the "Minitab").

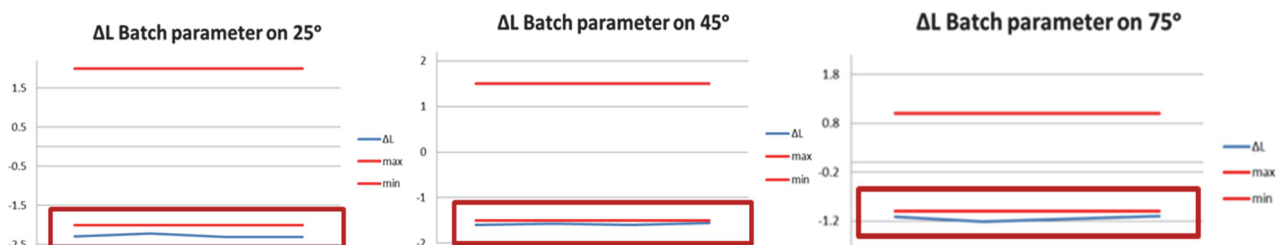


Figure 7: Results of color testing for the last four deliveries by suppliers.

4.2. Verification of actions and defying new activities.

After the report of non-compliance, preventive measures were carried out, i.e. color correction in the production system by adding additives, a re-measurement of the finished product was carried out (figure 8). As a definite solution, a modification of the formula for the preparation of paint in the production process of the supplier.

2h		Silver_Metalik			dE*			L*			a*			b*			C*			h								
D65/10		25			45			75			25			45			75			25			45			75		
Absolute Values																												
Limit / Tol																												
Limit / Tol																												
CheckZone																												
Status																												
		25			45			75			25			45			75			25			45			75		
SAMPLE 001		Pass	1.64	0.69	0.73	-1.55	-0.67	-0.32	0.06	-0.11	-0.03	0.54	-0.14	-0.05	0.28	0.18	0.6	-0.46	0	0.26								

12h		Silver_Metalik			dE*			L*			a*			b*			C*			h								
D65/10		25			45			75			25			45			75			25			45			75		
Absolute Values																												
Limit / Tol																												
Limit / Tol																												
CheckZone																												
Status																												
		25			45			75			25			45			75			25			45			75		
Match to Std		Pass	0.42	0.11	0.21	0.13	0.12	-0.11	0.01	-0.07	0	0.03	0.09	0.02	0	-0.02	-0.01	-0.04	-0.11	-0.01								
SAMPLE 001		Pass	0.42	0.11	0.21	0.13	0.12	-0.11	0.01	-0.07	0	0.03	0.09	0.02	0	-0.02	-0.01	-0.04	-0.11	-0.01								

24h		VR 612 Silver_Metalik			dE*			L*			a*			b*			C*			h								
D65/10		25			45			75			25			45			75			25			45			75		
Absolute Values																												
Limit / Tol																												
Limit / Tol																												
CheckZone																												
Status																												
		25			45			75			25			45			75			25			45			75		
Match to Std		Pass	0.13	0.61	0.23	0.42	0.6	0.23	0.03	-0.06	0.01	-0.03	0.07	-0.03	-0.04	-0.01	0.02	0.02	-0.09	0.02								
SAMPLE 001		Pass	0.13	0.61	0.23	0.42	0.6	0.23	0.03	-0.06	0.01	-0.03	0.07	-0.03	-0.04	-0.01	0.02	0.02	-0.09	0.02								

that have no impact, defined as process noises, air humidity inside the booth and temperature of the spray booth which together form one process system that affects the formation of colorimetry of products.

4.3.1 Hypothesis test

In the continuation of the work, minimum and maximum input parameter values for all factors are defined (Table 3). Since there are 8 factors in total on two levels with two repetitions in case a full testing plan is applied, DOE will be $2^8=256$, with two repetitions which is 512 testings in total.

Table 3: display of the minimal and maximum operating parameters (two levels) of input factors.

FACTORS	ACRONYM	MIN Value	MAX Value
Paint Value BC1	PV-BC1	165 ml	180 ml
Shaping Air BC1	SA-BC1	80	120
Turbine Speed BC1	TS-BC1	40000 rpm	60000 rpm
High Voltage BC1	HV-BC1	40 kV	50kV
Paint Value BC2	PV-BC2	110 ml	170 ml
Shaping Air BC2	SA-BC2	380	390
Turbine Speed BC2	TS-BC1	40000 rpm	60000 rpm
High Voltage BC2	HV-BC2	40 kV	50 kV

Taking into account the total number of necessary tests to perform full testing, cost-effectiveness is called into question, time it takes to spend on testing, therefore, it was decided to implement a difficult move in order to eliminate factors that do not have statistical significance.

That is, zero hypothesis and alternatives with a reliability index $\alpha = 0.05$ (if there is $p < 0.05$ statistical difference, that is, it represents the probability that hypothesis may be correct) is defined, as shown in Table 4.

Table 4: Defining a zero and alternative hypothesis.

FACTORS	H_0	H_1
PV-BC1	There is no impact PV BC1 on ΔL parameter	There is impact PV BC1 on ΔL parameter
SA-BC1	There is no impact SA BC1 on ΔL parameter	There is impact SA BC1 on ΔL parameter
TS-BC1	There is no impact TS BC1 on ΔL parameter	There is impact TS BC1 on ΔL parameter
HV-BC1	There is no impact HV BC1 on ΔL parameter	There is impact HV BC1 on ΔL parameter
PV-BC2	There is no impact PV BC2 on ΔL parameter	There is impact PV BC2 on ΔL parameter
SA-BC2	There is no impact SA BC2 on ΔL parameter	There is impact SA BC2 on ΔL parameter
TS-BC2	There is no impact TS BC2 on ΔL parameter	There is impact TS BC2 on ΔL parameter
HV-BC2	There is no impact HV BC2 on ΔL parameter	There is impact HV BC2 on ΔL parameter

On the sample of the 14 shells, the measured colorimetry status for parameter L^* was subsequently changed for each of the 8 factors and compared with the first measurement using t-test (all data is processed in the "Minitab").

The results of the measurement of the base paint 1 (Basic Coat 1 – BC1) booth for factors "Paint Value", "Shaping Air", "Turbine Speed" and "High Voltage", after measurement showed that all factors have a significant impact on the parameter L^* except for the "Turbine Speed", i.e. the obtained values $p < 0.05$, as shown in figure 11.

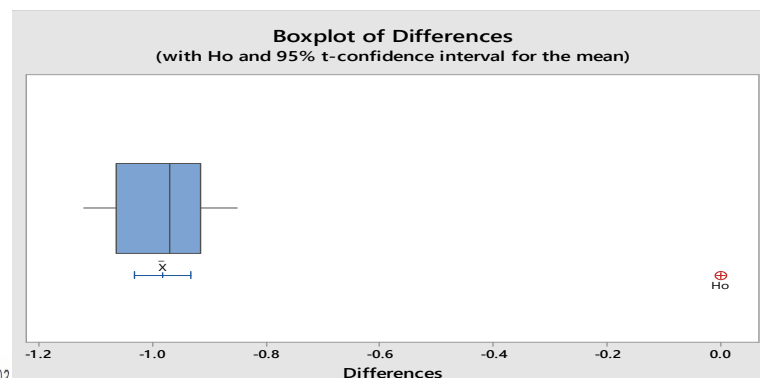
Paired T-Test and CI: Before, After for Paint Value BC1

Paired T for Before - After

	N	Mean	StDev	SE Mean
Before	14	-3.4357	0.0804	0.0215
After	14	-2.4529	0.0578	0.0155
Difference	14	-0.9829	0.0853	0.0228

95% CI for mean difference: (-1.0321, -0.9336)

T-Test of mean difference = 0 (vs \neq 0): T-Value = -43.09 P-Value = 0.002



Paired T-Test and CI: Before, After for Shaping

Paired T for Before - After

	N	Mean	StDev	SE Mean
Before	14	-3.4357	0.0804	0.0315
After	14	-2.6245	0.0725	0.0194
Difference	14	-0.8113	0.1019	0.0272

95% CI for mean difference: (-0.8701, -0.7524)

T-Test of mean difference = 0 (vs \neq 0): T-Value = -29.80 P-Value = 0.012**Paired T-Test and CI: Before, After for High Voltage BC1**

Paired T for Before - After

	N	Mean	StDev	SE Mean
Before	14	-3.436	0.080	0.021
After	14	-1.364	0.456	0.122
Difference	14	-2.072	0.489	0.131

95% CI for mean difference: (-2.354, -1.790)

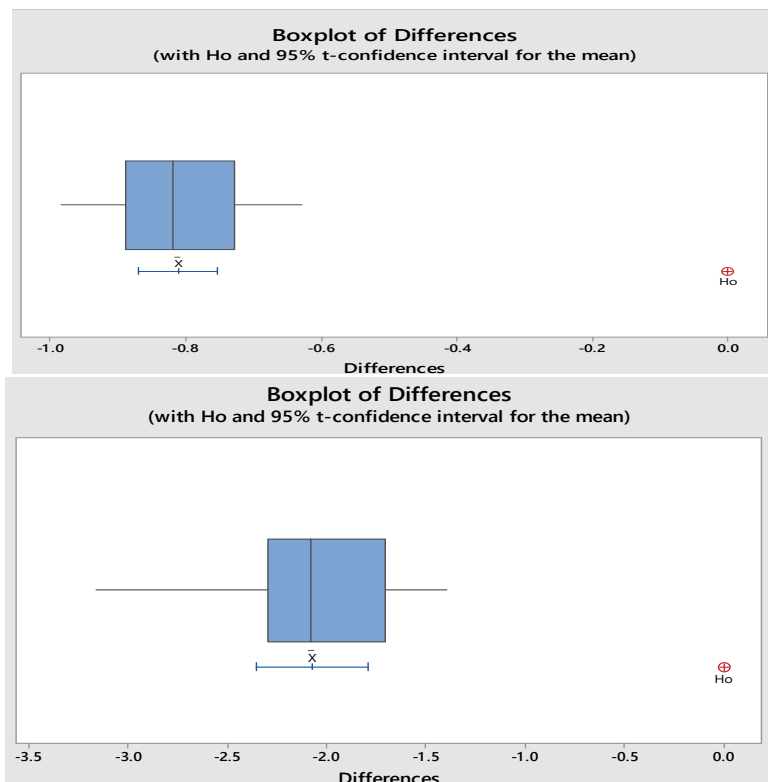
T-Test of mean difference = 0 (vs \neq 0): T-Value = -15.86 P-Value = 0.038

Figure 11: Display of results and t-tests for factors inside the base color 1 booth (Basic Coat 1-BC1).

The results of the measurement of the base paint 2 (Basic Coat 2 – BC2) booth for factors “Paint Value”, “Shaping Air”, “Turbine Speed” and “High Voltage”, after measurement showed that only factor “Paint Value” has a significant influence on the parameter L^* , that is the obtained values $p < 0.05$, as shown in figure 12.

Paired T-Test and CI: Before, After for Paint Value BC2

Paired T for Before - After

	N	Mean	StDev	SE Mean
Before	14	-3.436	0.080	0.021
After	14	-1.395	0.467	0.125
Difference	14	-2.041	0.499	0.133

95% CI for mean difference: (-2.329, -1.752)

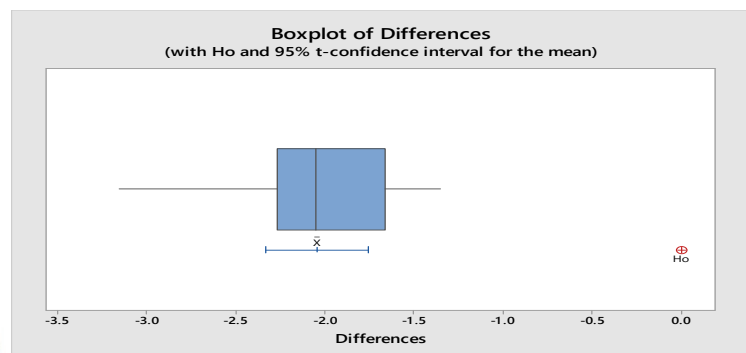
T-Test of mean difference = 0 (vs \neq 0): T-Value = -17.56 P-Value = 0.021

Figure 12: Display of t-test results for factors inside the base paint 2 booth (Basic Coat 2 – BC2).

4.3.2 Fractional Factorial

After the hypothesis test, all relevant input factors that have statistical significance in terms of parameter L^* have been identified. These factors will be the basis in the future development of the DOE project and creation of the “Fraction Factorial”.

Within the program “Minitab”, launching of the DEO has been executed, as shown in figure 13, with an option that the planned tests “ $1/2$ fraction” i.e. “fraction factorial” by two repetitions would increase the number of tests performed and the sensitivity of the experiment itself in order to identify a correlation between factors [14].

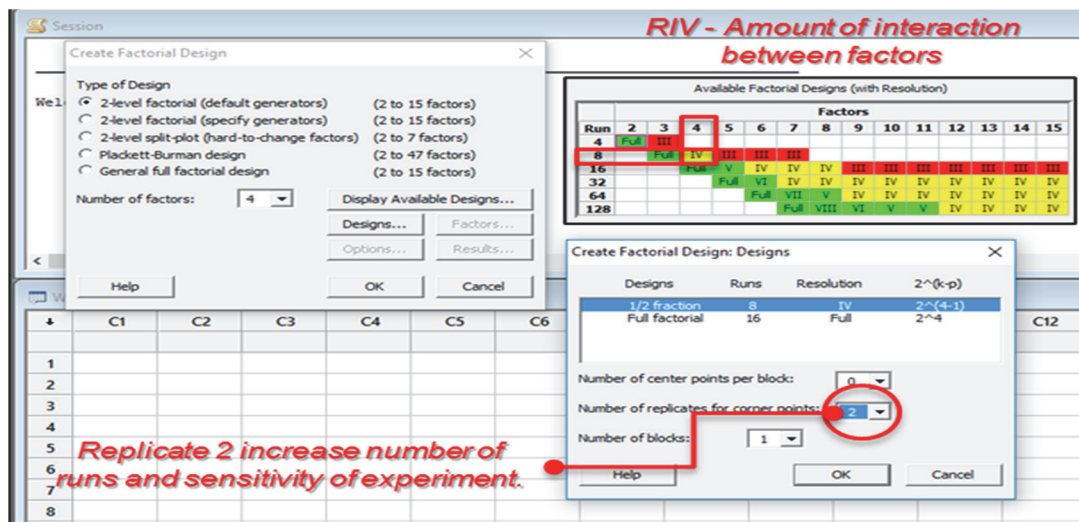


Figure 13: The experiment setting within the program.

Randomization to eliminate potential influence of unknown noise factors

Testing order and parameter combination

Results of test

Run	C1	C2	C3	C4	C5	C6	C7	C8	C9
	StdOrder	RunOrder	CenterPt	Blocks	PV-BC1	SA-BC1	HV-BC1	PV-BC2	Delta-L
1	14	1	1	1	180	80	50	170	-1.14
2	7	2	1	1	165	120	50	110	-2.41
3	4	3	1	1	180	120	40	110	-1.14
4	15	4	1	1	165	120	50	170	-2.62
5	16	5	1	1	180	120	50	170	-1.37
6	11	6	1	1	165	120	40	170	-3.41
7	3	7	1	1	165	120	40	110	-3.86
8	5	8	1	1	165	80	50	110	-1.71
9	9	9	1	1	165	80	40	170	-2.48
10	6	10	1	1	180	80	50	110	-1.39
11	13	11	1	1	165	80	50	170	-1.67
12	2	12	1	1	180	80	40	110	-2.74
13	12	13	1	1	180	120	40	170	-2.26
14	1	14	1	1	165	80	40	110	-2.65
15	8	15	1	1	180	120	50	110	-1.50
16	10	16	1	1	180	80	40	170	-3.15

Figure 14: The test setting, parameters and the measured values for the L* parameter.

In the figure 14 are shown the basic elements of the test setting, the test sequence (column C2), factor parameters (column C2:C8) as well as the measured values for each of the tests. (column 9).

4.4. Perceiving the obtained results and optimizing the process

Based on the regression of factors, i.e. analysis, the variations between factors, it was found that the factors of the value of color "paint value", as well as the voltage "high voltage" have the greatest influence on the output parameters of the testing of L* (figure 15) [15].

Factorial Regression: Delta-L versus PV-BC1, SA-BC1, HV-BC1, PV-BC2

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	8.7864	1.25520	5.80	0.012
Linear	4	6.4205	1.60513	7.42	0.008
PV-BC1	1	2.3409	2.34090	10.82	0.011
SA-BC1	1	0.1681	0.16810	0.78	0.404
HV-BC1	1	3.8809	3.88090	17.95	0.003
PV-BC2	1	0.0306	0.03062	0.14	0.716
2-Way Interactions	3	2.3659	0.78862	3.65	0.064
PV-BC1*SA-BC1	1	2.2052	2.20523	10.20	0.013
PV-BC1*HV-BC1	1	0.0006	0.00063	0.00	0.958
PV-BC1*PV-BC2	1	0.1600	0.16000	0.74	0.415
Error	8	1.7300	0.21625		
Total	15	10.5164			

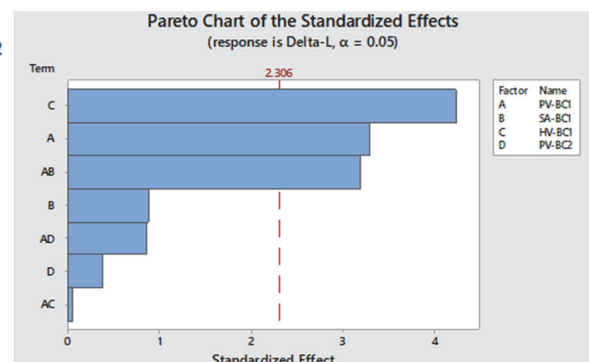


Figure 15: Regression of factors and their influence on the output parameter of testing L*

Based on all collected data within the software program "Minitab", a platform for optimizing parameters was launched in order to achieve the best results, that is, to make the output by optimizing the output value as close as possible to nominal requirements "Hit a target value" and to achieve as much of the desired index "Desirability Index-a" as possible, as shown in figure 16.

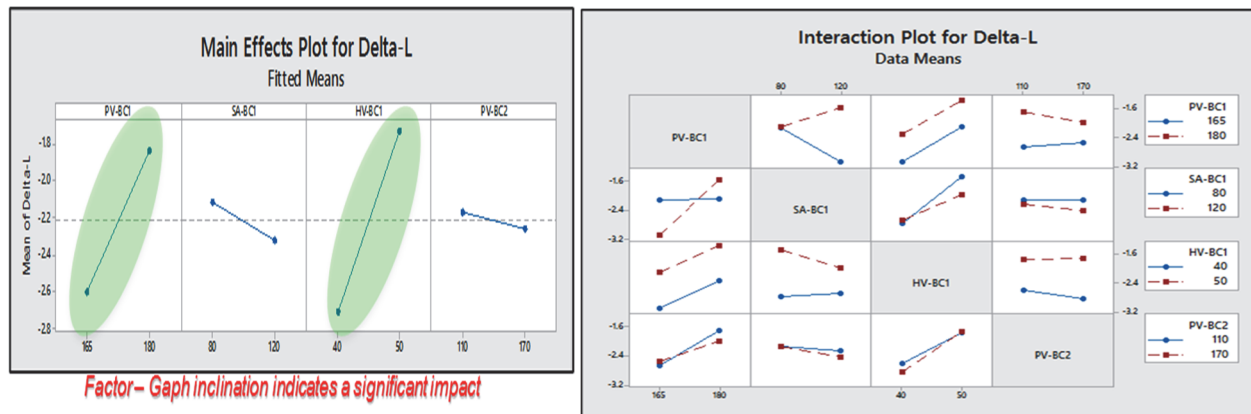


Figure 16: The effect of plot the influence of parameters, their interaction, relative to the output parameter of testing L*.

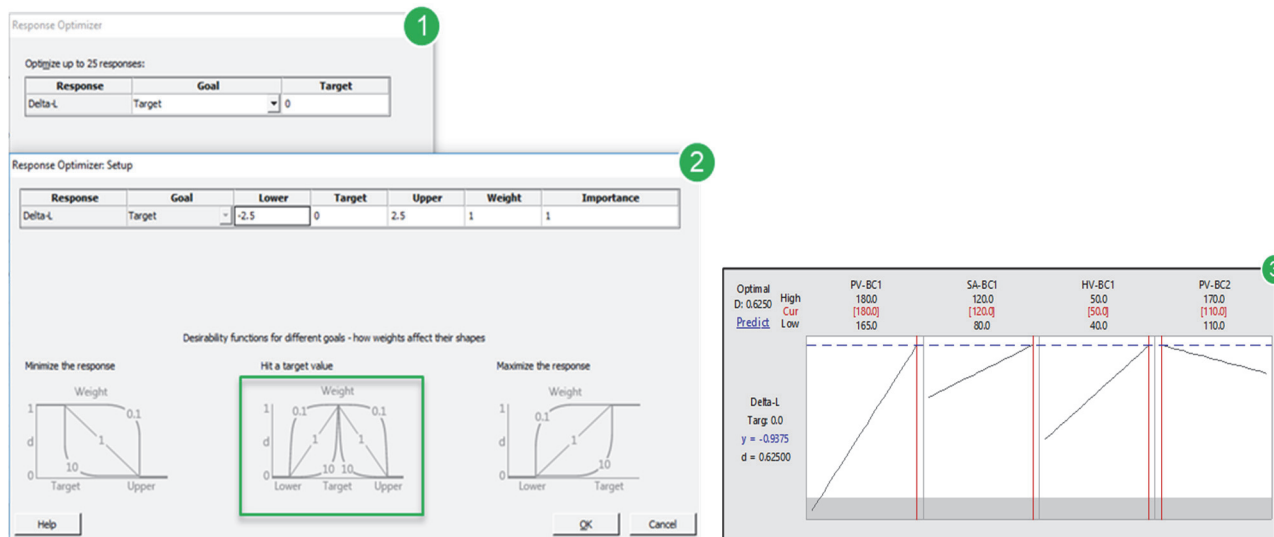


Figure 17: Parameter optimization using the "Minitab" software package

4.5. Product verification based on process optimization

After the software modification, a physical modification of the process parameters was also performed, as shown in the table 5.

Table 5: Setting of process parameters after more applications of this optimization are completed.

FACTORS	ACRONYM	RUN TEST1	RUN TEST 2
Paint Value BC1	PV-BC1	180 ml	
Shaping Air BC1	SA-BC1	120	
Turbine Speed BC1	TS-BC1	40000 rpm	60000 rpm
High Voltage BC1	HV-BC1	50kV	
Paint Value BC2	PV-BC2	110 ml	
Shaping Air BC2	SA-BC2	380	390
Turbine Speed BC2	TS-BC1	40000 rpm	60000 rpm
High Voltage BC2	HV-BC2	40 kV	50 kV

Performing a confirmatory experiments is the rule of completion of DOE, in the case of a partial experiment it is even essential. The validation of the experiment must include and eliminate factors whose main goal is to avoid wrong decisions due to the small number of tests performed. Figure 18 shows the validation results of that test [16].

RUN TEST 2

VR612 Silver_Metalik		dE*			L*			a*			b*		
D65/20		25	45	75	25	45	75	25	45	75	25	45	75
Absolute Values					100.25	68.1	46.21	-0.66	-0.65	-0.73	0.23	-0.84	-1.2
Limit / Tol					2.5	2	1.5	0.6	0.5	0.5	0.6	0.5	0.5
Limit / Tol					-2.5	-2	-1.5	-0.6	-0.5	-0.5	-0.6	-0.5	-0.5
CheckZone	Status	dE*			dL*			da*			db*		
		25	45	75	25	45	75	25	45	75	25	45	75
Match to Std													
Hauba_Centar	Pass	1.74	0.59	1.31	0.12	0.38	0.74	-0.01	-0.10	-0.05	0.02	0.09	0.02
Hauba_Desno	Pass	0.70	1.45	1.57	-0.15	1.67	1.40	0.09	-0.06	-0.04	-0.06	0.05	-0.12
Hauba_Levo	Pass	0.35	1.29	1.05	0.29	1.32	1.05	0.03	-0.07	-0.06	-0.12	0.05	-0.02
Krov_Desno_Nazad	Pass	0.91	1.14	0.85	-0.27	1.36	1.29	-0.06	-0.13	-0.08	0.09	0.15	0.02
Krov_Levo_Napred	Pass	0.51	1.07	0.53	-0.37	0.40	0.59	-0.08	-0.18	-0.09	0.30	0.27	0.12
Poklopac_Rezervoara	Pass	1.19	1.62	1.53	-0.15	1.04	1.21	0.02	-0.13	-0.06	0.00	0.07	-0.03
Pr_Desna_Vrata	Pass	0.24	1.91	1.30	-0.12	1.20	0.87	-0.05	-0.15	-0.13	0.15	0.28	0.13
Pr_Desni_Blatobran	Pass	3.59	2.41	3.80	-0.84	1.60	1.38	-0.03	-0.16	-0.12	0.06	0.22	0.05
Pr_Leva_Vrata	Pass	1.17	1.29	1.15	0.11	0.70	0.06	-0.07	-0.11	-0.06	0.15	0.21	0.08
Pr_Levi_Blatobran	Pass	2.74	1.81	2.89	-0.80	1.71	1.31	-0.03	-0.12	-0.08	0.00	0.16	0.04
V_Vrata_Desno	Pass	0.49	1.20	1.00	0.43	0.48	0.40	0.08	-0.06	-0.05	-0.13	0.07	0.02
V_Vrata_Levo	Pass	1.20	1.32	0.52	0.16	0.86	0.11	-0.01	-0.14	-0.07	-0.02	0.13	0.08
Za_Desna_Vrata	Pass	0.71	1.99	1.22	0.67	1.35	1.23	-0.01	-0.14	-0.11	0.12	0.17	0.13
Za_Desni_Blatobran	Pass	0.91	1.15	0.77	-0.36	1.21	0.56	-0.07	-0.13	-0.04	0.14	0.14	0.01
Za_Leva_Vrata	Pass	0.32	1.81	1.33	-0.27	0.84	0.09	0.01	-0.12	-0.09	0.09	0.27	0.12
Za_Levi_Blatobran	Pass	0.18	2.07	1.29	0.01	0.73	0.03	-0.04	-0.10	-0.04	0.13	0.16	0.04

Figure 18: Positive results of validation of new process parameters.

Table 5: new setup of machine was done based on the test and observed results.

FACTORS	BEFORE	AFTER	FACTORS	BEFORE	AFTER
PV-BC1	165 ml	180 ml	PV-BC2	170 ml	110 ml
SA-BC1	80	120	SA-BC2	380	380
TS-BC1	40000 rmp	40000 rmp	TS-BC1	40000 rmp	40000 rmp
HV-BC1	40 kV	50 kV	HV-BC2	50 kV	50 kV

	1st	2st
	ΔL	ΔL
Pr_Desni_Blatobran	-0,82	-0,84
Pr_Levi_Blatobran	-0,78	-0,8

5. CONCLUSION

World-class production is an operational strategy that, if well applied, gives a new dimension of production that corresponds to the rapid inclusion of new high-quality products. In this paper WCM strategy was applied to optimize the process of painting the shell of vehicles in FCA Serbia Ltd.

The practical contribution of the paper is related to problem solving of inadequate color matching during serial production on the example of production of a "Fiat 500L" passenger vehicle was solved. By applying DOE, through the Kaizen method, the non-compliances of colorimetry were eliminated and the process of painting the shell of the vehicle was improved, after which the verification of proposed solutions and optimization of the mentioned process were carried out.

The theoretical contribution is reflected in the definition of the world class manufacturing (WCM) methodology for the elimination of nonconformities in the automotive industry. The limitations of the work are reflected in the small number of repetitions of the experiment, so future directions of research should be in this sense.

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