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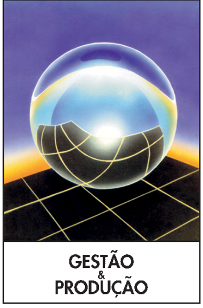

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Use of the robust design methodology for identification of factors that contribute to the intensity of the "orange peel" aspect on painted bumper surfaces

Uso do projeto robusto para identificação de fatores que contribuem para a intensidade do aspecto de "casca de laranja" em superfície de para-choques pintados

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Abstract: Even with the considerable development of techniques for automotive paint in recent decades, the bumper is a car part that still has many problems related to the aspect of its painted surface. This study aimed to identify the clear coat application factors that affect on the intensity of orange peel appearance on painted bumpers surfaces and offer an optimum design of factors through the robust design methodology. In this research conducted in automated paint sector of a bumper company, the robust design helped in the identification of variability cause in a production process by applying an experiment and statistical techniques, in an agile and with little waste material way. The experiment tested various combinations of levels of the clear coat application factors (speed, flow, revolution per minute, operation voltage, atomizing air pressure) in the bumper samples. The intensity of the orange peel on coated surfaces samples was measured by a Wave Scan device that provides the wavelength reading as a function of two measures: Long Wave and Short Wave. The main results obtained by variance analysis of noise signal ratio showed that the factors that have significant effects on the value of the Short Wave response wavelength are: revolution per minute, operation voltage and the interactions flow*operation voltage and speed*operation voltage. The factors that significantly affected the response value of the Long Wave wavelength are: flow, atomizing air pressure, revolution per minute, operation voltage and the interaction speed*operation voltage. As a result of analysis of the noise signal mean, it is presented the factors optimum design: speed = 920 m / s; flow = 160 ml/min; atomizing air pressure = 180 bar; revolution per minute = 90 revolutions / minute; operation voltage = 180 kilovolts.

Keywords: Automotive paint; Orange peel; Bumpers; Robust design.

Resumo: *Mesmo com a evolução considerável das técnicas de pintura automotiva nas últimas décadas, o para-choque é uma autopeça que ainda tem diversos problemas relacionados ao aspecto da sua superfície pintada. O objetivo deste artigo foi identificar os fatores de aplicação do verniz que interferem na intensidade do aspecto de casca de laranja em superfícies de para-choques pintados e propor uma combinação ótima dos fatores através da metodologia do projeto robusto. Na pesquisa realizada no setor de pintura automatizada de uma empresa de para-choques, o projeto robusto auxiliou na identificação das formas de variabilidade do processo de produção através da aplicação de um experimento e de técnicas estatísticas, de forma ágil e com pouco desperdício de material. O experimento testou várias combinações dos níveis dos fatores de aplicação do verniz (velocidade, vazão, rotação por minuto, alta tensão, ar modelador) em amostras de para-choques. A intensidade da casca de laranja em superfícies pintadas de verniz das amostras foi medida pelo equipamento Wave Scan, o qual fornece a leitura do comprimento de onda em função de duas medidas: Short Wave e Long Wave. Os principais resultados obtidos através da análise da variância da razão sinal ruído revelaram que os fatores que têm efeitos significativos no valor resposta do comprimento de onda Short Wave são: rotação por minuto, alta tensão além das interações vazão*alta tensão e velocidade*alta tensão. Já os fatores que afetaram significativamente o valor resposta do comprimento de onda Long Wave são: vazão,*

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*ar modelador, rotação por minuto, alta tensão e a interação velocidade*alta tensão. Como resultado da análise das médias do sinal ruído, foi apresentada neste trabalho a combinação ótima dos fatores: velocidade = 920 m/s; vazão = 160 mililitros/minuto; ar modelador = 180 bar; rotação = 90 rotações/minuto; alta tensão = 180 quilovolts.*

Palavras-chave: *Pintura automotiva; Casca de laranja; Para-choque; Projeto robusto.*

1 Introduction

The competitive marketplace in the automotive sector has transformed the global economy since the decade of 70, when the western vehicle manufacturer companies started to lose market power control for Japanese competitors (Costa & Queiroz, 2000, p. 27). Also, at the end of this decade, assembly plants passed through a process of "vertical disintegration", inverse way to the vertical integration, which meant the loss of the responsibility and control of all the productive processes of a product, i.e., outsourced companies got involved in the process. The result was the increase on the complexity and significance of the relationship with the suppliers and the requirements related to the supplied products (Vanalle & Salles, 2011, p. 238).

In Brazil, the competition in the automotive sector became very tight after the opening of the domestic market for import automobiles in 1992 and the coming of more foreign assembly plants, beyond traditional GM, Ford, Volkswagen and Fiat (Pierozan, 2001, p. 13). The competition among the biggest automobile industries stimulated the development of technologies in the processes related to the productive system. For example, the automotive painting followed this scenario of quality improvement, since it was important for the assembly plants that the produced cars could have differentiated paints that would fulfill the requirements regarding to brightness, color tones, durability to corrosion, break-ups, and scratches, among others damaging agents. However, the technical improvement within this painting field cannot be attributed only to the will of the companies in improving its processes. The legislation has a great share of responsibility over these changes, as the requirements grounded by environment, health and safety regulations that became valid to stimulate the responsibility of the companies regarding the material toxicity and its recycling, mainly substances as solvent and paints (Jurgetz, 1995, p. 53).

The competition in the Brazilian automotive industry contributed for the installation of auto parts factories in the country, which improved its processes due to the interest of the assembly plants in getting high-level suppliers in the market. The painting line of the bumper manufacturer companies is an example. Beyond compact systems with low time of the product in the painting process, automatized and simplified processes are also among the requirements that the car assembly plants imposed to the painting sector (Mirrha, 2013, p. 61).

Parallel to the concern regarding the process development and a faster cycle time in production, there is the necessity to produce products with quality. Before the purchase decision, the client has the tendency to equate the value of quality, cost and delivery period (Montgomery & Runger, 2012).

> The painting of an automobile is without a doubt one of the most visible and concrete quality requirements and it's considered of great importance for the majority of the buyers (Pierozan, 2001, p. 13).

Therefore, the role that the quality fills as a decision factor shows its competitive value and becomes a differential for the ability to control the product quality and to guarantee a steady process. As such, the quality of a product can be assured through the minimization of the variability on the process parameters in a production line (Samohyl, 2009).

In the automotive industries, statistical methods are widely used by the engineering for the control and improvement of the quality. According to Samohyl (2009), the application of the statistical concepts in the quality control in industries was initiated through Walter Shewhart, in the decade of the 1920s, in the United States. However, the greatest promoter of the benefits related to statistics applied in factories was William Edwards Deming who diffused the Statistical Quality Control (SQC) in the assembly plants of Japan (Chiavenato, 2004). The statistical process control (SPC) is an efficient tool for a process that searches for stability and improvements through the reduction of the operations variability (Montgomery & Runger, 2012). As for Monks (1987), statistical tools, such as control graphs are vital for the control of processes. Therefore, the challenge is to use the statistical concepts in the objective to reach improvement and comprehension of the process, not only to control the processes. For this purpose, the experiment planning techniques are sufficiently useful in the resolution of engineering problems. From the premise that all the processes are formed by controllable variable, through a planning, experiments can be applied to determine which variables have greater influence in the performance of the process (Montgomery & Runger, 2012, p. 338). The robust project is a method that reduces the number of experiments to discover an ideal combination among the controllable variables over the process, providing the quality improvement with reduced costs (Chen & Chuang, 2008, p. 668).

In this context, this work sought to answer the following of problem research: Which are the factors that interfere in the appearance of the orange peel on painted bumper surfaces?

The hypothesis of work was that there was an excellent combination of controllable factors for the varnish application in bumpers and that through the Robust Project methodology it would be possible to identify it.

Aiming to validate this hypothesis, this article presents the varnish application factors that interfere on the intensity of the orange peel aspect on painted bumper surfaces.

2 Quality control in automotive painting

The requirements of the customers for *Total Quality Management (TQM)* and ISO certification made the auto parts painting industry implement and intensify the quality control in its process (Weiss, 1997, p. 223).

The finished product of the automotive painting process involves a complex range of requirements. Among them are the brightness, color, durability, breaking strength, paint layers adhesion, and resistance to scratches (Jurgetz, 1995, p. 53). In practice, all the automotive coating surface has an intensity of the orange peel, even a minimum one (Adamsons, 2000, p. 1382). When this intensity exceeds the acceptable values, many quality requirements of the parts are affected. The intensity of the orange peel surfaces influence in the properties and functional characteristics of the product is a distrust of the industry, that searches to characterize the problem (Najjar et al., 2005, p. 6088).

The quality control of the brightness and the intensity regarding the orange peel on the part can be executed through a device that measures the existing wave length on the surface of the painted part and the intensity of reflected light. The device Wave Scan has the function to measure the appearance of the painting coating. Through the wave length, the equipment calculates the distinction of the image (*Distinctness of Image*), this means, it measures the quality of an object-image that is reflected by the surface of the part (Domenico & Henshaw, 2012, p. 676).

According to Adamsons (2012, p. 751), it is possible to identify the relation between the reduction of the brightness and the loss of image distinction. The Wave Scan is capable to measure both, the intensity of the orange peel aspect and the brightness of the part. The instrument is equipped with a reflector that measures the intensity of the reflected light. By means of a light LED (*Light Emitting Diode*) the surface of the part is illuminated in an angle of 20°. The reflection is captured by the lens of a device and then measured (Domenico & Henshaw, 2012, p. 676). Figure 1 illustrates the concepts of brightness, orange peel and *DOI* (*Distinctness of Image*).

2.1 Types of quality defects in the automotive painting

The challenge in a painting line is to keep the application in order to guarantee the part aspect quality and the requirements of the client regarding some quality parameters. However, many application problems can be identified in a line of industrial painting process. Some painting problems can be noticed during the application of paint coatings, other ones are only detected after the cure of the paint layers. According to Carvalho (1993, p. 47), the imperfections referring to paint composition, preparation and application process are frequent.

In order to study the defects proceeding from the painting process, technologies of microscopy measurement are used for the analysis of these imperfections that appear on the painted surface. Thus, through microscopy it is possible to perceive changes in the coating. The images generated by the microscope can be generated through the surface or the cross-section view (Adamsons, 2012, p. 745).

Based in the considerations made by Carvalho (1993, p. 47-57), Fazenda (2005, p. 712-718) and Pierozan (2001, p. 80-83), some of the main defects related to the industrial painting will be described to follow:

- **Dripping:** The dripping occurs due to an accumulation of paint in vertical surfaces. The dripping may occur with any type of substance, primer, base or varnish;

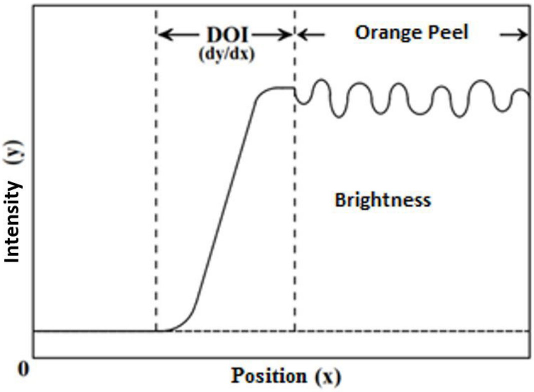


Figure 1. Characteristics of the aspects used to monitor alterations of the automotive systems. Source: Adapted from Adamsons (2000, p. 1365).

- **Orange Peel:** The orange peel, as it says, refers to the same appearance as the surface of an orange peel. In this case the unevenness of the paint layer occurs;
- **Blistering:** It's an application problem which looks similar to small blisters that appear on the surface of the part after the paint application and drying. The small blisters are caused by the disordered evaporation of the solvent in the paint through the paint coating;
- **Displacement:** It's about the loss of adhesion of a layer with the other, or a layer with the substrate surface;
- **Spot:** It refers to the non-uniformity of the color in the surface of the painted part. It's easily more perceived in parts painted with metallic color than in parts with solid color due to the aspect of "shade" that it presents in the regions of the surface;
- **Craters:** It is an application problem that presents depressions on the surface of the part which can expose the under-layers. The craters that are displayed in the paint film are formed by blisters, which after being breached, cannot be leveled anymore;
- **Impurities:** They are particles proceeding either from the painting system itself or the environment which get housed in the surface the unit before the cure of the paint. The impurities can appear in any layer of the paint coating.

3 Design of experiments

The statistics is very requested in situations wherein a great amount of information exists and needs to be analyzed. However, it is at the moment of the design of experiments that the statistical activities are highlighted. It is at this moment that the data collection is made and any simple planning error can cause misleading conclusions in the final stage of data analysis (Barros et al., 2010, p. 19).

Planned experiments based on statistics enhance the development of experimental process and, being supported by statistical techniques during the data collection and analysis, result in the scientific objectivity in favor of the problem resolution (Montgomery & Runger, 2012, p. 339). The design of experiments is a capable scientific method to identify and associate the ideal levels of the factors in a process in order to improve the performance and the capacity of production (Muhammad et al., 2013, p. 1175). In the process of design and analysis of experiments, the statistical techniques assist in the identification of factors (parameters) that interfere in the characteristics of the quality, i.e., in the response variable (Costa et al., 2005, p. 16).

A statistics technique of the design of experiments is the Robust Project, which provides a way to identify the significant factors of a process with a reduced number of experiments.

3.1 Robust project methodology

The methodology of the Robust Project was developed by the Japanese engineer Genichi Taguchi and introduced to great North American companies in the decade of 1980s (Montgomery, 2005, p. 464).

The foundation of the robust project is the minimization of the variability of the products and processes with the objective to improve the quality and the reliability of the same ones. The methodology developed by Taguchi uses the delineation of experiments to determine an ideal configuration for the parameters of the process, as well as, to analyze the existing interactions between the controllable factors (Lai et al., 2005, p. 446).

When compared with others statistical techniques, the robust project has the attainment of results in reduced time and cost as main advantage (Muhammad et al., 2013).

According to the Taguchi methodology, the non-controllable variables are called the noise factors (Kim et al., 2004, p. 56). These factors represent anything that is responsible for causing interferences in the performance of a functional characteristic in a product. According to Arvidsson & Gremyr (2008, p. 26), the noise is a simple variation source that deviates a responsible parameter for the characteristic of quality of the target value and induces the loss. The more indicated level for a parameter, or the combination between them, is established according to the reduction of the noises of a functional characteristic of the product.

Over the two fields that the quality engineering control works on, out of the production line (off- line quality control) and inside of the production line (On-line quality control), it is possible to detect noises. The different sources in which a noise can be detected made appropriate their categorization in the following way (Arvidsson & Gremyr, 2008, p. 27; Ross, 1991, p. 201): External noises, Internal Noises and Unit-to-Unit Noises.

The external noises are the factors that cause variation and have environment origin, which come from outside affect the product. For example, temperature, humidity, pressure, time and even human.

The internal noises are responsible for the variability that occurs in the interior of the product. They are the internal changes in the product or process which are resulted from the deterioration of the performance. The current of a battery and the mileage of a car are examples of internal noises. Both the external noises and the internal noises are only detected by the quality control out of the production line.

The noises called unit-to-unit noises are resulted from the incapacity of a manufacture process to produce identical units. The raw material of a product and processes without standardization are the biggest sources of this type of noise. Regarding the unit-to-unit noises, they can be detected by the off-line and on-line quality control.

For the benefit of optimum performance of the experiment, it is important to classify the factors properly. These factors can be divided in five groups (Mori, 1990, p. 91).

- Control factors: They are factors wherein it is possible to establish the levels and keep them. For example: Elements of an electric circuit;
- Indicative Factors: They are factors which levels can be attributed. However, the highest levels do not make sense if applied in the experiment. For example: the difference in the use condition of a product;
- Block factors: They are factors wherein levels can be attributed, but no technical verification exist in order to apply highest levels. These factors are classified to prevent their effects to be mistaken for the control factors effects. For example: new machinery and new batches;
- Supplemental factors: Factors used only to register the experimental and environmental conditions;
- Noise factors: They are factors which the values cannot be determined nor kept. They influence in the results of the experiment.

4 Research method

This research is classified as quantitative and explanatory. The technical procedure used in this work was the experiment. An experiment is lead by a researcher that by making the use of hypotheses identifies the relation between the variables. The planned control of the independent variables makes the researcher able to analyze the effect in the dependent variable (Miguel et al., 2010, p. 48).

The chosen company for the development of this research is a German multinational manufacturer of plastic components for automobiles, supplier for the main worldwide assembly plants. It has three industries in South America, being one in Mexico and two in Brazil. The main component produced is the bumper. The average production is 2500 bumpers/day. The processes that involves the production of bumpers are: injection, painting and assembly. The painting line of this industry of plastic components has a variety of 20 models of bumpers, which can be painted in 10 different colors each.

For the development of the research, the robust project method was taken, which involved eight stages that are classified in the following phases: planning, execution and analysis (Bernardin, 1994, p. 38; Kumar et al. 1996, p. 89; Lai et al., 2005, p. 449; Wu & Chen, 2005, p. 2407). The stages carried through this research are illustrated in Figure 2.

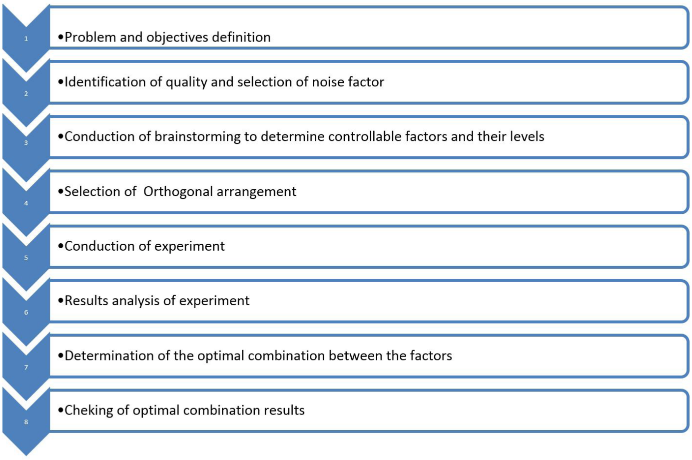


Figure 2. Stages of the robust project. Source: The authors (2015).

The planning phase involved four stages of the robust project method. The first stage refers to the problem and objective definition. At this stage, the impact of the orange peel problem in the bumper painting line was presented and the objectives to identify the factors that interfere in the intensity of the problem were defined. The second stage was the identification of the quality characteristic and the noises factors. The stage demanded the definition of the quality characteristic regarding the studied problem. Further, the noise factors that had relation with the quality characteristic were determined. At the third stage a *brainstorming* activity was carried through for the determination of the controllable factors and their levels. At this point of the work, the cause and effect diagram was used to classify the diverse factors inserted in the process and, based on the norm ASTM D5286 (ASTM, 2005), controllable factors of the experiment were chosen. The levels of each controllable factor were established by means of technical background description acquired by the technician and engineers involved in the painting process. The last stage of the planning phase dealt with the election of the orthogonal arrangement. The fourth stage needed the information from the previous stage wherein the numbers of controllable factors and the number of levels for each one of them were determined. These values enabled the choice of an orthogonal arrangement more relevant to the experiment.

The next phase was the execution, which only comprised the fifth stage of the robust project method. In order for the experiment tests to be conducted, the preparation of the specimen, the assembly of a hook for these parts and the programming of the painting robots was previously necessary. Only then, each control factor treatment combination that the chosen orthogonal arrangement determined in its matrix was executed, as well as the replication of each assay of the experiment. The measurement of the orange peel aspect intensity on the painted samples was realized through the equipment Wave Scan model BYK AW-4824 Micro Wave-Scan.

The data analysis was the final phase of the project. At this phase, the software MINITAB was used to calculate the signal-noise ratio, to generate the table of the ANOVA and the graphs of interactions between the control factors. At the seventh stage of the robust project, the optimum combination between the factors was determined. At this point, from the signal-noise ratio average values analysis, the control factors optimum levels and the interaction between them were calculated. At the stage number eight, the confirmation of the optimum combination occurred. At this stage, the verification test was carried through to assure that the optimum combination would result in acceptable values in the measurement of the orange peel intensity. Thus, a new assay of the experiment was carried through using the levels according to the optimum combination established through the signal-noise ratio and the values of the noise factors verified.

5 The structuring of the robust project

The first stage of the robust project refers to the problem and objective definition. Elements that guided the experiments. The complete process of the bumper manufacture starts at the injection of polypropylene granules, passes by the virgin bumper painting, and then gets the assembly of the components of the bumper already painted. Figure 3 shows the flowchart of bumper production at the studied company, with emphasis in the painting process. As the Figure 3 shows, the virgin bumper reaches the injection process and it is placed on a support (hook) which is fixed to the transporter of the line. The transporter moves the part for the manual cleaning n°1 and n°2. The first one is cleaning with cloth dampened with alcohol and compressed air, in the second, the cleaning is done with cloth containing resin, and ionized air. After the cleaning, the part goes through the cabins where it is put through the operations of buckling, primer, base and varnish, application through painting robots. After the application of all the paint layers, the bumper remains 40 minutes in the painting line oven, responsible for assisting the cure of the varnish. After the period inside the oven, the part is removed of the line and taken to the workstations where a visual inspection is executed. During this inspection, the quality of the painting on the bumper is evaluated and its destination is defined. From this point, there are four ways the part can go into: assembly, polishing, sanding and scrapping.

The parts in compliance go straight for the assembly, whence they are sent for the customer. The parts that present problems which are considered complex go for the sanding. This phase corresponds to the withdrawal of the layers of paint by means of a sandpaper. Whence, the parts could be reworked, that is, they will pass through all the painting process again. The defects identified in the bumpers that cannot be reworked make these parts inappropriate for the assembly and sale to the customer. Therefore, they are sent for the "*scrap*" where they are ground and reused in the injection process, while the parts that present simple defects which can be repaired, go for the burnishing process. In this process, the parts remain at the workstations where the operators use a thin sandpaper to level the defective region and to polish the part. After the burnishing operation is completed, the operator carries through another inspection in the part. If the bumper is in acceptable conditions, it is sent for the assembly process. If not, the part receives

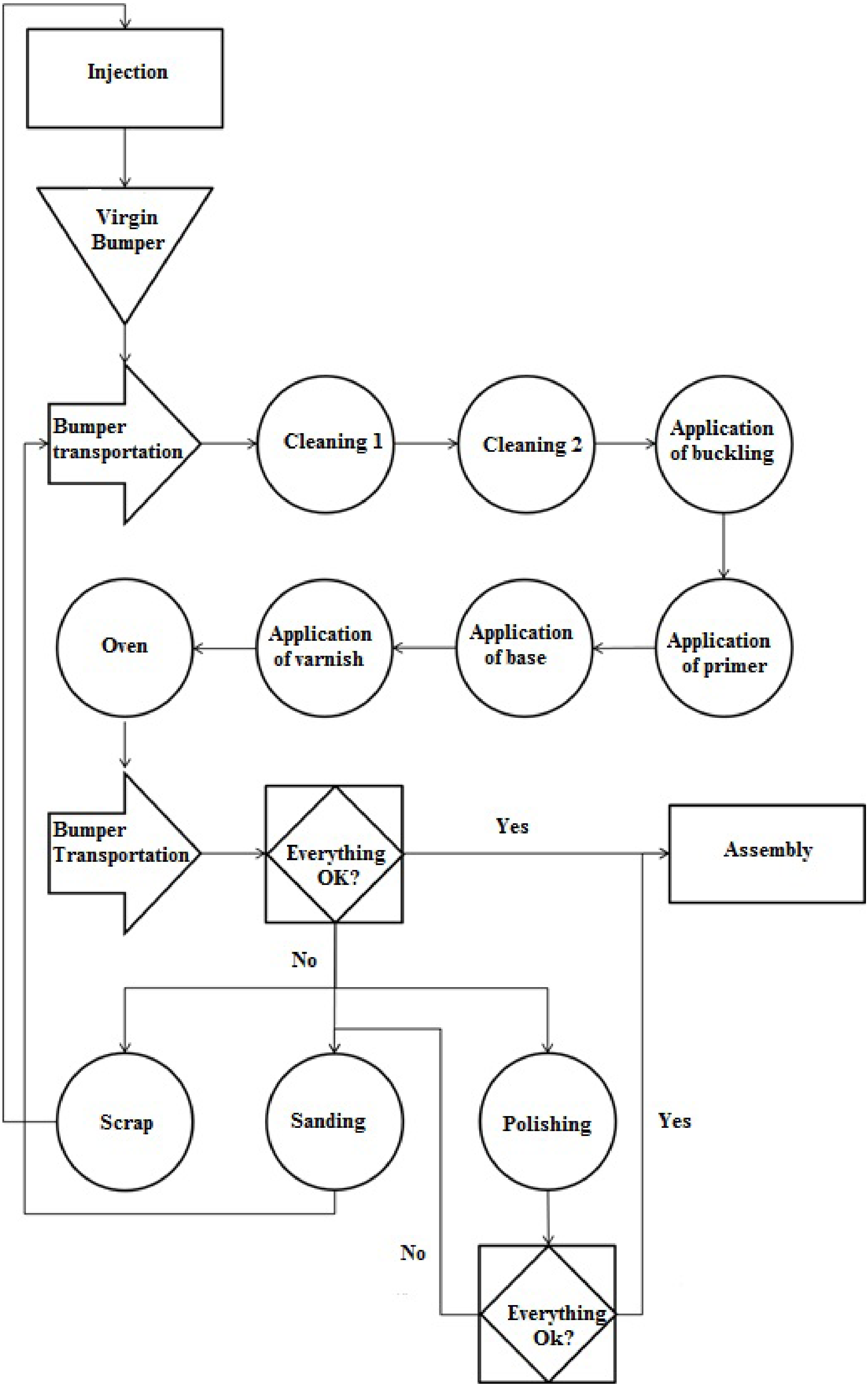


Figure 3. Flowchart automatic painting line. Source: The authors (2015).

the sanding and goes back to the painting line to be reworked. 48% of the parts that pass through the painting process are considered by the operators of the visual inspection as parts in compliance. The remain parts, about 52%, are considered non-compliant. Within the non-compliant parts, approximately 31% of them are sent for the burnishing operation. The parts that go to the burnishing process still can be recovered and sent for the assembly. However, the burnishing work demands a significant number of operators, 8 in each shift, responsible for repairing these defective parts.

Within the main defects in the parts sent for burnishing (orange peel, varnish, dirt, craters, gases, spots, cracking, blistering), the orange peel stands as the main defect. The orange peel nearly represents alone the same ratio of the sum regarding all the other defects. Moreover, in the burnishing operation, bumpers with this type of defect take twice the time for repairing when compared with the other painting defects.

The level of orange peel on the parts can be measured using the Wave-Scan equipment through two values that represent the SW (*Short Wave*) and LW (*Long Wave*) wave length, both having the unit in millimeters.

The conditions for approving the SW and LW values are set by an internal norm of the client (Table 1).

Table 1. Quality norm for the Wave Scan.

Noise Factor	Acceptable condition	No Acceptable condition
Short Wave (SW)	$0 \leq SW \leq 25$	$SW > 25$
Long Wave (LW)	$0 \leq LW \leq 8$	$LW > 8$

Source: The authors (2015).

Considering that the use of the Wave-Scan in 100% of the painted parts is impracticable for the productive flow, this measurement method is applied only for the sampling inspection. Therefore, having only the visual inspection carried through by the operators in the after-painting bumpers gives room for imperfections in the identification of parts with non-acceptable levels of orange peel.

In order to better understand the amplitude of the orange peel problem in the studied company, Figure 4 shows a histogram that demonstrates the SW data dispersion for a sample of 55 painted bumpers, of the same model, chosen randomly, submitted to the scanning of the Wave-Scan. In Figure 5, it can be concluded that the most common measurement of the orange peel in the parts is between 40 ± 2.5 mm. Also, it's verified that approximately 90% of the measured bumpers possess disapproved levels. In the histogram, the dotted line illustrates the line that separates the acceptable and not acceptable levels for the SW wave length.

The measurement of the wave length in the group of bumpers also showed the dispersion of the LW wave length through Figure 5. In Figure 5, between the 12 ± 2 mm interval, a concentration of measurements can be identified. In comparison with the histogram that represents the SW wave length, in the LW, a larger frequency of considerable values next to the acceptable by the clients was found.

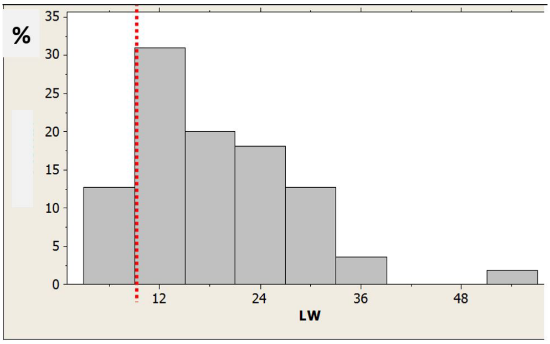


Figure 4. SW wave length histogram. Source: Minitab (2015).

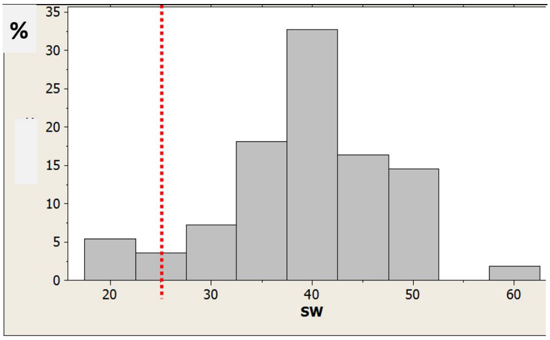


Figure 5. LW wave length histogram. Source: Minitab (2015).

However, nevertheless, there is an amount of approximately 85% of parts out of the desirable 8 mm, as the dotted line traces. Therefore, the problem of the orange peel was identified as a critical problem for the automatic painting line in the company to be studied, because beyond compromising the quality of the aspect of the painted bumpers, this imperfection affects the agility of the production line and jeopardizes the delivery of the parts to the final client. The identification of the problem enabled the definition of the objectives of the experiment.

5.1 Identification of the quality characteristic

The robust project sustains itself on the optimization of the quality characteristic of a product by means of a process less and less sensible to the variations. However, a robust process can be conquered only with the comprehension of the causing factors of this variation. The study of these factors occurs through the Signal-Noise Ratio and Orthogonal Arrangement.

Having the quality characteristic selected in the work clearly, the ways to quantify it, through the types of SW and LW wave, can be classified as the noise factors of the experiment project. It can be concluded that the lower the values SW and LW the better for the quality characteristic, this means, it's indicated that the lower signal-noise ratio type is the best, also known as *Lower is Best* (*LB*).

To assist the analysis of the problem about the orange peel level on the bumper painted surface, the graphical method called cause and effect diagram was used. Starting from a *brainstorming* with technicians and engineers of the company, the possible causes for variation in the quality characteristic of this matter were raised. The painting line of this study consists of a process with total automatized application. The painting robots have many parameters that characterize the paint application.

According to the ASTM D5286 (ASTM, 2005) norm and the empirical knowledge from the technician and engineers, the parameters related to the varnish application are: distance of the towards the part, acceleration, high tension, rpm (rotations per minute), atomizaton, outflow and speed. As the interaction between them can or cannot guarantee the quality of the painting, all of them were pointed as factors that can interfere on the orange peel level of the part. However, during the *brainstorming*, by decision of the technicians, two of the factors were considered as supplemental ones, i.e., they only served for registry. They were the dispenser distance and acceleration, which had fixed values during all the assays. While the other factors were selected as controllable, since there was a great interest to get the ideal combination and understand the interaction between them.

Table 2 presents in the first column the selected controllable factors. In the following column, a symbology for each one of the factors was adopted, in intention to facilitate the understanding of the experiment. In the third column, the measure unit for each factor is represented. In the following columns, each factor is measured and divided in three levels. The technicians found convenient to establish minimum values (level 1), lower than the ones currently in use, and maximum values (level 3), higher than the values used today (level 2), for varnish application in the parts. It is important to clarify that all the values of all the factors represented in Table 2 are results from a multiplication of a number by the real values of application. This measure was taken to preserve the true data of varnish application in the painting sector of the studied company. Thus, the chosen controllable factors were: speed, outflow, air, rpm and tension.

During the studies of the controllable factors effects in the orange peel defect, the bibliographies of Ross (1991, p. 88-89) and Mori (1990, p. 35-36) were used in order to delineate an orthogonal arrangement (Table 3). The type of the chosen arrangement is the L_{27}, therefore, the matrix of the corresponding experiment is described this way: $L_{27}(3^5)$, where the number 27 represents the combinations of the factor levels in lines, the number 5 shows the number of factors of the experiment organized in columns, and number 3 indicates the amount of levels of each factor.

5.2 Conduction of the experiment

Before the conduction of the tests, some conditions in the painting line needed to be adapted, so that the realization of the experiment would be possible. This period of preparation can be divided in four stages: specimen; hook; robot program; measurement method. The first stage was about the preparation of the specimen that needed to be available in an enough quantity and acceptable quality in the injection conditions for the painting. The raw material of the specimen used for the assays was the injected polypropylene. The specimen was a plain part, measuring approximately 200 mm wide and 900 mm long. These parts used in the experiment were cut from a single model bumper by means of a cutting machine. In total, 54 specimen were used to fulfill all the assays. The second stage of the preparation involved the assembly of an exclusive iron hook to dispose the specimen in the best way possible to pass through the painting process. The hook was designed in order to support as many parts as possible without jeopardizing the limitations of the production line. Thus, the structure of the hook held three lined up

Table 2. Levels of the controllable factors.

Control Factors	Simbol	Unit	Level 1	Level 2	Level 3
Speed	A	m/s	680	800	920
Paint Fluid Pressure	B	psi (kPa)	160	190	220
Atomizing air pressure	C	psi (kPa)	180	210	240
Rotating atomizer head speed	D	Rotação / min	90	110	130
Operating voltage	E	kilovolts	150	180	210

Source: The authors (2015).

Table 3. Matrix experiments of the orthogonal arrangement type l_{27}.

Test Number	Level of Factors				
	A	B	C	D	E
1	680	160	180	90	150
2	680	160	180	90	180
3	680	160	180	90	210
4	680	190	210	110	150
5	680	190	210	110	180
6	680	190	210	110	210
7	680	220	240	130	150
8	680	220	240	130	180
9	680	220	240	130	210
10	800	160	210	130	150
11	800	160	210	130	180
12	800	160	210	130	210
13	800	190	240	90	150
14	800	190	240	90	180
15	800	190	240	90	210
16	800	220	180	110	150
17	800	220	180	110	180
18	800	220	180	110	210
19	920	160	240	110	150
20	920	160	240	110	180
21	920	160	240	110	210
22	920	190	180	130	150
23	920	190	180	130	180
24	920	190	180	130	210
25	920	220	210	90	150
26	920	220	210	90	180
27	920	220	210	90	210

Source: The authors (2015).

specimen having the same distance between them. As such, for each round in the painting line, three parts could be painted. For this experiment, in which parts would not receive primer nor base application, only the programming of the robots responsible for the buckling of the parts and varnish application was necessary. As the reduced superficial area, the geometric simplicity and the position of the specimen enhanced the automatized painting process, only one robot for buckling and one robot for varnishing were enough for the accomplishment of each one of the operations. In the same way, the program for a varnishing robot was developed. The program consisted of three coats from the robot gun (Bell), perpendicular to the surface of the sample, with a 120 mm *overlap* between them for each part. As the hook held three parts, the contamination risk during the painting application due to the proximity between them was verified, as this fact could interfere in the final results of the experiment. Due to this possibility, a support to the hook was made, so that, with a special ribbon, the protection to the inferior parts from receiving the excess of the product that would drop during the application onto the superior parts would be possible. The last preparation stage was to define the correct measurement method to guarantee the reliability of the results. In this regard, a 150 mm long iron gauge was made to limit the Wave Scan scanning area on the painted parts. The gauge was fitted into the central hole of the part and it limited and ensured the measuring in the same region in all the parts of the experiment.

All the stages of preparation finished, the tests execution phase was initiated. In each one of the assays, the first step was to submit the specimen to a visual inspection to prevent that parts with superficial deformations or imperfections were used in the tests. Also, before entering the painting line, the part was numbered with the number of the assay, dates and number of the round of the line for further identification. After the approval, the specimen was placed in an exclusive hook to enter in the painting line. The capacity of the hook made possible to paint three parts each time. Then, the loaded hook was placed on the transporter of the line. Already in the painting line, the first operation received by the parts was the cleaning with a cloth dampened with alcohol and compressed air. Soon after, the parts were submitted to the second operation, also cleaning, wherein a cloth with resin and ionized air was wiped in all the surfaces of the specimens. All the processes until this moment were manual. In the following stages the operations were totally automatized. At the next moment, the specimen received a buckling treatment in all its surfaces. Soon after the buckling, the technician set up the levels of the parameters for the varnish application, established in the matrix experiment, for each specimen. Therefore, the next operation experienced by the specimen was the application of the varnish layer. During the process some information were collected to assure the repetition of the environment conditions and the raw material of each assay. The values referring to the varnish temperature and viscosity, the varnish cabin conditions, such as, air pressure, humidity and temperature were written down. Finally, the parts were submitted to a heated oven during approximately 40 minutes, responsible for the cure of the varnish. The complete painting process for each test lasted 2 hours approximately. After the parts came out of the oven, they were removed from the hook and taken to the laboratory for analysis. At this stage of the experiment, the laboratory technicians executed the measurement of the wave-scan length of the superficial waves on the varnish layer through the wave scan equipment. The values given by the measurement equipment were then written down.

Finally, the parts were stored in appropriate place in case of reevaluation need. After finishing the procedures for the execution of the three tests, the preparation for the next three parts that would enter in the painting line was initiated. The choice of the test number that would enter in the painting process was taken through a random selection.

5.3 Analysis of the experiment results

After realizing all the twenty-seven tests of the experiment, the repetition of each one of them was performed. The noise factors values were retrieved through the Wave-Scan device and can be seen in Table 4. The SW_1 and LW_1 noise factors values represent the first test round and the numbers pertaining to the SW_2 and LW_2 represent the second round, where each assay had a repetition. In the table, the values highlighted in green represent the acceptable conditions of the orange peel level. At a first moment, a difficulty to reach the orange peel desired values in the short wave factor and an easiness to reach the acceptable numbers for the long wave noise factor could be evaluated through the data from the noise factors on Table 4.

Thus, the values of the Table 4 were used to carry through the variance analysis for the signal-noise ratio of both factors. Considering first the SW noise factor, the variance analysis is expressed from Figure 6.

In order to make a fast explanation of the structure on Figure 6, it's possible to notice that the first column (*Source*) shows all the factors and passive interactions of analysis. The second column (*DF*) displays the degrees of freedom values (gl) of each factor and interaction. The third column (*Seq SS*) presents the sequential sums of squares (SQ) of each factor and interaction. The fourth column (*Adj SS*) represents the adjusted sequential sums of squares of the factors and interaction that repeats the values of the sequential sums of squares, excepted the total sum of the squares. The following column (*Adj SM*) shows the sequential sums of mean squares (SQM). After the explanation of the structure in Figure 6,

Table 4. Signal-noise of the experimental matrix type l_{27}.

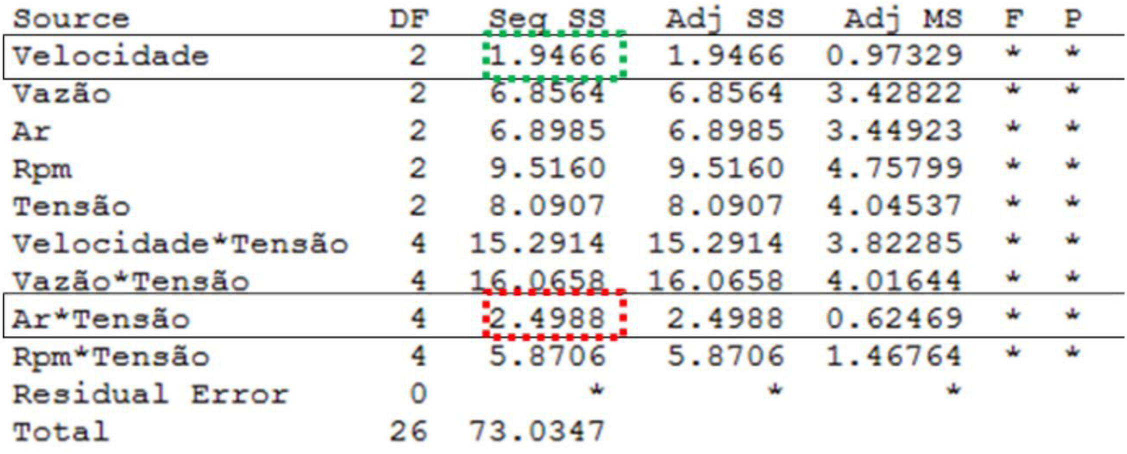
Test Number	Level of Factors					Noise Factor				S/R (dB) SW	S/R (dB) LW
	A	B	C	D	E	SW_1	LW_1	SW_2	LW_2		
1	680	160	180	90	150	**23.7**	**5.9**	**23.6**	**5.1**	-27.48	-14.83
2	680	160	180	90	180	25.6	**5.9**	**24.9**	**4.8**	-28.05	-14.61
3	680	160	180	90	210	30.8	**6.0**	25.7	**6.9**	-29.06	-16.21
4	680	190	210	110	150	29.6	8.2	32.5	9.5	-29.85	-18.96
5	680	190	210	110	180	39.2	11.4	40.5	**7.7**	-32.01	-19.76
6	680	190	210	110	210	29.3	**5.6**	31.0	8.1	-29.59	-16.86
7	680	220	240	130	150	33.8	10.2	38.3	12.9	-31.15	-21.31
8	680	220	240	130	180	36.0	10.1	44.9	18.1	-32.19	-23.32
9	680	220	240	130	210	32.8	8.5	40.4	16.7	-31.32	-22.44
10	800	160	210	130	150	29.3	**5.4**	35.7	**6.3**	-30.28	-15.37
11	800	160	210	130	180	27.6	**6.9**	33.0	9.1	-29.66	-18.14
12	800	160	210	130	210	37.3	**6.9**	39.3	14.5	-31.67	-21.10
13	800	190	240	90	150	32.9	10.0	35.9	9.4	-30.74	-19.74
14	800	190	240	90	180	36.1	8.4	28.3	**6.8**	-30.22	-17.66
15	800	190	240	90	210	29.6	**7.9**	31.0	**6.9**	-29.63	-17.40
16	800	220	180	110	150	29.2	**7.0**	32.5	8.4	-29.80	-17.77
17	800	220	180	110	180	**24.6**	**5.3**	**23.1**	**7.4**	-27.55	-16.17
18	800	220	180	110	210	30.5	**7.5**	35.5	11.0	-30.40	-19.48
19	920	160	240	110	150	28.5	10.0	32.1	10.1	-29.64	-20.04
20	920	160	240	110	180	**15.0**	**4.7**	**24.2**	**4.9**	-26.08	-13.63
21	920	160	240	110	210	38.9	15.3	25.1	**5.9**	-30.30	-21.29
22	920	190	180	130	150	28.3	**6.3**	27.0	**5.8**	-28.84	-15.64
23	920	190	180	130	180	30.7	**6.3**	38.1	**7.2**	-30.78	-16.61
24	920	190	180	130	210	38.5	10.0	25.5	**6.4**	-30.28	-18.48
25	920	220	210	90	150	36.3	**7.7**	35.2	10.2	-31.07	-19.12
26	920	220	210	90	180	**21.3**	**4.2**	**18.2**	**5.5**	-25.94	-13.79
27	920	220	210	90	210	38.2	9.0	44.1	8.8	-32.31	-18.99

Source: The authors (2015).

It was necessary to make a detailed analysis of the values obtained from it. According to Figure 6, the interaction between the Air (C) and Tension (E) reveals itself no significant, for presenting very low value relative to the sum of the squares.

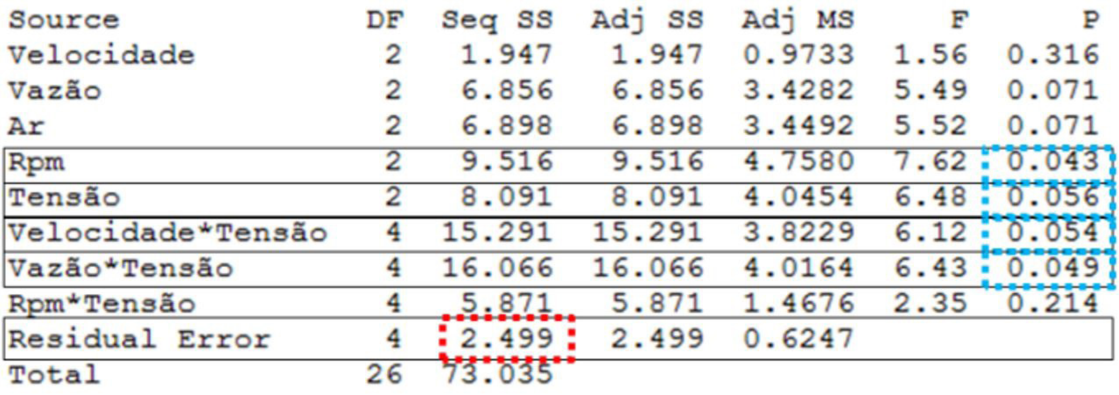
Then, the sequential sums of squares from this interaction was used as residue, that is, it was removed from the adjustment. Thus, the residue will have four degrees of freedom and SQe = SQ_{CxE} = 2,4988, according to the new Figure 7. It's valid to highlight that the Speed factor also presented a low value in the sum of the squares, but, as the Speed*Tension possess an expressive value, this main factor was not used to add the values of the residue. It is important to emphasize that the interactions Speed*Outflow, Speed*Air, Speed*Rpm, Outflow*Air, Outflow*Rpm and Air*Rpm are not present in the analysis because it is not possible to estimate them only with the collected data. The F values can be obtained through the ratio between the sequential sums of mean squares of each factor and the sequential sums of mean squares of the residue. In the Speed factor example, the following calculation is given: 0.9733 ÷ 0.6247 = 1.56.

Thus, based on the Figure 8, it was possible to carry through the analysis of the results from the p-value, since values above of 0.05 indicate that the factor is not significant. However, during the analysis of values next the 0.05, the experience of the professionals in the area was added to determine either the significance or non-significance of the factor or interaction at hand. Therefore, the Figure 8 reveals the main factors Speed, Outflow, Air and the interaction Rpm*Tension as non-significant. However, the Rpm main factor and the Outflow*Tension interaction show the p-value less than 0.05, i.e., the effect of these factors are significant. The case of the Tension controllable factor and the Speed*Tension interaction displays cases of p-value higher than 0.05, but not much. It was determined that in these two cases the effect of both are significant. Another indication of the importance of the factors, is that the sums of squares from the Rpm factors, Tension and the Speed*Tension and Outflow*Tension interactions



```
Source             DF   Seq SS   Adj SS    Adj MS  F  P
Velocidade          2   1.9466   1.9466   0.97329  *  *
Vazão               2   6.8564   6.8564   3.42822  *  *
Ar                  2   6.8985   6.8985   3.44923  *  *
Rpm                 2   9.5160   9.5160   4.75799  *  *
Tensão              2   8.0907   8.0907   4.04537  *  *
Velocidade*Tensão   4  15.2914  15.2914   3.82285  *  *
Vazão*Tensão        4  16.0658  16.0658   4.01644  *  *
Ar*Tensão           4   2.4988   2.4988   0.62469  *  *
Rpm*Tensão          4   5.8706   5.8706   1.46764  *  *
Residual Error      0        *        *         *
Total              26  73.0347
```

Figure 6. Analysis of the SW signal-noise ratio variance Number 1. Fonte: Minitab (2015).



```
Source             DF  Seq SS  Adj SS  Adj MS     F      P
Velocidade          2   1.947   1.947  0.9733  1.56  0.316
Vazão               2   6.856   6.856  3.4282  5.49  0.071
Ar                  2   6.898   6.898  3.4492  5.52  0.071
Rpm                 2   9.516   9.516  4.7580  7.62  0.043
Tensão              2   8.091   8.091  4.0454  6.48  0.056
Velocidade*Tensão   4  15.291  15.291  3.8229  6.12  0.054
Vazão*Tensão        4  16.066  16.066  4.0164  6.43  0.049
Rpm*Tensão          4   5.871   5.871  1.4676  2.35  0.214
Residual Error      4   2.499   2.499  0.6247
Total              26  73.035
```

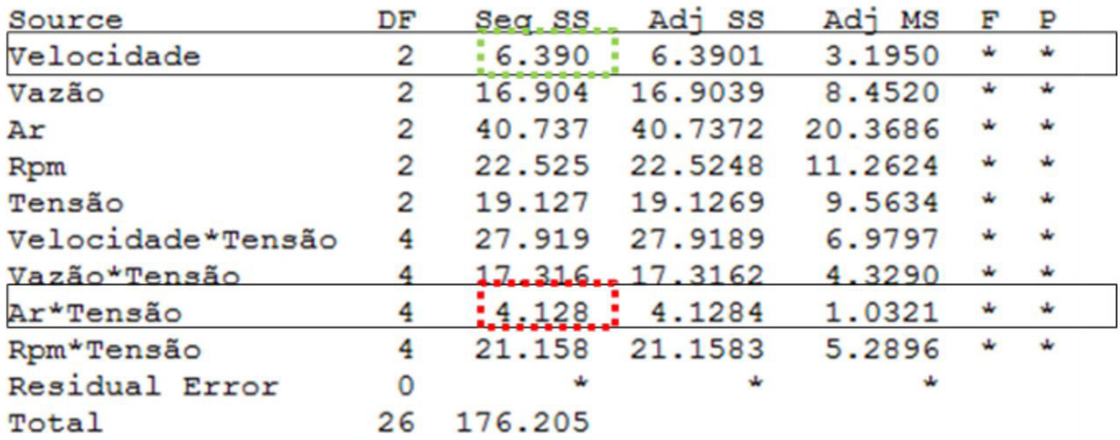
Figure 7. Analysis of the SW signal-noise ratio variance Number 2. Fonte: Minitab (2015).

represent more than 65% of the total effect on the SW noise factor.

The LW noise factor was analyzed in the same way as the SW noise factor. According to the Figure 9, the Speed controllable factor presented a low value in the sum of the squares, but, as the Speed*Tension possess an expressive value, this main factor was not used to add the values of the residue. Nevertheless, the Air*Tension interaction has a small sum of squares value, that is, it will be used to add the sum of squares of the residue. Thus, the residue will have four degrees of freedom and $SQ_R = SQ_{AIR\ X\ TENSION} = 4.128$ (Figure 9). It is valid to emphasize that the interactions Speed*Outflow, Speed*Air, Speed*Rpm, Outflow*Air, Outflow*Rpm and Air*Rpm are not present in the analysis because it is not possible estimate them only with the collected data. According to Figure 9, it is possible to identify that the Speed factor and the Outflow*Tension and Rpm*Tension interactions possess the p-value higher than 0.05, it means, without significant effect. However, the main factors Outflow, Air, Rpm, Tension and the Speed*Tension and Outflow*Tension interactions possess the p-value lower than 0.05, which indicates that their effects are significant.

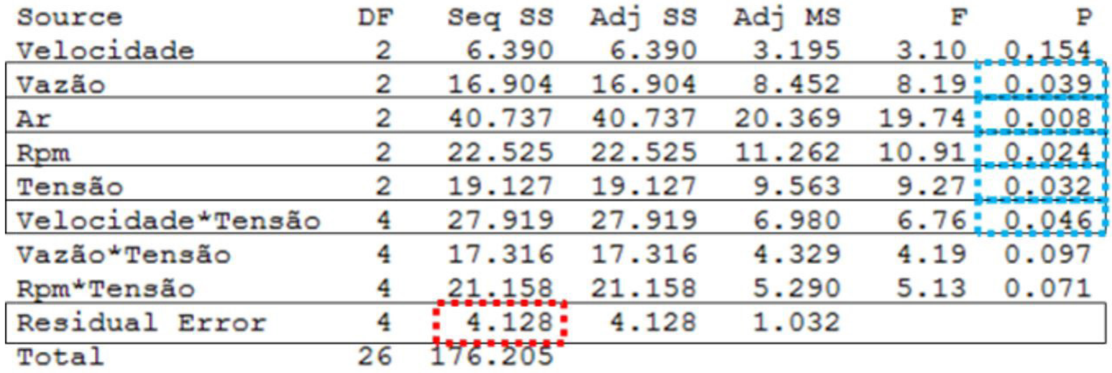
The information about the variance analysis made possible to have the evaluation of the main controllable factors that influence in the SW noise factor and also the ones that are not significant. Beyond the factors, the importance of the Outflow*Tension and Speed*Tension interactions in reply of the noise factor, as well as, the insignificance of the Rpm*Tension interaction can be analyzed. Aiming to fully understand the relation between the factors that compose each interaction, it was necessary to use one of the tools of the robust project, the interaction graph. This type of graph serves to display a behavior change of one of the factors when it has a variation in different levels of the other factor, related to the characteristic in interest. The Figure 10, 11, 12, 13, 14 and 15 illustrates the interaction between the analyzed variable.

Carrying on with the analysis of the noise factors and looking for the optimum combination among the levels of the controllable factors, the robust project provides the average of the value analysis for the signal-noise ratio.



```
Source               DF   Seq SS    Adj SS     Adj MS   F   P
Velocidade            2    6.390    6.3901     3.1950   *   *
Vazão                 2   16.904   16.9039     8.4520   *   *
Ar                    2   40.737   40.7372    20.3686   *   *
Rpm                   2   22.525   22.5248    11.2624   *   *
Tensão                2   19.127   19.1269     9.5634   *   *
Velocidade*Tensão     4   27.919   27.9189     6.9797   *   *
Vazão*Tensão          4   17.316   17.3162     4.3290   *   *
Ar*Tensão             4    4.128    4.1284     1.0321   *   *
Rpm*Tensão            4   21.158   21.1583     5.2896   *   *
Residual Error        0        *         *          *
Total                26  176.205
```

Figure 8. Analysis of the LW signal-noise ratio variance Number 1. Fonte: Minitab (2015).



```
Source               DF   Seq SS   Adj SS   Adj MS       F       P
Velocidade            2    6.390    6.390    3.195    3.10   0.154
Vazão                 2   16.904   16.904    8.452    8.19   0.039
Ar                    2   40.737   40.737   20.369   19.74   0.008
Rpm                   2   22.525   22.525   11.262   10.91   0.024
Tensão                2   19.127   19.127    9.563    9.27   0.032
Velocidade*Tensão     4   27.919   27.919    6.980    6.76   0.046
Vazão*Tensão          4   17.316   17.316    4.329    4.19   0.097
Rpm*Tensão            4   21.158   21.158    5.290    5.13   0.071
Residual Error        4    4.128    4.128    1.032
Total                26  176.205
```

Figure 9. Analysis of the LW signal-noise ratio variance Number 2. Fonte: Minitab (2015).

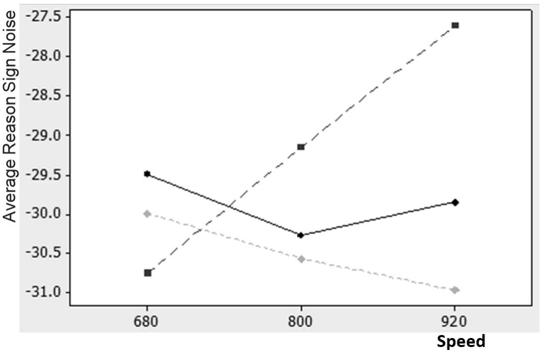


Figure 10. Speed*tension interaction graph (SW). Source: Minitab (2015).

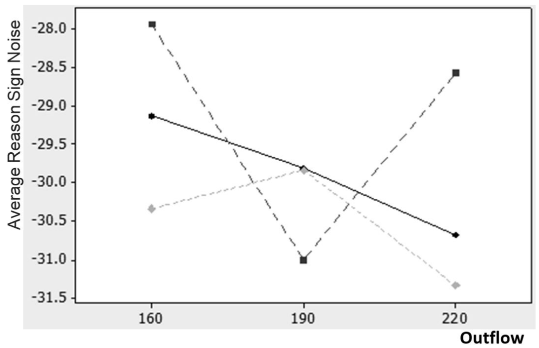


Figure 11. Outflow*tension interaction graph (SW). Source: Minitab (2015).

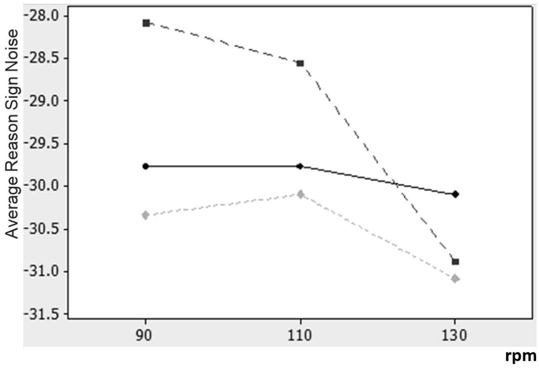


Figure 12. Rpm*tension interaction graph (SW). Source: Minitab (2015).

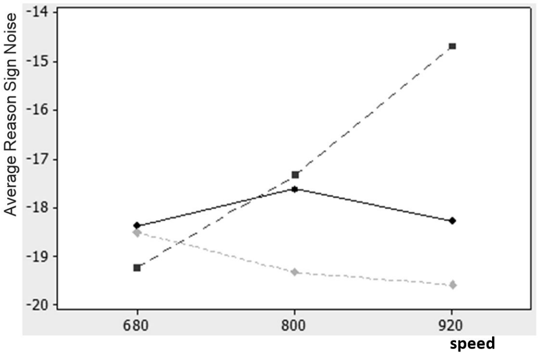


Figure 13. Speed*tension interaction graph (LW). Source: Minitab (2015).

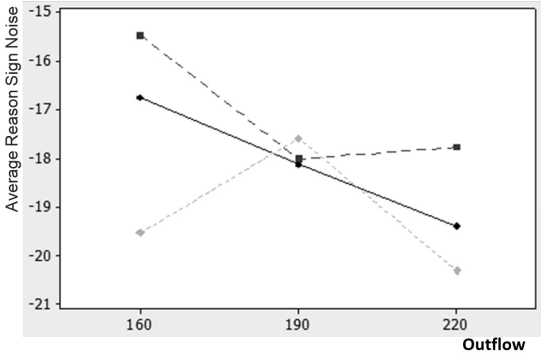


Figure 14. Outflow*tension interaction graph (LW). Source: Minitab (2015).

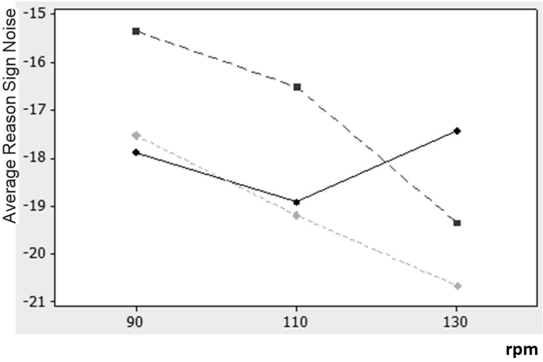


Figure 15. Rpm*tension interaction graph (LW). Source: Minitab (2015).

Based in the values obtained by the calculations of the SW signal-noise ratio in Table 4, the Table 5 about the means averages was created, wherein the five controllable factors are found disposed in columns, and their three levels are organized in lines, wherein the lowest levels correspond to the No. 1, the intermediate to the No. 2 and highest to the No. 3. For example, the value on the Speed factor column with the line of the Level No. 1 (- 30.08 dB), corresponds to the average of all the values of the SW signal-noise ratio, wherein the tests had the factor speed lowest level (680 m/s).

Still in Table 5, in the reference line “Variation”, the resultant values of the difference between the highest value and lowest value of the three signal-noise ratio mean values for each controllable factor can be found. In the Speed factor column, for example, the highest value (- 29.47 dB) among the three, deducted by the lowest value (-30.08 dB), results in the value of 0.61 dB. The values of these differences serve to classify in the "Performance" line which factor has higher signal-noise ratio variation. In this case, the Tension factor is the one which occurs higher variation. Also, it is possible to evidence that the Rpm and Tension factors effects are approximately two times more significant than the Speed factor effect.

Based on the assumption that the maximization of the signal-noise ratio is desirable, it is possible to establish the optimum combination for the SW noise factor. The values of the levels that maximize the signal-noise ratio for each controllable factor are highlighted by the dotted lines in the Figure 16. Therefore, the optimum combination is: Speed = 920; Outflow = 160; Air = 180; Rpm = 90; Tension = 180. While the remaining factors had not presented optimum combination levels compatible with the values configured for the current varnish application. The speed, for example, in the optimum combination appears with its highest level. While the outflow factors, air and rpm demonstrated to be better applied to the lowest levels regarding to the values used in the currently line.

Through Figure 17, it is possible to perceive which are the levels in each factor that maximize the signal-noise ratio: Speed = 920; Outflow = 160; Air = 180; Rpm = 90; Tension = 180. Also, in the form: A_3, B_1, C_1, D_1, E_2.

Thus, it is possible to notice that only the tension (E) is being used in the current application with the level presented in the optimum combination (E_2). While the remaining factors had not presented optimum combination levels compatible with the values configured for the current varnish application. The speed, for example, in the optimum combination appears with its highest level. While the outflow factors, air and rpm demonstrated to be better applied to the lowest levels regarding to the values used in the currently line.

The test of the optimum combination was applied following the same number of repetitions of the experiment. As see on Table 6, the values of the SW_1 and LW_1 noise factors represent the first sample from

Table 5. Table of the Lower is Best average signal-noise ratio (SW).

Level	Speed	Outflow	Air	rpm	Tension
1	-30.08	-29.13	-29.14	-29.39	-29.87
2	-29.99	-30.22	-30.26	-29.47	-29.16
3	-29.47	-30.19	-30.14	-30.69	-30.50
Variation	0.61	1.08	1.13	1.30	1.34
Performance	5	4	3	2	1

Source: Minitab (2015).

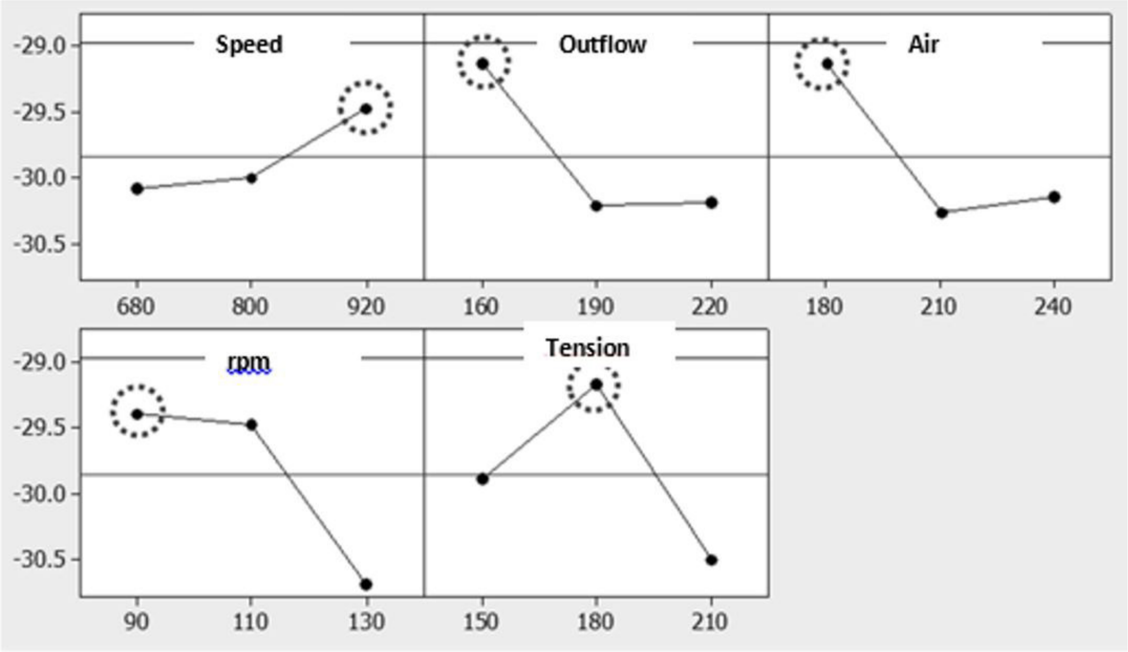


Figure 16. Main effects for the Lower is Best signal-noise ratio (SW). Source: Minitab (2015).

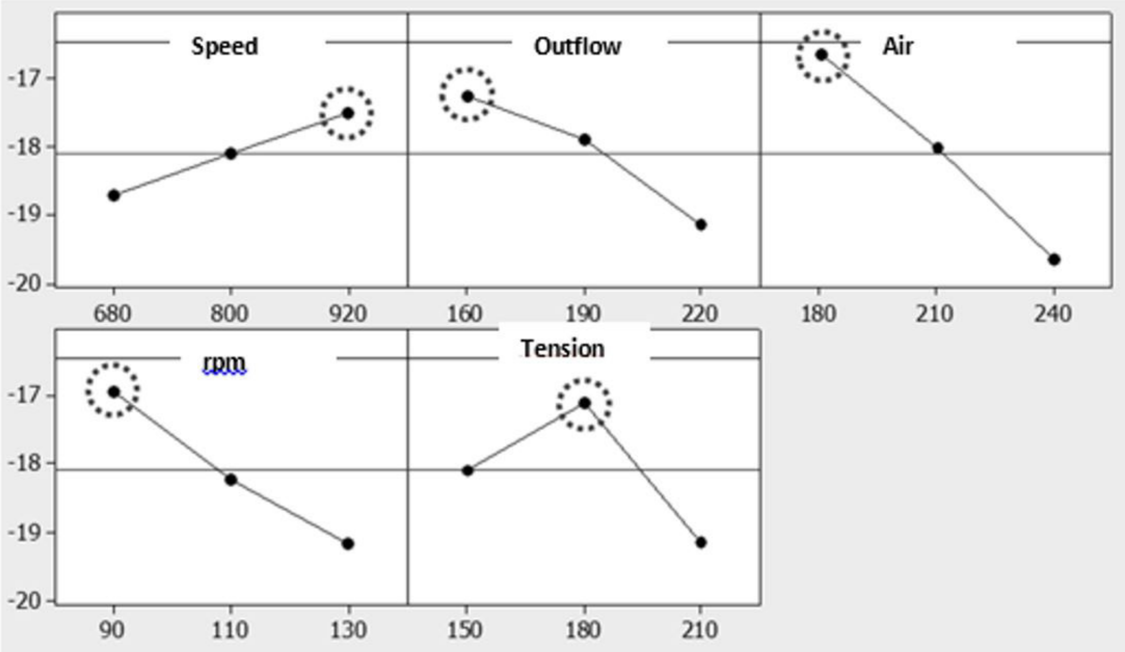


Figure 17. Main effects for the Lower is Best signal-noise ratio (LW). Source: Minitab (2015).

Table 6. Optimum combination.

Test number	Level of Factors					Noise Factor			
	A	B	C	D	E	SW_1	LW_1	SW_2	LW_2
Optimum Combination	920	160	180	90	180	15.2	4.1	14.8	4.1

Source: The authors (2015).

the test of the optimum combination and the numbers pertaining to the SW_2 and LW_2 represent the second sample with the same levels of the controllable factors. The values reached for the length of the LW wave, are better than the ones obtained during all the tests of the experiment. While for the SW noise factor, the first value of 15.2 mm in the SW_1 column, even acceptable, is higher than the lowest value of the experiment obtained in the assay No. 20, as Table 4 shows. However, the second SW value, 14.8 mm, is the best value when compared with all the values from the tests of the experiment. Thus, the average of the values obtained from the optimum combination is lower than all the averages from the tests of the experiment.

6 Final considerations

The accomplishment of the research in the partner company depended on a deepened understanding about the production process of the bumpers. The analysis of the norms that regulate the automotive painting was a prerequisite of the work in order to make possible the accomplishment of the experiment. The research about the robust project disclosed an appropriate methodology that would facilitate the attainment of the results in reduced time and cost. The flowchart of the robust project stages presented here was followed rigorously and the results of its application were achieved successfully. Therefore, according to the point of view of the chosen method, it is possible to affirm that the robust project objective of identifying and reducing the means of variability of the production process, without eliminating them, aiming to improve the product quality was achieved.

The work was also concerned about identifying the causes of variability in the painting process that can result in the intensification of the orange peel aspect in the bumpers. For such, the cause and effect diagram elaborated here made explicit the causes of variability of the painting line that can come to cause the effect of orange peel on the surface of the painted part. The revision of literature and the technical description of the professionals who act in the painting process of plastic parts made possible the election of the most appropriate controllable factors to the application of the experiment: speed, outflow, air, rpm and tension.

The study of the existing interactions between the involved controllable factors in the experiment took place through the significant changes in the values of the signal-noise ratio averages in certain levels of a factor when another factor varied. For the SW noise factor, only the 180 kV of the controllable tension factor presented interaction with the factors: speed, outflow and rpm. For the LW noise factor, the interaction between the speed and tension factors was noticed only by significant changes of the signal-noise ratio averages on the 180 kV level of the controllable tension factor While the interaction with the outflow factor was perceived in all the levels of the tension factor: 150 kV, 180 kV and 210 kV. Also, the interaction with the rpm factor could be analyzed in two levels of the tension factor: 180 kV and 210 kV.

The proposal for improvement of the product quality, as the robust project method aims, came up through the proposal of an optimum combination on the levels of the varnish application parameters.

After the application of the signal-noise ratio calculations to all the tests of the experiment, it was found that acceptable conditions of orange peel are more easily reached for the LW noise factor than for the SW factor.

For the SW noise factor, controllable factors that possess greater influence in the value of the dependent variable are: rpm and tension. Beyond these two, the interactions that also proved to be influential in the SW values were: the outflow*tension and speed*tension. As for the speed factor, it did not prove to be significant as the only factor to determine the intensity of the orange peel aspect in painted bumpers, however, it possessed relevance when associated with certain levels of the tension factor. Thus, for the SW factor, the non-significant factors and interactions are: speed, outflow, air, air*tension and rpm*tension.

Through the p-value study, it was proven that outflow, air, rpm and tension are the controllable factors that most affect the LW noise factor values. In the interactions, only the speed*tension presented significant effects in the LW dependent value. However, it is important to point out that for the LW noise factor, even it presenting several optimum controllable factors, the air factor turned out to be the most important among them. In this case, the non-significant factors and interactions were: speed, air*tension, outflow*tension and rpm*tension.

It is important to highlight that beyond having direct contribution for the industry, this research also contributes for the academia, since the success of the application of the robust project in the present study clearly strengthens the effectiveness of the method. Moreover, it proves the importance of the interaction among the applications of statistical techniques in the productive reality of the industry for processes improvement.

Challenges found throughout this research must not be forgotten, since despite the fact that one of the researchers belong to the board of employees of the related organization, the research experienced some delays due to time restrictions to organize the experiments within the studied industrial routine.

Future works can explore the interference of the varnish preceding layers in the occurrence of orange peel on the bumper painted surfaces. In other words, is it possible to follow the same methodology of the present work to investigate the factors of the primer and base application? Another opportunity raised for new research is to identify the impacts of different types of variability causes on the orange peel level, in painted bumpers, not selected in this work for the development of the experiment. For example, the factors related to the raw material used in the painting: parameters for the preparation of the primer, base or varnish.

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