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RESEARCH ARTICLE OPEN ACCESS

USE OF THE TAGUCHI METHOD FOR ANALYSIS OF TEMPERATURE REDUCTION IN THE REFRIGERATION LABORATORY - NUTENGE – UEMA

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ABSTRACT

The Robust Design method, also called the Taguchi Method, was developed by the engineer and statistician Genichi Taguchi to improve productivity and optimize engineering projects and products. Robust Design focuses on improving the fundamental function of the product or process, making projects more moldable and perfecting the engineering applied to it. It is a most effective method available to improve quality and simultaneously reduce the development interval for projects or products. The main objective of Taguchi's methodologies is to design and manufacture high quality products in a short time, avoiding more expensive and slower trial-error methods. The applications of Taguchi's methods can be seen beyond the academic environment, as well as in everyday life. To verify the effectiveness of this method, the concepts of Orthogonal Matrices, Signal / Noise calculations and effects of noise factors and interactions between them will be applied in a case where there is a room (Refrigeration Laboratory) to be cooled by air conditioning machines according to pre-selected noise parameters. Cases like this, commonly seen in a virtual environment, are analyzed for verification of the effectiveness in reducing the temperature of the fluid contained inside the room.

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INTRODUCTION

The application of the Taguchi Method, or Robust Design, is widely used in product design and process development research. As it is a method that applies a specific number of tests based on a predefined table of results, the so-called orthogonal matrix, the process becomes cheaper, as the analysis maker will not resort to trial-error and the project will become cheaper. For this report, we will have the application of the Taguchi method in a hypothetical case in which it is desired to reduce the temperature of a fluid in a plastic bottle (the fluid applied to the problem is water) and the effectiveness of experiments commonly seen in the virtual sphere will be verified. , in which a liquid at low temperature is obtained in a few minutes of this submerged in a medium with a cold mixture. The parameters will be given based on the most common tools applied in these experiments, to which the results will be analyzed and obtained through the method, verifying which one has the greatest relation to each other. It is worth noting that in the Taguchi method, if a significant number of noise factors in the system are taken into account, these factors will be neglected for this next report. The Taguchi method makes it possible to determine the best combination of factors and interactions that influence the behavior of the response variable of a given process. Generally, the use of the method requires less sampling effort, reducing the cost of tests, without prejudice to the conclusions obtained (ROSA et al., 2009).

MATERIALS AND METHODS

Segundo Lima et al. (2011), o planejamento de experimentos é a metodologia mais adequada para estudar vários fatores de processo e a complexidade de suas interações, de forma a aumentar a probabilidade de solucionar problemas, através de análises estatísticas. Essa metodologia é considerada poderosa para a melhoria da qualidade e produtividade, tendo sido, nos últimos anos, cada vez mais aplicada na indústria brasileira, principalmente pelas do segmento automobilístico (SILVA e SILVA, 2008). Segundo Souza et al. (2011), Robin et al. (2010) e Rosa et al. (2009), o planejamento de experimentos é muito utilizado para se definir quais dados e em quais condições devem ser coletados durante a experimentação, para garantir melhor precisão estatística na análise de resultados. Segundo Neto et al. (2007), a aplicação deste método na sua forma tradicional, com matrizes completas 2k, onde k representa a quantidade de fatores investigados e uma réplica completa requer 2 x 2 x 2 x ......2 = 2k observações, implica em um grande número de experimentos, o que pode tornar inviável o estudo, devido aos altos custos com ensaios. The Taguchi method makes use of the Signal to Noise ratio (S / N), which is a logarithmic function used to optimize the product's process or design, minimizing variability. This quantity is derived from the communications industry, where it has been used for almost a century, representing the relationship between sensitivity and variation of a given measurement system. According to Souza et al. (2011), there are three types of relationship (S / N):

- Smaller is better (the lower the response value, the better for the process);
- Bigger is better (the higher the response value, the better for the process);
- Nominal is better (the closer to the specification, the better for the process).

According to Taguchi et al (2004), three types of noise are identified:

External noise: environmental variables or conditions of use that disturb the product's functions. Eg temperature, humidity, etc.

Internal noise: changes that occur as a result of wear;

Piece-by-piece noise: although products are manufactured to the same specifications, there is a difference between them.

The goal is to minimize noise through quality online and offline activities. Taguchi proposes the use of optimization techniques and theories, together with the design of experiments, with the ultimate goal of minimizing losses to society. From a special set of matrices called orthogonal matrices, a standard determines how to conduct the minimum number of experiments that can offer complete information on all factors that affect the performance parameter. The objective of the orthogonal matrix method is to choose the level combinations of the input design variables for each experiment, so that a plausible result can be obtained for the optimization of the desired system. The minimum number of experiments given to the Taguchi method can be calculated according to the degrees of system levels, as shown in Equation 1:

$$N = 1 + \sum_{i=1}^{NV} (Li - 1) \quad (1)$$

Where,

N - Number of Experiments;
Li - Levels (Levels) of the system.

According to Castro (2014), The loss function, proposed by Taguchi, is a cost function associated with the deviation from the ideal presented by the product. It is proportional to the square of the standard deviation, and can be expressed as in Equation 2, and shown in a graph as in Graph 1:

$$L(y) = k(y - y_{\circ})^2 \quad (2)$$

Where,

L (y) - value of the function, in monetary units;
y - value presented by the product, for the characteristic under observation;
k - proportionality constant;
y_0 - target value.

Based on the loss-function, Taguchi formulated reasons in which he called the signal-to-noise (Y / N), suggesting that the optimization of these quotients constitutes the way of minimizing the loss-function. Each of the reasons was originated so that a specific problem could be solved. The ones presented below, according to three distinct types of problems, are the best known (Equation 3, 4 and 5):

The nominal value is the best:

$$SN_T = 10\log\left(\frac{\bar{y}}{S^2}\right) \quad (3)$$

The lowest value is the best (the lower the better):

$$SN_S = -10\left(\frac{1}{n}\sum_{i=1}^{n} y^2 i\right) \quad (4)$$

The highest value is the best (the higher the better)

$$SN_L = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y^2 i}\right) \quad (5)$$

Where:

ym - average results (answer)
s2 - variance of results (answer)
n - number of experiences in the set performed

Analysis Process

The analysis made to identify the most efficient process is shown below from the Taguchi method.

Defining Taguchi Criteria: In the experiment applied in this report, there is a room (refrigeration laboratory) at an initial ambient temperature in which it is subjected to cooling in a time of 1 hour immediately after the temperature of the place was recorded. The quality criterion is the “lower-the-better” temperature tolerance obtained for the project to be worked on. Thus, the signal-to-noise ratio for this case is shown in equation 4 mentioned above. As part of the first stage of application of the taguchi method in defining quality criteria, noise factors must be pre-established to be analyzed in an experiment.

Noise Factors for the Experiment: For the process, the noise factors are: the shift (morning at 9 am and afternoon at 3 pm) to which the room is subjected to cooling; door (open or closed) and lamp (on or off). in order to carry out the following process, the influences of other noise factors such as the temperature of other equipment inside the room were disregarded.

Experiment levels and factors: In this step, details of the levels and numbers of these factors must be presented. These levels will be:

For the shift: level 1 - morning and level 2 - afternoon;
For the door: level 1 - open; level 2 - closed;
For the lamp: level 1 - on; level 2 - off.

Materials Used

As materials applied to this experiment, we have:

- Thermo anemometer model tad-500 of 0.3-45 m / s and 0 to 60ºc: used to measure the temperature of the environment, figure 1.
- 4 lamps
- 3 air conditioning
- Refrigeration laboratory door of NUTENGE-UEMA.

Figure 1. Term - anemometer used in the experiment

For each test applied, precautions were taken regarding the test environment, in addition to the calibration of the measuring instrument being always verified. All procedures were duly standardized.

Determination of the orthogonal matrix: For the following experiment, the following taguchi orthogonal matrix was adopted (table 1). The matrix accompanies the experiment, to which the parameters will be studied. The results obtained in these experiments are used to analyze the data and predict the quality of the components produced.

Test results: The test made using the defined orthogonal matrix was performed twice so that the quality studies determined by the project could be conducted.

Table 2 shows the general profile of the results obtained in the tests, including the averages of both measured temperatures. It presents one of the first tests carried out, with 2 air conditioners turned on at the same time in the morning (at 9 am) with the door open and the lamp on.

Table 1. Orthogonal matrix adopted for the 4-factor experiment

N° EXPERIMENT	NOISE FACTORS		
	1	2	3
1	Level 1	Level 1	Level 1
2	Level 1	Level 2	Level 2
3	Level 2	Level 1	Level 2
4	Level 2	Level 2	Level 1

Source: taguchi (1987).

At first glance, we have that the fourth experiment (morning, closed and off) obtained a better average temperature for the desired tolerance, however, values of the signal-to-noise ratio must be obtained in order to have a more structured parameter. Thus, applying the formula of equation 1, considering the levels 1 of each noise factor as low level, while those of level 2 are considered high level, we have the following results for the experiments carried out.

Study of the effects of factors: The effect of a factor verifies the change in the response according to the level of each factor. Studying the effects of the factors is a differential in verifying the problem, because, in many cases, the factors studied do not alter the performance of other factors, which can be defined as interaction. The effects are compared against each other until a response is obtained and the interaction of the system is verified. As in the previous topic, considering the levels 1 of each noise factor as low level, while those of level 2 are considered high level, we can observe the interaction of each factor. The first two factors to note are: shift (factor a) and door (factor b). Tab. 3 shows the relationship of these factors and their calculation of effect:

The main effect of factor A is the difference between the average response between its high and low levels:

$$Ef.A = \frac{26,6+24,7}{2} - \frac{25,8+24,6}{2}$$

$$Ef.A = 0,25$$

We see that, changing factor A from the lowest to the highest level, there is an average response of 0.25 ° C. The main effect of factor B is also the difference between the average response between its high and low levels:

$$Ef.B = \frac{24,6+24,7}{2} - \frac{25,8+26,2}{2}$$

$$Ef.B = -1,35$$

Thus, we have that, changing factor B from the lowest to the highest level, there is a drop in the average response of - 1.35 ° C. We can also verify that the difference between the high and low levels is not constant:

For factor A:

$$26,2-25,8 \neq 24,7-24,6$$
$$0,4 \neq 0,1$$

For factor B:

$$24,6-25,8 \neq 24,7-26,2$$
$$-1,2 \neq -1,5$$

Now, with the factors Shift (Factor A) and Lamp (Factor C), we see the table of factors Tab. 4 and levels and, later, the effect calculation between them:

The main effect of factor b is the difference between the average response between its high and low levels:

$$Ef.B = \frac{24,7+24,6}{2} - \frac{25,8+26,2}{2}$$

$$Ef.B = -1,35$$

Table 2. General results obtained in the experiment

N° EXPERIMENT	NOISE FACTORS			OBTAINED TEMPERATURES		MÉDIA (°C)	S/R
	SHIFT	DOOR	LAMP	RESULT 1 (°C)	RESULT 2 (°C)		
1	Morning	Open	Connected	26,3	25,3	25,8	-28,23
2	Morning	Closed	Off	24,4	24,8	24,6	-27,81
3	Afternoon	Open	Off	25,9	26,5	26,2	-28,36
4	Afternoon	Closed	Connected	24,9	24,5	24,7	-27,85

Table 3. Effects a-b

FACTOR A	FACTOR B	
	B low	B high
A low	25,8	24,6
A high	26,2	24,7

Table 4. A-C effects

FACTOR A	FACTOR C	
	C low	C high
A low	25,8	24,6
A high	24,7	26,2

Table 5. B-C effects

FACTOR B	FACTOR C	
	C low	C high
B low	25,8	26,2
B high	24,7	24,6

The main effect of factor A is the same as the previous one, changing factor A from the lowest to the highest level:

$$Ef.A = \frac{24,7+26,2}{2} - \frac{25,8+24,6}{2}$$

$$Ef.A = 0,25$$

The main effect of factor C is also the difference between the average response between its high and low levels:

$$Ef.C = \frac{24,6+26,2}{2} - \frac{25,8+24,7}{2}$$

$$Ef.C = 0,15$$

Thus, we have that, changing the factor C from the lowest to the highest level, there is an average response of 0.15 °C. We can also see that the difference between high and low levels is not constant.

Para fator A:

$$26,2-24,6 \neq 24,7-25,8$$

$$1,6 \neq -1,1$$

Also indicating that there is interaction between the mixture and the adopted container. For the last effect analysis, we have the comparison between the Shift (Factor B) and the Lamp (Factor C), in Tab. 5.

We see that changing factor b from the lowest to the highest level, there is a drop of -1.35 c in the average response, as in the previous case. The main effect of factor c is also 0.15 c, as previously calculated:

$$Ef.C = \frac{24,6+26,2}{2} - \frac{24,7+25,8}{2}$$

$$Ef.C = 0,15$$

We can also verify that the difference between the high and low levels is not constant:

For factor b:

$$26,2-25,8 \neq 24,6-24,7$$
$$0,4 \neq -0,1$$

For factor c:

$$26,2-24,6 \neq 24,7-25,8$$
$$1,6 \neq -1,1$$

Thus, we see that there is interaction between time and the laboratory room. In order to verify which interaction is most significant, we calculate the interaction effect that can be given by the difference in the averages of the high and low levels of each case.

Checking the process with minitab software: Using the minitab software, we can obtain general interaction data

Table 6. General results obtained in the minitab software

N° EXPERIMENT	SHIFT	DOOR	LAMP	RESULT 1 (°C)	RESULT 2 (°C)	MEDIA (°C)	RAZSR1	DESVP AD1	MED1
1	Morning	Open	Connected	26,3	25,3	25,8	-28,2335	0,5	25,8
2	Motning	Closed	Off	24,4	24,8	24,6	-27,8189	0,2	24,6
3	Afternoon	Open	Off	25,9	26,5	26,2	-28,3664	0,3	26,2
4	Afternoon	Closed	Connected	24,9	24,5	24,7	-27,8541	0,2	24,7

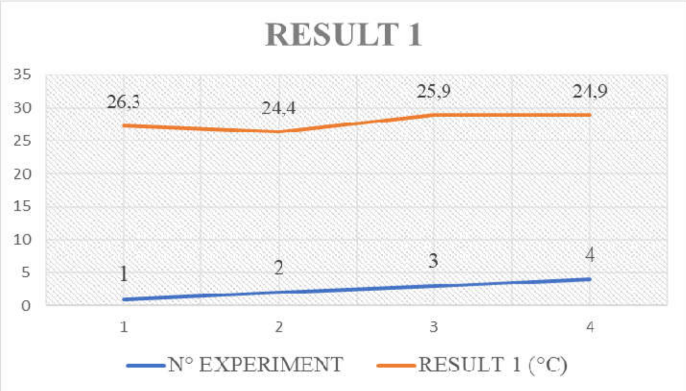

Figure 2. Experimental result 1

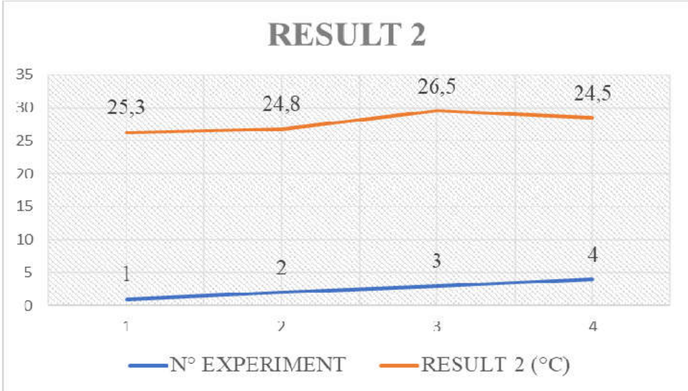

Figure 3. Experimental result 2

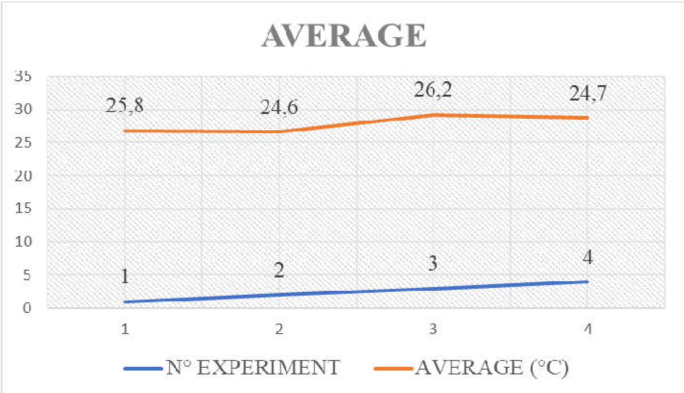

Figure 4. Average results

through graphics generated in the program. From the values determined in table 1, other significant data can be obtained, such as standard deviation and signal-to-noise ratio of the system. Table 6 shows the results obtained in the studies done through this software, which comes to emphasize the results of the given system. Other results that can define the comparative result of the systems are the interaction graphs for the data. It shows the integration in a very marked way. For better understanding, a graph with parallel lines indicates that the observed factors have no interaction. However, whatever the slope present in one of the compared factors may indicate an interaction. Factors that intersect in an interaction graph indicate that the system is interactive and have a very strong interaction (the slope of the line on the graph is directly related to the degree of interaction between the factors).

RESULTS AND DISCUSSIONS

The results indicate that, comparing all the factors and those that present the greatest interaction and significance at the temperature of a room (refrigeration laboratory), in the following cases you vary: manhã, afternoon, open door, dated cover, light linked or Unlinked light, presents relevant results for the reduction of the internal temperature of the room and a better economy and performance of two conditioned ar equipment.

For each um two results we can analyze that:

- Or a less efficient method for a greater economy of electrical energy and a greater efficiency of two conditioning devices of ar, during, or the experiment takes place at a determined time of one hour, since it has been found to have varied analyzes and verified as lower and higher Temperatures have seen that it was tracked in the middle of all the experiments and collected the values to verify or deviate pattern.
- Comparing or performing mixtures, the results are more positive when a mixture is used with alcohol, after the temperature remains more accentuated and with a higher speed than with a mixture of gelated water with gel;

At a higher temperature it is given, significantly, I do not experience 2 in that it was made by pela manhã, with a dated cover and detached light, noting-it is also noted that either energy ganho or that within a year it can generate an expressive financial economy and a greater efficiency two are conditioned além of a greater longevity of the machines;

The interferência das variáveis also significant, but less accentuated (with a remain of -1.6 ° C ao vary from dated cover, detached light and pela manhã).

Therefore, in a general profile, no case of these experiments, we have an optimized result that says that for a given situation in which an individual needs to cool down a room (refrigeration laboratory with a longer time and lower temperature, in the best way to obtain such results would be : Submeter or environment as follows varies, dated doorway, detached light and pela manhã, since during a period of one hour there is an expressive ganho and a greater refrigeration of the environment.

CONCLUSION

According to what was verified over the year, taguchi presents a method used in order to reduce the number of tests of different configurations to the applied case. It was verified that the time was a factor of great influence or limit of the time of cooling of an environment, mainly of a room (refrigeration laboratory), with changes in various and suas combinations for a higher level of conditioning equipment, Because the energy consumption is higher, therefore, or the taguchi method will be effective in the environment and the energy level of a conditioning machine. A more optimized result of the experiment can be obtained, which was validated in two ways: manual and computational (minitab software), in order to validate the responses obtained in the applied situation. The taguchi method shows that it is very fair not that it says it respects the number of experiments carried out and compares two results obtained, being quite significant for the industrial, amateur or academic production environment.

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