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Didactic tool applied into data collection and variability study in a process

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Abstract: The objective of this paper is to present an application of design of experiments in which students learn how to get real data with application to a case using the catapult, and generate their statistical analysis through software, in order to have a great reliability, at the work development. The variation factors are selected between maximum and minimum levels accepted by catapult. The experimenting has showed. The results of the experiment are collected connected to the desired range, they are presented in tables and interaction graphs and Pareto graph. Doing the experiments it has been showed that not all variables of the catapult initially considered affect the quality of the result of the experiment. That is, for adjusting the bands considered only one factor has a significant effect on the quality of the experiment, it can be stated that there is no need to set a specific value of the catapult, but rather a range of values within which the experiment will have good performance.

Keywords: Catapult, Design of Experiments (DOE), Software Minitab®

1. Introduction

There is a consensus among teachers relate education and work as part of academic life in objectives and concrete terms [1], bringing opportunities for both students and school. Allied to this, students are engaged through activities proposed based on actual problems and also it is provided an integration of study with work [1].

The use of real information is a way enough practice to understand better problems presented in classroom [2].

MiniTab® is currently used in statistics teaching at universities and companies around the world [3], in business training, in consulting and in 'Six Sigma' courses, especially in certifications such as Green Belt and Black Belt, because of its capacity to perform statistical analyses and its ease of use. So, the knowledge of this tool makes students better prepared for the job market [4].

The design of experiments is one of the most important tools inserted in DMAIC (define, measure, analyse, improve, and control) methodology. This tool searches problems solutions in a coordinated way and the improvement of processes and people involved in the same activities always defined by the project manager [5]-[10].

The six sigma DMAIC method was critically compared with insights from scientific theories in the field of problem solving [11]-[15]. It was used to examine multiple measures of experience and their relationship to the performance of work teams [16], the impact of adopting Six Sigma on corporate performance [17], and also in manufacturing execution systems (MESs) [18], in information security risk management (ISRM) [19] and in a knowledge management system [20].

Factorial design with general guiding principles with an experimental objective and how a DOE is conducted with a simple illustrative example was provided by [21]-[26]. The design of experiments has been used as a consolidated tool for data analysis in several industrial activities, such as biochemistry [27]-[28], heat transfer [29], environmental [30], and health [31].

Once data are collected, edited, summarized and otherwise prepared for detailed analysis, basic methods of statistical inference can be applied through software MiniTab® to address stated experimental and management objectives [32]-[42].

The objective of this paper is to present an application of design of experiments in which students learn to get real data with application to a case study as an example the catapult, and generate their statistical analysis using MiniTab® version 16.

2. Materials and Methods

2.1. Materials

In the practical experiments for this work were used:

- a didactic catapult developed by NCMR company [43], Figure 1;
- Measuring tape, Figure 2, with five meters of total length used for actual measurements;
- Aluminium foil, which is used to mark the final landing point after throwing the ball;
- Wide tape for fixing the catapult, the measuring tape and the aluminium foil on the test track;
- Table tennis balls with two different weights;
- Software MiniTab®, which is used to plot the data and to obtain both results, numerical and graphical.

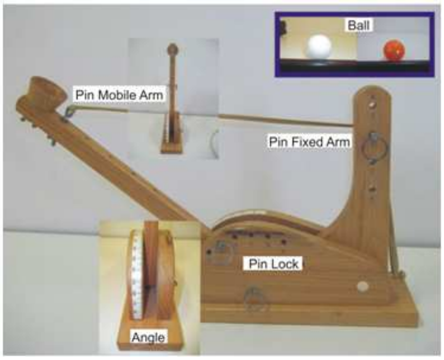
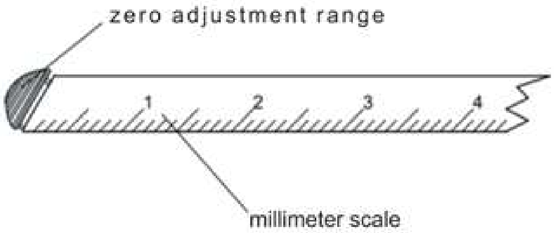


Figure 1. *Details of catapult used in the experiment*



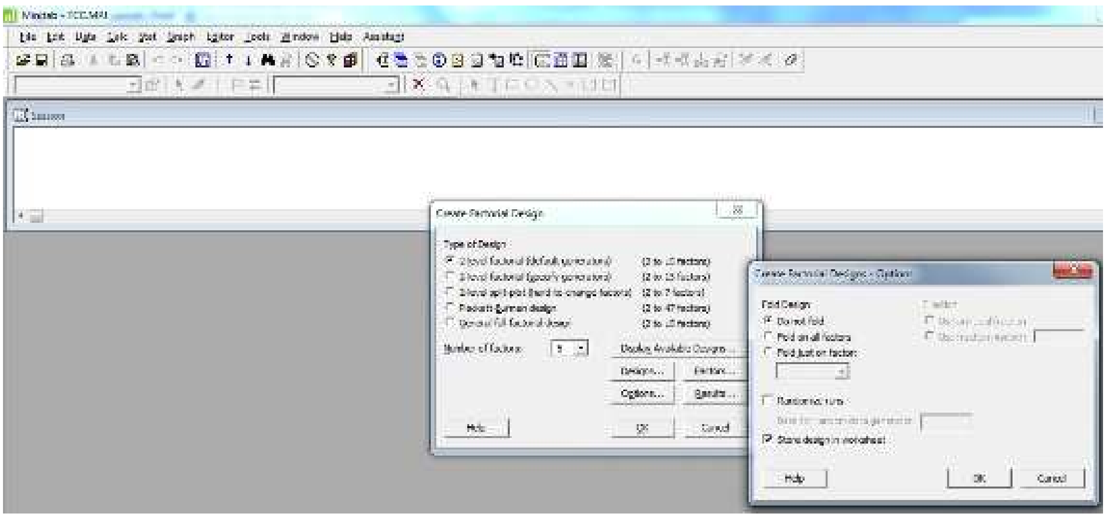


Figure 2 – *Measuring tape*

Table 1. *Maximum and minimum variables levels for the catapult experiment*

Inputs	Minimum level	Maximum level
Angle	90o	180o
Pin lock	1	6
Pin mobile arm	1	5
Pin fixed arm	1	4
Ball	white	orange

The test track was built according to the following stages:

- The first step was the aluminium foil fixation, avoid bending, because of that, the identification of the first ball bounce could be impaired;
- The second step is to fix the wide tape up paper, where "0" on the scale is exactly at the catapult base;
- The third step is to fix the catapult in order to avoid catapult dislocation by forces applied to it during its work, giving greater reliability to the data, not generating faults in the process, after performing these procedures;
- Then the MiniTab® use begins, after setting it according

to described in item 3;

- Results are noted in the experiment entries, as shown in Table 1, and all graphics needed for the experiment analysis are generated;
- All interactions that are not important to the process are discarded, until only the most important information for the experiment left.

2.2. Methods

Five variation factors between the maximum and minimum levels accepted by catapult are selected in order to develop the work with greater reliability, where the information is presented in Table 1 and showed in Figure 1.

The process optimal point will be found by the design of experiments technique of full factorial with five factors to investigate, in two levels for each factor, totalling an initial sampling of thirty-two results.

The use of MiniTab® version 16 will be of great value to this process, because it provides a step by step sampling conduction and at the end it shows the factor or factors that really matter in the range of correct metric for analysis.

3. Initial Setup Procedures

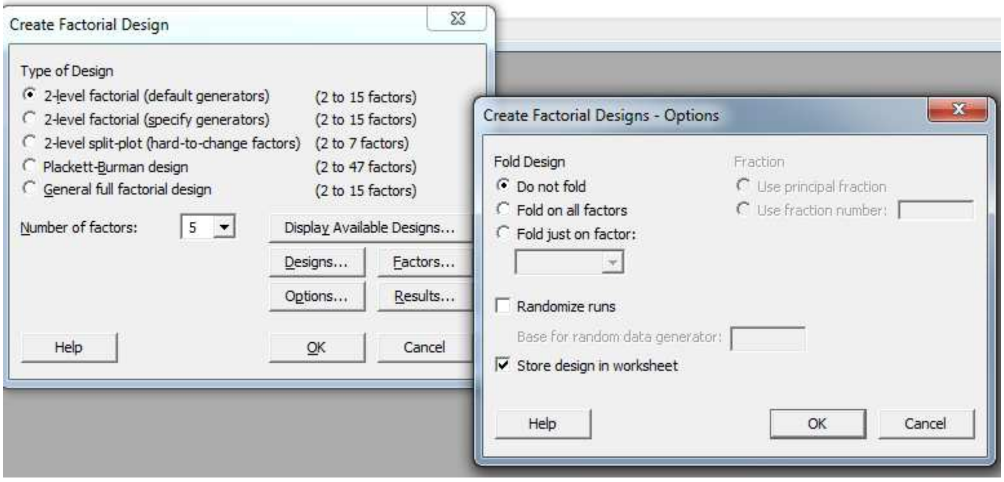


Figure 3*. Initial step to creating the DOE*

At software MiniTab® choose "Stat/DOE/Factorial/Create Factorial Design" option, as shown in Figure 3. It will open a window that shows all kinds of design that can be made. The option will be used is "2-level factorial (default generators) (2 to 15 factors)" and in "number of factors" choose "five" that will be the factors number worked in this experiment, because it is seeking process reliability and the highest number of possible answers at this point.

After this verification click on the option "designs", choose in this window "full factorial = 32 runs", which will work in a maximum resolution for the experiment (25 = 32) that used two factor levels, always the maximum and minimum for each of the five variances. The other options in this window should be "centre number of points", "by block = 0", so that "number of replicates for corner points = 1" and "number of blocks = 1".

3.1. Display Available Designs

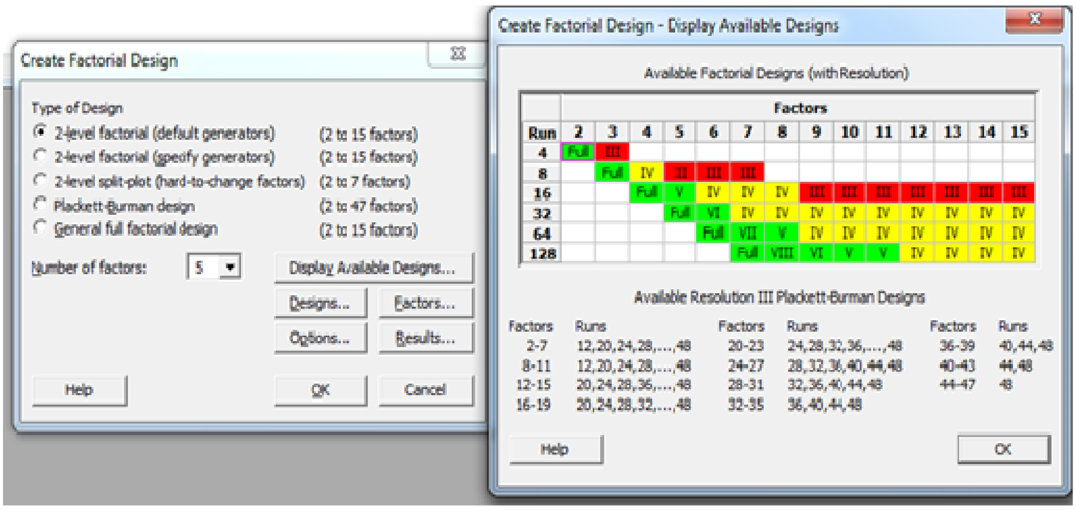


Figure 4. *"Display available designs" option*

The next stage is to see how many samples may be run, through "display available designs" option, according to the factors number chosen as variables for the process in study; it is possible to choice making the maximum reasonable number of experiments or less. The colours shown in the table prompted at "display available designs" window indicate the intensity for each choice that may have, shown in Figure 4.

3.2. Variables Insertion

In the "Factors" option is possible to insert the experiment variables and to write factors that influencing the catapult, as shown in Figure 5.

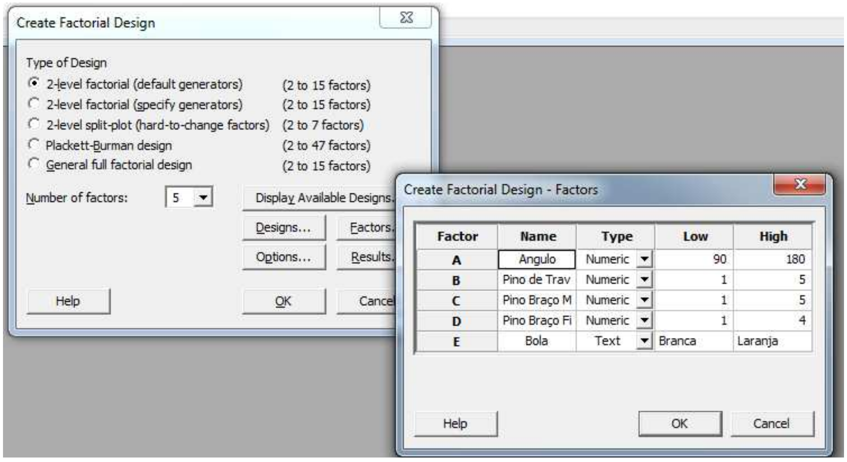


Figure 5. *Maximum and minimum factor values inserted*

It is important to remember that must be entered in a consistent manner, for example, the ball type is a text type and its limits are given relate to the ball colour. If it was placed as a numeric type, MiniTab® does not accept the factor creation and gives error: "factors must be numeric", then returns to the input screen of factors. The lower and upper limits of each factor are used as maximum and minimum levels that the catapult allows.

3.3. Data Comparison

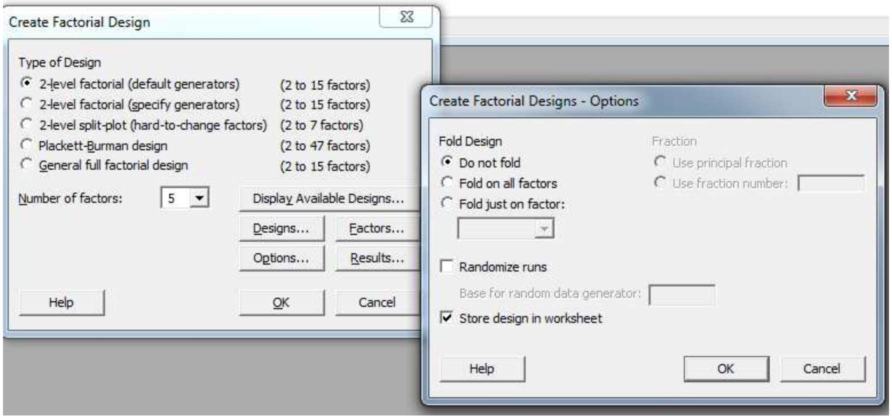


Figure 6. *Configuration for data collection*

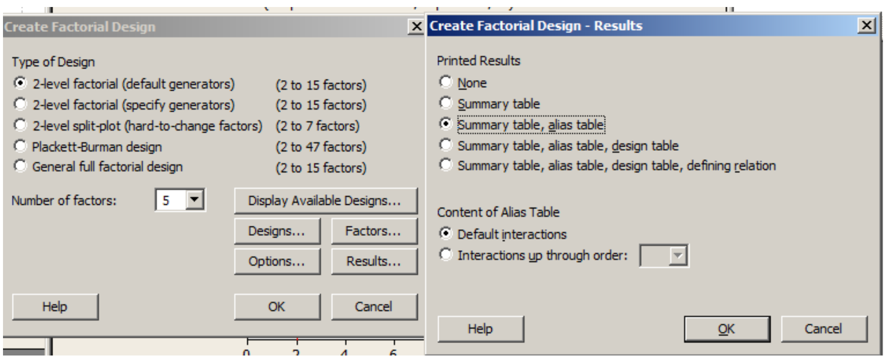


Figure 7. *Other configuration for data collection*

In this stage, there are data comparisons to determine how many times each possibility appeared for each variable. After typing and data confirmation, it must standard extra options in “fold design”, where “do not fold” is chosen and only “store design in worksheet” is ticked, as shown in Figure 6.

Into the “results” option, “summary table” and “alias table” for “printed result” also “default interactions” for “content of alias table” must be chosen. After that steps completed, it must click on the "OK" button and data are compared with each other, as shown in Figure 7.

This procedure is done in order to eliminate any vice at the experiment time, because the performance may not have interference towards excessive repetition of the same variable, and with these changes it is obtained a more accurate integration.

4. Results and Discussion

4.1. Results with Five Variables

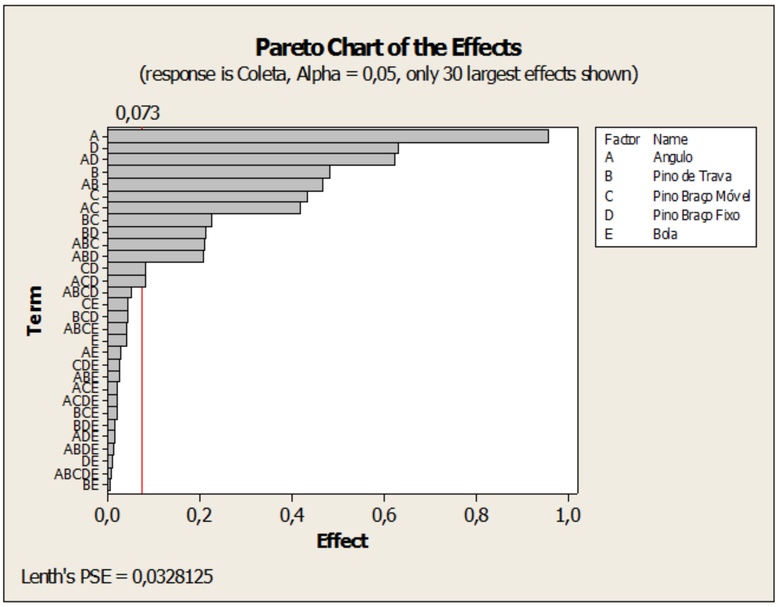


Figure 8. *Pareto chart generated data of Table 2*

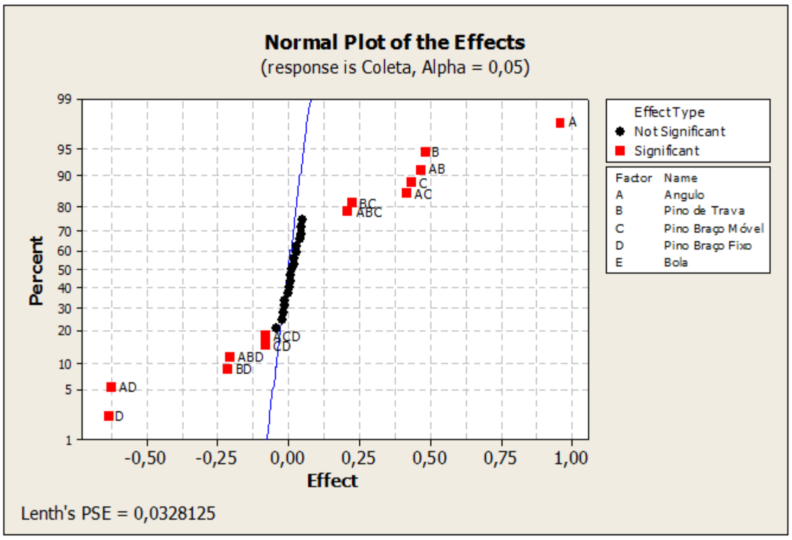


Figure 9. *Test effects generated plotted from Table 2*

The results of data collection for the catapult experiment related to range balls are shown in Table 2.

Based on data from Table 2 the main effects and interaction one can be estimated, as shown in Figures 8 and 9, where it can be noted that the indicator angle is in extreme evidence.

It is observed in Figure 8 that among the main effects, the most significant are A (angle) and D (fixed arm pin). Among the interaction effects, the most significant are AD (angle and fixed arm pin), AB (angle and lock pin) and AC (angle and mobile arm pin), however, because they are so closed each other around reference line their information is confused.

Thus, it becomes difficult to determine with these results which combination is the most important of the catapult experiment. It is noted that Figure 9 shows data generated from Table 2, the further away from the reference line is the most significant variable to the experiment, and therefore the closer the variable has less significance for the experiment.

Figure 10 shows the experiment interaction graphs in which it is observed that some main effects and interaction ones are far from reference line. This indicates that these effects are significantly different from zero, it is clear that the significant main effects are: A (angle), D (fixed arm pin) and AD (angle and fixed arm pin). As for other purposes, it appears that are distributed along a line therefore are not significant in this catapult experiment.

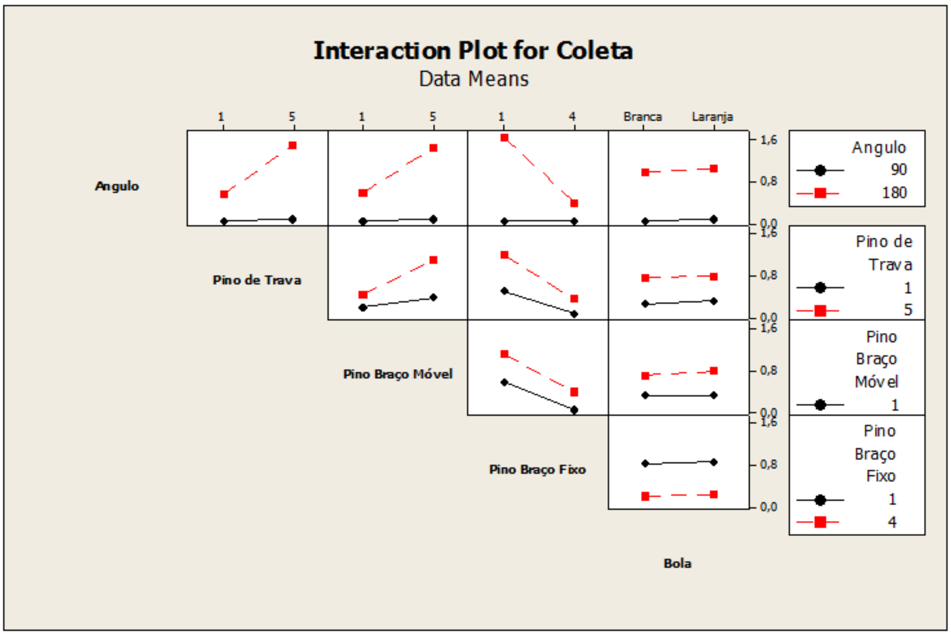


Figure 10. *Interaction graph for data generated from Table 2*

Analyzing the experiment results it could make the interactions elimination, in order of least significance in the experiment, as steps shown in Figure 11, which shows the way into the factor analyses framework and Figure 12 shown how to remove the interaction less significant for the process.

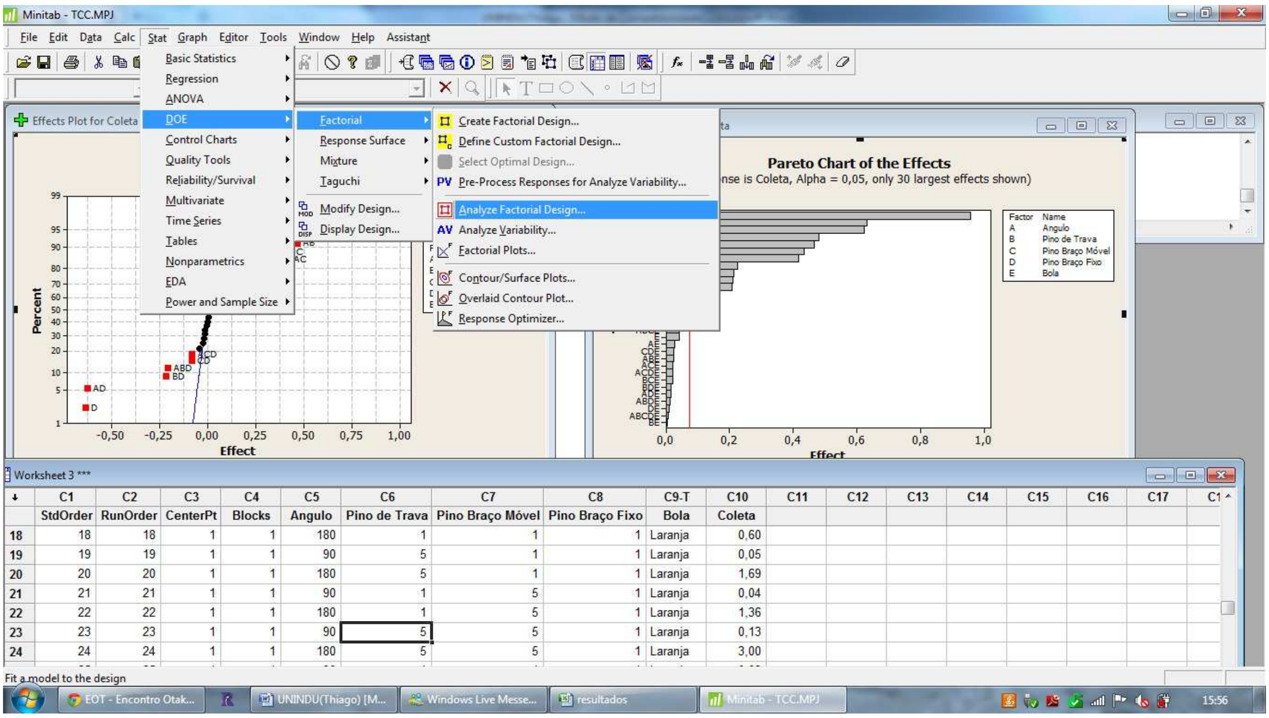


Figure 11. *Path to factor analyses framework*

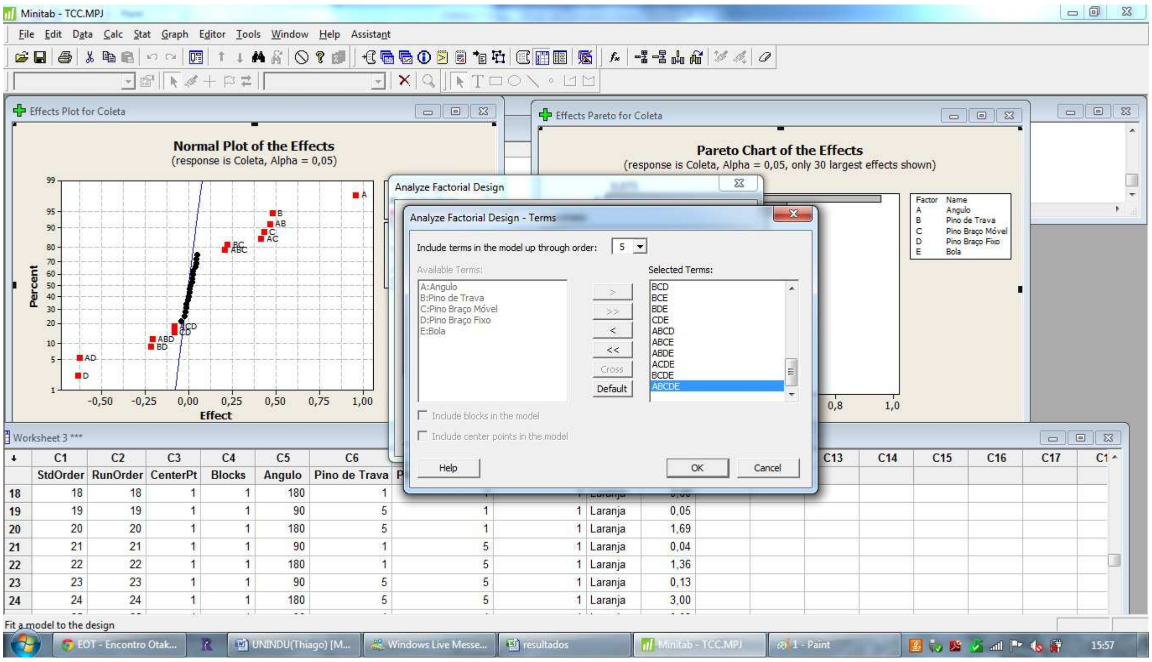


Figure 12. *Removing interaction with less influence on the process*

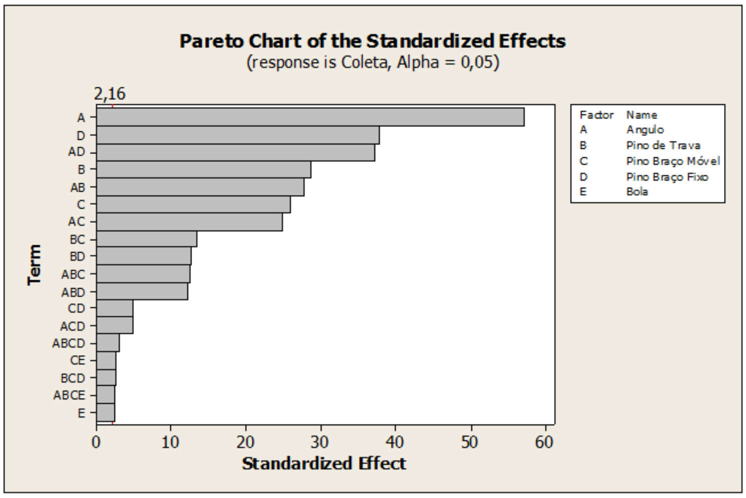


Figure 13. *Graph of effects with variables without significance withdrawal*

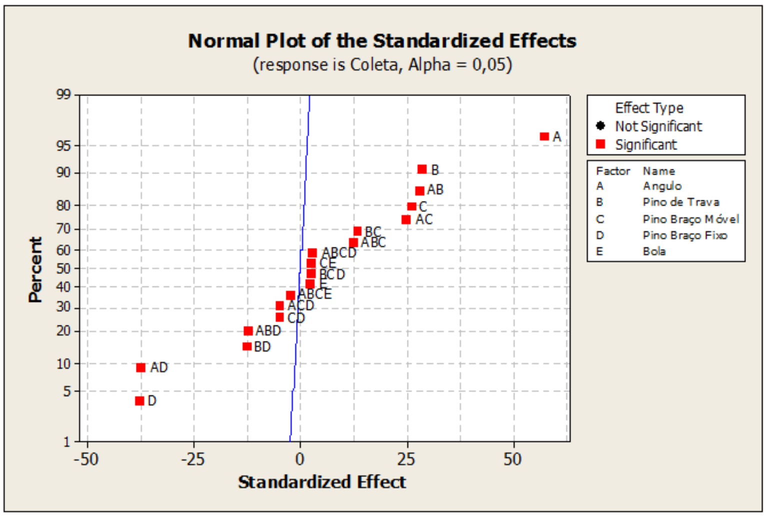


Figure 14. *Pareto chart with bars within the limit of significance*

The withdrawal of the interactions must occur one by one to not undermine the reliability of the experiment; all interactions from left side of the reference line of the graph are removed. In this action is used the Lenth's method that aims to decide which effects are significant for experiments without replication [44], always from the group with the highest factors value together to the lowest one, from bottom to top, this should be performed until do not have interactions in the same, it was performed sequentially removing the following interactions sequentially: BCDE, ABDE, ACDE, ADE, BDE, BCE, ACE, ABE, CDE, BE, DE and finally AE, as shown in Figures 13 and 14.

It may be noted that the three indicators that stood out in this experiment were angle, lock pin and fixed arm pin, but the biggest indicator that graphically displays the results in relation to experience noticeably.

Table 2. *Results generated from data collection for five variables*

Angle [degree]	Lock pin	Pin mobile arm	Pin fixed arm	Ball	Distance [cm]
90	1	1	1	white	0.05
180	1	1	1	white	0.64
90	5	1	1	white	0.05
180	5	1	1	white	160
90	1	5	1	white	0.05
180	1	5	1	white	123
90	5	5	1	white	0.05
180	5	5	1	white	300
90	1	1	4	white	0.05
180	1	1	4	white	0.05
90	5	1	4	white	0.05
180	5	1	4	white	0.05
90	1	5	4	white	0.05
180	1	5	4	white	0.05
90	5	5	4	white	0.03
180	5	5	4	white	121
90	1	1	1	orange	0.05
180	1	1	1	orange	0.6
90	5	1	1	orange	0.05
180	5	1	1	orange	169
90	1	5	1	orange	0.04
180	1	5	1	orange	136
90	5	5	1	orange	0.13
180	5	5	1	orange	300
90	1	1	4	orange	0.03
180	1	1	4	orange	0.03
90	5	1	4	orange	0.03
180	5	1	4	orange	0.03
90	1	5	4	orange	0.05
180	1	5	4	orange	0.35
90	5	5	4	orange	0.1
180	5	5	4	orange	130

4.2. Results with Three Variables

It was used three indicators for this second experiment, the angle that noticeably affects the first experiment and mobile arm pin and balls of different weight for new tests, shown in Table 3, it can be seen data already plotted with their interconnections with six replications for each interaction, and at experiment time ten throws were carried out and four replications were eliminated when the two largest and the two smallest values that would be released in MiniTab®, making the experiment of greater reliability, to obtain the lowest variability in the results.

The significance points of the experiment are shown in Figure 15, where is clearly seen that there are two points more significant than other, and Figure 16 shows by means of Pareto chart that points A and C are the most important experimentation, but as there are many points to the left of the reference line are removed as previously described, always those with lower significance for the experiment, until reaching the reference line or until there are no more to be analysed.

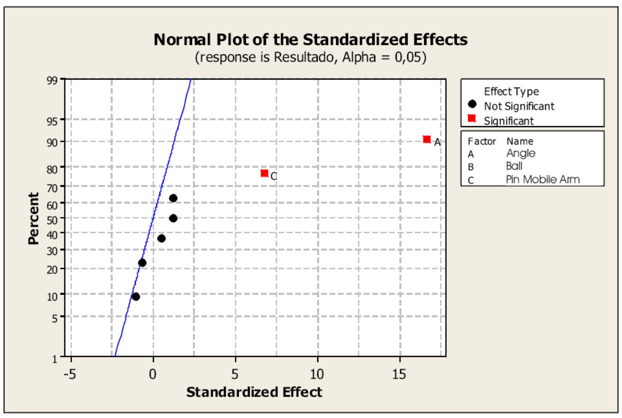


Figure 15. *Graph showing effect of significance points*

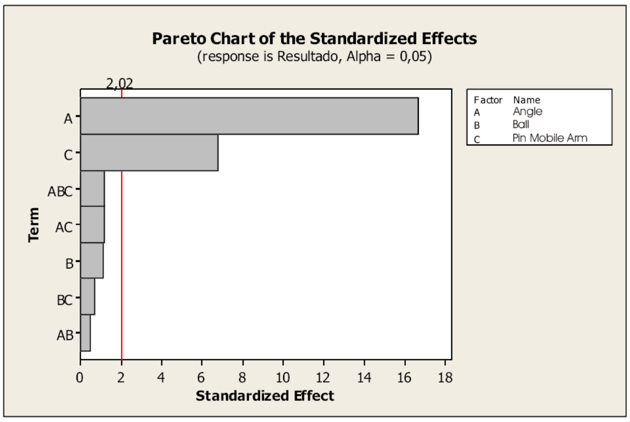


Figure 16. *Pareto chart showing columns below the reference line*

With no significant variances for the experiment, it can already see more clearly the point A significance for the year, and it is possible a final analysis where the angle is rather variable that has most significance in the experiment, then it was commonsense stop to remove the points, shown in Figure 17 and Figure 18.

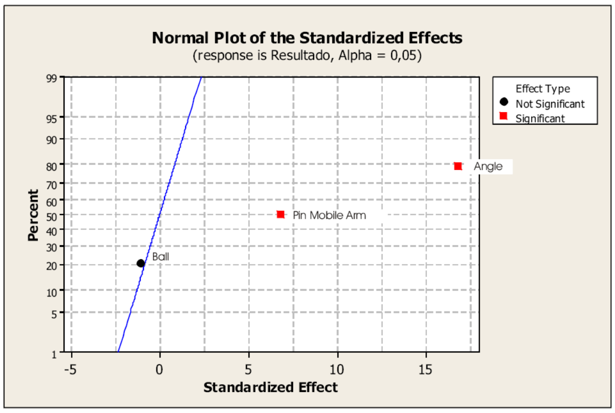


Figure 17. *Graph of experiment end effect*

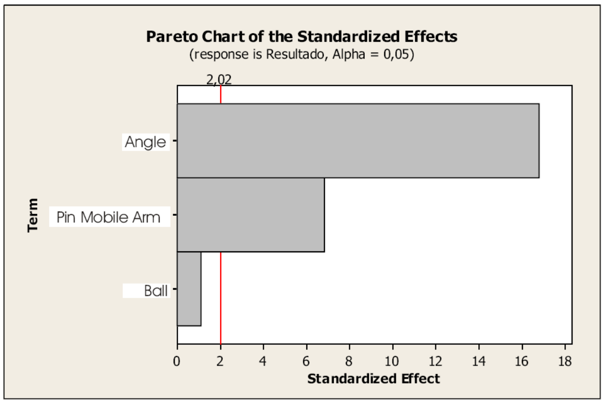


Figure 18. *Pareto chart showing the actual experiment significance*

Table 3. *Data plotted with six replications*

Angle [degree]	Ball	Pin fixed arm	Distance [m]
180	orange	3	4.3
150	orange	1	1.51
180	orange	1	3.66
150	orange	1	1.51
150	orange	1	1.52
180	orange	3	4.35
150	white	1	1.52
150	orange	1	1.53
150	white	3	1.98
150	orange	3	1.95
150	white	1	1.53
150	white	3	2
150	orange	1	1.52
180	orange	1	3.65
180	white	1	3.33
180	white	1	3.35
150	orange	1	1.52
180	orange	1	3.65
180	white	3	4.45
180	orange	3	4.45
150	orange	3	1.98
180	white	1	3.37
150	orange	3	2.02
180	orange	1	3.6
180	white	3	4.5
180	orange	1	3.54
180	orange	1	3.53
180	white	1	3.4
150	white	1	1.54
150	white	3	2.01
150	orange	3	2.04
150	white	3	2.02
150	white	1	1.55
150	orange	3	2.04
180	orange	3	4.47
180	white	3	4.5
180	white	3	4.65
180	white	1	3.4
150	white	3	2.02
150	white	1	1.57
180	white	1	3.45
180	white	3	4.7
150	orange	3	2.02
150	white	3	2.06
150	white	1	1.61
180	white	3	4.8
180	orange	3	4.5
180	orange	3	4.6

4.3. Comparison of the Results

Both experiments show that the angle is the indicator with the most influence on the final result, this proof are statements of plots in Figure 16 and Figure 18, where the Pareto chart visually showed a large difference between the variable "angle" and the other ones in a search for better results.

5. Conclusions

It could show that not all variables initially considered for the catapult experiment affect the quality of the experiment result. That is, for adjusting the bands considered only one factor has a significant effect on the experiment quality, it can be stated that there is no need to set a specific value for the catapult angle, but rather a range of values within which the experiment will have good performance.

This work has presented a methodology based on design of experiments (DOE), which will be useful to develop projects more effectively.

Because the lack of appropriate procedures and techniques in levels setting, the catapult experiment generates the high variability in terms of the ball reach outcome, this fact demonstrated need to use statistical tools and to perform new experiments and this provided through the second experiment a proof that the first experiment can be considered.

And finally showing the need for future experiments, not only to encourage the use of these techniques in business, but also promote school and company approximation.

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