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APPLICATION OF COMPARATIVE EXPERIMENT IN ANALYSIS OF WOOD STRENGTH

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Abstract: The paper describes a method of comparative experiment, which is a simple method of design and analysis of experiment in which the effects of two different treatments are compared. The aim of this experimental method is to compare the differences of the dependent variable after obtaining the results of the experiment and to conclude whether one of the treatments is more effective than the other or that both treatments are equally effective. To explain this method, we will take the example of determining the maximum force when bending fifteen slab samples of two different types of wood, solid and fibreboard. Maximum force data were obtained in the laboratory of the Technical Faculty Bihac on the universal testing machine. The data were processed by the method of comparative experiment in the classical way and by the software package R intended for statistical and experimental data processing.

Keywords: comparative experiment, software package R, statistical & experimental data processing

1. INTRODUCTION

Design of Experiment is one of the new scientific disciplines whose object is the scientific-research experiment. The word experiment is inspired by the Latin word of the experiment, which translates into an opus or an excuse. There are several different definitions of experiments, but from the engineering point of view we can say that the experiment presented a scientifically designed opus that includes the operation system, algorithm and experimental technique, to test an object under well-defined regimes and conditions. The experiment is used in the final phase of the research when it is the key criterion for verifying the truth of theory and hypothesis. One experiment can have different meanings. Thus, in engineering analyzes, the experiment may be the preparation of pieces of a material and the measurement of the characteristics of that piece. It may also mean studying the moon by sending monthly footage or studying the Earth's Ozone Layer. Also, the experiment may also mean studying the effects of certain drugs in the treatment of certain diseases in humans. In all of these studies it is assumed that the visible part of the population or data is representative. Design of Experiment (DOE) is a powerful tool for achieving significant product quality improvements and process efficiency. For the design of the experiment it can also be said that it is the methodology of applying statistics in the process of performing the experiment. As such discipline is not just a engineering problem but is used in different social sciences [1].

A well-planned experiment allows us to get clear interpretations and avoid complicated analyzes. The poorly planned experiment gives us some wrong conclusions of a process. Design of Experiment is of particular importance in all quantitative studies, especially when multiple factors are studied at the same time to examine and compare their effects [2].

2. SIMPLE COMPARATIVE EXPERIMENTS

Simple comparative experiments are those in which we compare two conditions or treatments. A comparative experiment starts with a question or hypothesis that asks how two or more treatments affect some response. When a scientist wants to know the difference between the effects of treatment A and treatment B on dependent variable C, he will run an experiment in which all of conditions are the same except for one. After receiving the results of the experiment, the scientist can compare the difference in the dependent variable C for each treatment. We can conclude either that one treatment is more effective than the other one or that both treatments have the same effectiveness [1].

The main keys to a comparative treatment are control and randomization. Control refers to holding constant all of the other variables that could affect the outcome. Randomization refers to randomly assigning the experiments subjects to the two or more treatment groups. It also allows for valid conclusions and statistical analysis across treatments.

Comparative experiment can save scientist the trouble of having to allocate resources to a second run with a different treatment. Comparative experiments do not need to include control which can be a problem if both treatments yield similar results [3].

3. PRACTICAL EXAMPLE OF COMPARATIVE EXPERIMENT

To compare results for some experiment we made 15 samples of different type of wood, solid spruce and fibre wood. Sample dimensions are 19x50x361 [mm] according to standard BAS EN 789. The samples were bended in four points. We increased bending force from zero to the value of force at which sample breaks.



Figure 1. Bending of wood sample

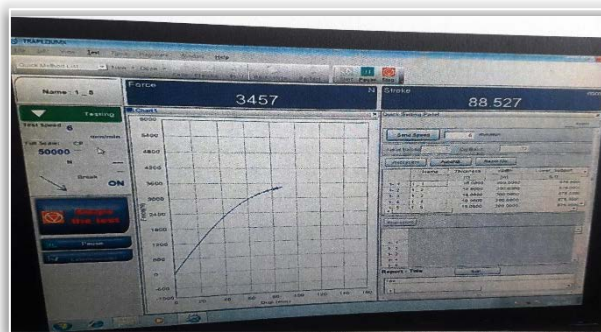


Figure 2. Measuring of force

So we had total of 30 samples and measured maximum force in Newton [N] before sample breaks at the Shimadzu testing machine in the Laboratory at the Faculty of Technical Engineering in Bihac. Figure 1 shows bending of wood sample at the Shimadzu testing machine and Figure 2 measuring of force. Software that measures force and also other mechanical characteristics and is connected to the testing machine is Trapezium X software [4].

Trapezium X software is compatible with Shimadzu testing machine and can carry out various test ranging from simple test control to complex custom made patterns, using the industries first data search and preview function, free layout reports, visual wizard settings, quick panel and quick conditions lists. Complicated parameter settings can be specified while viewing the overall process flow using the Test Parameter Wizard. Guidance for operating procedures is linked to the software help function and displayed on each screen. Easy to understand illustrations are used for test control, specimens and data processing parameter screens. The illustration changes automatically depending on the test mode and specimen material which is selected by the operator [5].

We obtained results for maximum force presented in Table 1. According to the obtained results we can make a dot diagram which is often used in comparative experiment, Figure 3.

Table 1. Maximum Force results

Sample	Maximum Force (N) Solid Wood	Maximum Force (N) Fibre wood
1	2513	3100
2	2347	3000
3	2197	3088
4	2009	3484
5	1825	3550
6	2513	3382
7	2470	3507
8	1987	3317
9	2445	3589
10	2346	3368
11	2066	3375
12	2446	3492
13	1558	3191
14	2086	3322
15	1886	3370

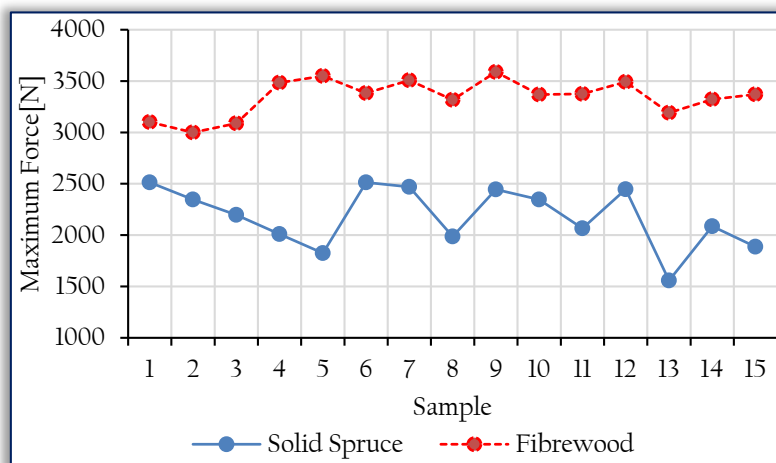


Figure 3. Dot diagram for the maximum force data in Table 1

Visual examination of results gives us obvious conclusion that maximum force of fibrewood is greater. Arithmetic means of both types of wood are 2179,60 [N] for Solid Wood and 3342,33 [N] for Fibrewood. Analysis of datas by Comparative Experiment will show us differences in both sample types. To compare both treatments we will use statistical hypothesis. In our example we compare maximum force of two treatments and we will have:

$$H_0: \mu_1 = \mu_2 \text{ - null hypothesis}$$

$$H_1: \mu_1 \neq \mu_2 \text{ - alternative hypothesis}$$

μ_1, μ_2 – Mean Maximum Forces of wood

To compare means of both treatments we will use following statistical equation:

$$t_0 = \frac{\bar{y}_1 - \bar{y}_2}{S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad (1)$$

where: \bar{y}_1, \bar{y}_2 - Means of Maximum forces; n_1, n_2 - Number of Samples; S_p - Estimated Common Variance computed:

$$S_p^2 = \frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1 + n_2 - 2} \quad (2)$$

S_1^2, S_2^2 - Individual Sample Variances

Individual sample variances are calculated by equations (3) and (4).

$$S_1^2 = \frac{(2513-2179,60)^2 + (2347-2179,60)^2 + \dots + (1886-2179,60)^2}{14} = 85018 \quad (3)$$

$$S_2^2 = \frac{(3100-3342,33)^2 + (3000-3342,33)^2 + \dots + (3370-3342,33)^2}{14} = 31584 \quad (4)$$

Table 2. Basic statistical terms of both samples

	Solid Wood	Fibre wood
Aritmetic Mean	2179,60	3342,33
Variance	85018	31584
Standard deviation	291,5	177,7
Number of samples	15	15

Standard deviation of samples are calculated by equations (5) and (6).

$$S_1 = \sqrt{85018} = 291,5 \quad (5)$$

$$S_2 = \sqrt{31584} = 177,7 \quad (6)$$

Now we can show basic statistical terms of both samples in table 2.

From t - Distribution table (Figure 4) we define value of t for level of significance $\alpha = 0,05$ and degrees of freedom $n_1 + n_2 - 2 = 28$. The t value from t - Distribution table is $\pm 2,048$.

We will reject null hypthesis if t_0 from equation (1) is $t_0 > +2,048$ or $t_0 < -2,048$. Area of accepting or rejecting null hypothesis is shown in Figure 5.

t	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1	1.500	1.376	1.253	1.131	1.010	0.891	0.775	0.661	0.549
2	0.816	0.701	0.587	0.474	0.361	0.250	0.141	0.033	0.026
3	0.765	0.651	0.537	0.424	0.311	0.200	0.091	0.033	0.026
4	0.741	0.627	0.513	0.400	0.287	0.176	0.067	0.033	0.026
5	0.727	0.613	0.499	0.386	0.273	0.162	0.053	0.026	0.026
6	0.718	0.604	0.490	0.377	0.264	0.153	0.044	0.026	0.026
7	0.711	0.597	0.478	0.365	0.252	0.144	0.035	0.026	0.026
8	0.706	0.592	0.473	0.360	0.247	0.139	0.030	0.026	0.026
9	0.703	0.588	0.469	0.356	0.243	0.135	0.026	0.026	0.026
10	0.700	0.585	0.466	0.353	0.240	0.132	0.026	0.026	0.026
11	0.697	0.582	0.463	0.350	0.237	0.129	0.026	0.026	0.026
12	0.695	0.580	0.461	0.348	0.235	0.127	0.026	0.026	0.026
13	0.694	0.579	0.460	0.347	0.234	0.126	0.026	0.026	0.026
14	0.692	0.578	0.459	0.346	0.233	0.125	0.026	0.026	0.026
15	0.691	0.577	0.458	0.345	0.232	0.124	0.026	0.026	0.026
16	0.690	0.576	0.457	0.344	0.231	0.123	0.026	0.026	0.026
17	0.689	0.575	0.456	0.343	0.230	0.122	0.026	0.026	0.026
18	0.688	0.574	0.455	0.342	0.229	0.121	0.026	0.026	0.026
19	0.688	0.574	0.455	0.342	0.229	0.121	0.026	0.026	0.026
20	0.687	0.573	0.454	0.341	0.228	0.120	0.026	0.026	0.026
21	0.686	0.572	0.453	0.340	0.227	0.119	0.026	0.026	0.026
22	0.686	0.572	0.453	0.340	0.227	0.119	0.026	0.026	0.026
23	0.685	0.571	0.452	0.339	0.226	0.118	0.026	0.026	0.026
24	0.685	0.571	0.452	0.339	0.226	0.118	0.026	0.026	0.026
25	0.684	0.570	0.451	0.338	0.225	0.117	0.026	0.026	0.026
26	0.684	0.570	0.451	0.338	0.225	0.117	0.026	0.026	0.026
27	0.684	0.570	0.451	0.338	0.225	0.117	0.026	0.026	0.026
28	0.683	0.569	0.450	0.337	0.224	0.116	0.026	0.026	0.026
29	0.683	0.569	0.450	0.337	0.224	0.116	0.026	0.026	0.026
30	0.683	0.569	0.450	0.337	0.224	0.116	0.026	0.026	0.026

Figure 4. t - Distribution table

Now we can calculte t - value (equation (1)) but first we have to calculate estimated common variance, equation (2).

$$S_p^2 = \frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1 + n_2 - 2} = \frac{(15-1)*85018 + (15-1)*31584}{15 + 15 - 2} = 58301 \quad (7)$$

$$S_p = \sqrt{58301} = 241,45 \quad (8)$$

Calculated t - value will be:

$$t_0 = \frac{2179,60 - 3342,33}{241,45 \sqrt{\frac{1}{15} + \frac{1}{15}}} = -13,18 \quad (9)$$

We can conclude that null hypothesis is rejected because $t_0 < t$ and means of maximum forces of solid and fibre wood are significantly different.

4. PRACTICAL EXAMPLE OF COMPARATIVE EXPERIMENT IN R

R is the programming language and environment for statistical calculations and visualization. It is free to use and provides a wide range of statistical methods for linear and nonlinear modelling, classical statistical tests and others. In this paper, it will be shown that the programming language R can easily solve an example of a previously performed classic experiment [6,7].

First we will make text file with experimental datas of maximum force, Figure 6. Now we can show Program Code for our example, Figure 7. Command `print(summary(maxforce))` from Figure 7 shows us statistical characteristics of both sample groups results, Figure 8. Command `boxplot(maxforce)` from Figure 7 allows to plot boxes of our experimental results, Figure 9. Finally, command `t.test(maxforce$Solidwood, maxforce$Fibrewood, var.equal = TRUE)` calculates t - value for our example, Figure 10.

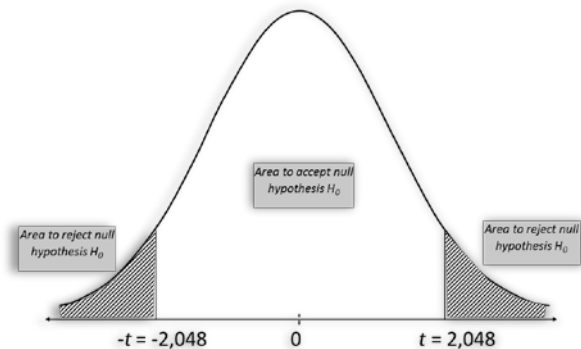


Figure 5. t - Distribution with 28 degrees of freedom with the critical region $\pm 2,048$

Solid wood	Fibre wood
2513	3100
2347	3000
2197	3088
2009	3484
1825	3550
2513	3382
2470	3507
1987	3317
2445	3589
2346	3368
2066	3375
2446	3492
1558	3191
2086	3322
1886	3370

Figure 6. Text file of experimental datas for R

```
# Comparative experiment, Strength of wood
# Nedim Hurem, Damir Hodzic, Atif Hodzic - Faculty of Technical Engineering Bihac
# Input values
maxforce <- read.table("c:/maxforce.txt", header = TRUE)
print(maxforce)
# Statistical characteristics of both groups
print(summary(maxforce))
# Plot the results
boxplot(maxforce)
# Calculating t value
t.test(maxforce$Solidwood, maxforce$Fibrewood, var.equal = TRUE)
```

Figure 7. Program code in R for comparative experiment of wood strength

Solidwood	Fibrewood
Min. :1558	Min. :3000
1st Qu.:1998	1st Qu.:3254
Median :2197	Median :3370
Mean :2180	Mean :3342
3rd Qu.:2446	3rd Qu.:3488
Max. :2513	Max. :3589

Figure 8. Statistical characteristics of both sample groups results



Figure 9. Box plots for the maximum force of solidwood (spruce) and fibrewood

```
Data: maxforce$Solidwood and maxforce$Fibrewood
t = -13.188, df = 28, p-value = 1.557e-13
Alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-1343.3363 -982.1304
Sample estimates:
Mean of x mean of y
2179.600 3342.33
```

Figure 10. Results for t – test of wood strength in R

If we compare results from R with results from classic calculation we can see that the results are similar. We can conclude that program code in R for determining difference of means for maximum force of two different types of wood is correct.

5. CONCLUSION

Design of Experiment is an important scientific field in engineering disciplines. Simple Comparative Experiment is one of the methods which is used to compare datas from two treatments. Software package R is a free code package that is accessible to everyone. It is very simple to reach conclusions for some experiment if you use R software.

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