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STATISTICAL PROCESSING OF 3D PRINTER PRINTING TIME DATA AND ANALYSIS OF INFLUENTIAL FACTORS

Abstract: *The use of 3D printers is very common in industry today due to the easy production of parts or prototyping of some products. One of the problems that can occur when printing is the length or time of printing. In this paper, statistical analysis was used to process data on the printing time of 3D printers, and based on such statistical analysis, a conclusion was reached about the factors that have an impact on printing time. Six parameters were taken into account, on the basis of which the analysis of the printing time was performed.*
Key words: *Statistical, analysis, time, printing, 3D printer*

1. INTRODUCTION

3D printing is a technological paradox that is constantly evolving and bringing changes in various industries. This technology brings numerous benefits, including faster production, waste reduction and product personalization. With increasing interest and investment in research and development, 3D printing can be expected to become ubiquitous in manufacturing and significantly impact the way we make and use objects in the future [1]. The basic idea of 3D printing lies in the additive process of creating objects, contrary to traditional methods of processing materials that are often subtractive, such as CNC machines. This process involves the layering of materials, such as plastic, metal, ceramic or even biological materials, to create a three-dimensional object [2].

The speed of 3D printing depends on a number of factors, the most important of which include, design complexity, object size, printer speed, layer thickness, material, printer settings, support and infill, software optimization, post-processing, … All these factors should be considered when planning 3D printing in order to optimize the printing speed according to the needs and requirements of the project [3].

The aim of this paper is to use a statistical tool to analyze the influence of some of the parameters of the 3D printer on the printing time of one model. In this case, six different factors were analyzed, which are mostly adjusted before the actual printing. The paper consists of three more chapters, namely: research methodology, where the methodology of data collection, analysis results and the final conclusion are explained.

2. RESEARCH METHODOLOGY

2.1 Calculating of printing time

The software used to write the printer code Flashforge Creator Pro was used to calculate the time required to print the 3D model. That is, the software used in this case is FlashPrint version 3.23.1 64 bit. Figure 1 shows the layout of the desktop of the applied software.

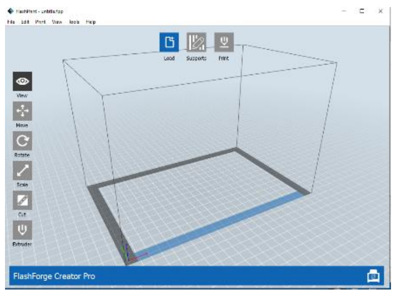

Fig. 1. Software FlashPrint software 3.23.1

The model that was applied in this case, i.e. for which the printing time was calculated, is the model shown in Figure 2.

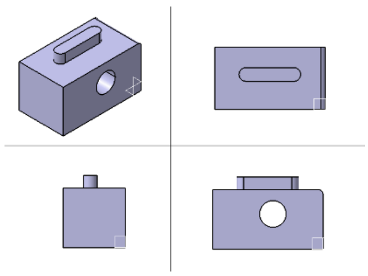

Fig. 2. 3D model that has been selected for printing

The displayed model is loaded into the printing software as shown in Figure 3.

Then, by selecting the print option, the print parameters are set as shown in Figure 4.

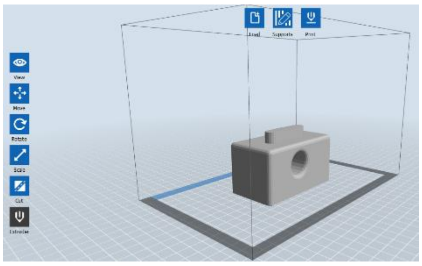

Fig. 3. 3D model in FlashPrint 3.23.1 software

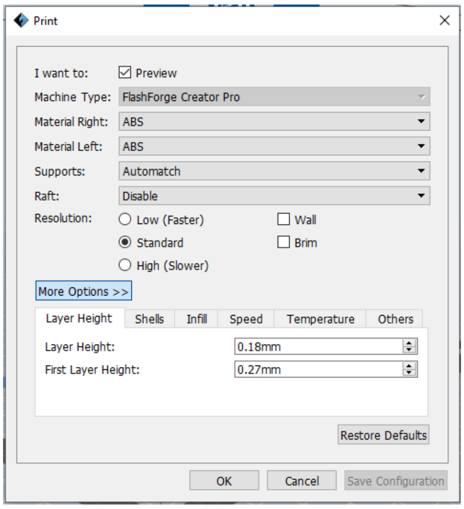

Fig. 4. A window in the software for setting print parameters

After setting the printing parameters of the 3D printer, information about the time required for the printer to print the selected model appears. An example of time is shown in Figure 5. This data was collated and analyzed based on software calculations.

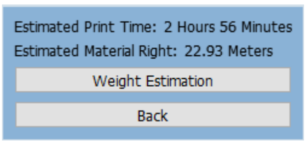

Fig. 5. Data on the required time of model printing

The time required for printing directly depends on the size of the model and the selected printing parameters. Keeping in mind that in this case, the analysis only includes the influencing factors of molding and setting, the model and its size were not taken into account. parameters that were applied and varied in this case are layer height, first layer height, travel speed of extruder, print speed, infill, extruder temperature. In this case, it was applied that the infill should be on the entire model without every other layer, except for the initial and final layers, being made of 100% material (full material). ABS plastic was always used as plastic. The fill pattern is set to always be a hexagon. The temperature of the platform is 60ºC.

In the case of six combined parameters, a total of five parameters were applied. The applied values of the parameters that were varied are shown in Table 1.

Table 1. Applied print parameter values

Parameter	Values
Layer height (mm)	0.10, 0.18, 0.25, 0.30, 0.40
Print speed (mm/s)	40, 50, 60, 80, 90
Infill (%)	0, 25, 50, 75, 100
Extruder temperature (ºC)	180, 190, 200, 210, 220
Travel speed (mm/s)	60, 70, 80, 90, 100
First layer height (mm)	0.18, 0.23, 0.27, 0.35, 0.42

Figure 6 shows the layout of the model's internal print. In this case, the layout of the interior of the model is shown for the selected infill values of 0%, 50% and 100%. Where the interior for 0% is completely hollow while in the case of 100% the interior is solid material.

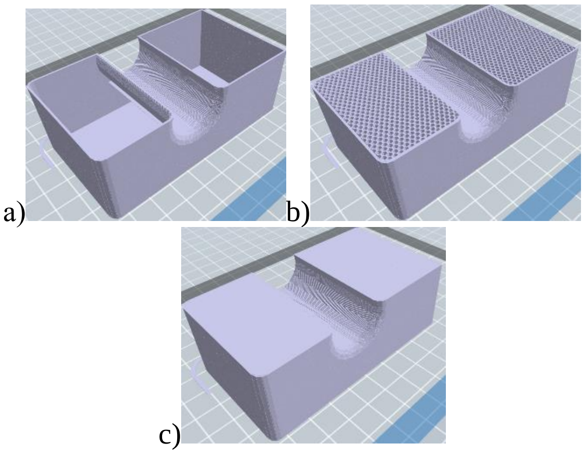

Fig. 6. Applied infill, where: a) 0%, b) 50%, c) 100%

2.2 Applied statistical analysis

Taguchi data analysis typically includes a design-of-experiments phase, where the factors, levels, and design of experiments are determined, and a data analysis phase, where the effects of factors on response are evaluated. By using mathematical models and statistical techniques, engineers and researchers can identify optimal settings of factors to improve the quality and performance of a product or process.

Taguchi data analysis is widely used in industry, especially in the automotive, electronics, pharmaceutical and other sectors where product quality and process efficiency are important. A detailed explanation of the method of calculation and analysis using Taguchi is presented in references [4].

In this case, a combination of parameters was determined by applying the Taguchi design of the experiment. Given that six factors with five levels were chosen, the combination model L25 was chosen. This means there are 25 combinations of factors. Also having in mind that the goal is to optimize the parameter so that the printing time is the shortest, a Taguchi analysis of the parameters for the shortest printing time was performed. Thus, the possibility of "smaller is better" was analyzed first. Parameters were also optimized to determine the combination that would result in the longest printing time using the "larger is better" option.

3. RESULTS

As 25 combinations of factors were taken into account, the result was that the minimum printing time is 70 minutes (combination 21), while the maximum time is 2936 minutes (combination 4). The results are shown in Figure 7. The average time is 823.64 minutes.

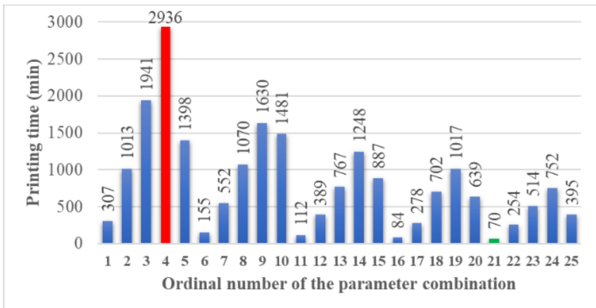

Fig. 7. Printing time depending on the combination of parameters

Taking into account that it is necessary to analyze the influence of various factors on the printing time, then it is necessary to make that time as short as possible. Thus, in this case, in Taguchi's analysis, it was assumed that the time should be as short as possible, that is, the "smaller is better" option was chosen. The results of the analysis are shown in Table 2. It can be seen that the largest influence is the occupancy within the model, followed by the height of one layer, the extruder print speed, the extruder travel speed, then the extruder temperature and finally the first layer height (FLH), which is shown in Table 2 The table shows the parameter values according to the assigned impact rank (R). Figure 7 graphically shows the aforementioned and the obtained values of influencing factors based on response for signal to noise (Rang S/N) and response for threats (Rang RM) are shown graphically.

Table 2. Analysis of the ranking of factors influencing the printing time

Level	Rang S/N	Rang RM
Layer height	2	2
Infill	1	1
Print speed	3	6
Extr. temp.	5	5
Travel of extr.	4	5
FLH	6	3

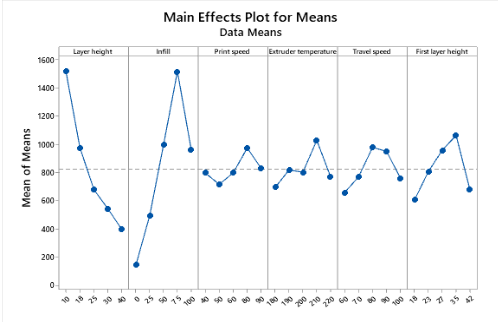

Fig. 7. Analysis of the influence of certain factors on the printing time based on effect for means

The analysis of the parameters to achieve the shortest printing time is shown graphically in Figure 8, while the values of the analysis of the parameters are given in Table 3. The table indicates the optimal values according to the parameter, i.e. according to the order of listing in Table 1.

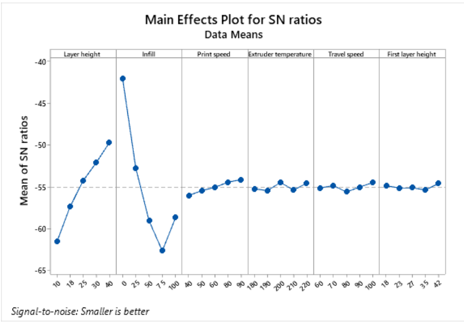

Fig. 8. Graphical analysis of the most favorable combination of factors for the shortest printing time

Table 3. Value analysis of the most favorable factors for the shortest printing time

Level	**1**	**2**	**3**	**4**	**5**
Layer height	-61.58	-57.38	-54.27	-52.11	**-49.73**
Infill	**-41.98**	-52.75	-59.04	-62.64	-58.66
Print speed	-56.02	-55.45	-55.04	-54.43	**-54.13**
Extr. temp.	-55.22	-55.45	**-54.46**	-55.4	-54.55
Travel of extr.	-55.14	-54.84	-55.6	-55.01	**-54.48**
FLH	-54.87	-55.13	-55.11	-55.37	**-54.59**

Considering that the highest quality print of the model with the highest resolution is obtained with the longest print time, the factors that would give the longest print time were analyzed. Thus, Figure 9 shows a graphic representation of the optimal values for the longest printing time. Table 4 shows the values of the analysis according to each parameter, and the most favorable parameter is marked according to the order of listing in table 1.

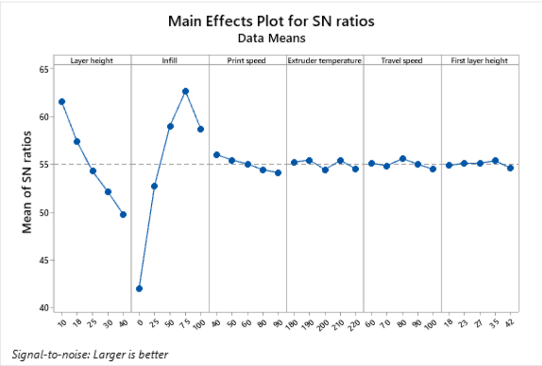

Fig. 9. Graphical analysis of the most favorable factors for the longest print time

Table 4. Analysis values of the most favorable factors for the longest printing time

Level	1	2	3	4	5
Layer height	**61.58**	57.38	54.27	52.11	49.73
Infill	41.98	52.75	59.04	**62.64**	58.66
Print speed	**56.02**	55.45	55.04	54.43	54.13
Extr. temp.	55.22	55.45	54.46	**55.4**	54.55
Travel of extr.	55.14	54.84	**55.6**	55.01	54.48
FLH	54.87	55.13	55.11	**55.37**	54.59

4. CONCLUSION

Statistical analysis of the printing time of the model on a 3D printer was performed using the Taguchi method. Based on the applied printer programming software, the printing time of the given model is determined. The result was that the filling inside the model has the greatest influence on the molding time, followed by the height of one layer, the press speed of the extruder, the travel speed of the extruder, then the temperature of the extruder and finally the height of the first layer. It was also determined by the application of statistical analysis which parameter values should be applied in this case for the shortest and longest printing time of the task model. Thus, it was determined what the influencing factors are, where it turned out that the height of the layer, the occupancy of the model and the printing speed are one of the most important factors that affect the printing time.

Future research will be limited to the statistical analysis of influential factors depending on the form of filling the interior of the model. In this case, only the model with hexagonal filling was analyzed. So the shape of the clean line and the triangular infill will be analyzed in the following researches.

5. REFERENCES

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