E-ISSN: 2717-2937 | P-ISSN: 2783-1337

International Journal of Research in Industrial Engineering

www.riejournal.com

Int. J. Res. Ind. Eng. Vol. 10, No. 2 (2021) 117–127.

Paper Type: Original Article

Optimal Value Determination for a Shape Changeable Furniture Design Parameters Using Full Factorial Design of Experiment Analysis

Mobasshira Zaman*

[1] Department of Industrial Engineering and Management, Khulna University of Engineering & Technology, Khulna, Bangladesh; mobasshirazamanpropa@gmail.com.

Citation:

Zaman, M. (2021). Optimal value determination for a shape changeable furniture design parameters using full factorial design of experiment analysis. *International journal of research in industrial engineering, 10*(2), 117-127.

Received: 06/01/2021 Reviewed: 12/03/2021 Revised: 09/04/2021 Accept: 01/05/2021

Abstract

Optimization and selecting effective design parameters are a big issue in the field of product design and development. The optimal value determination for design parameters is a challenge for the furniture industry. Therefore, an appropriate statistical approach is required. In this research the full factorial two-level four-factor design of experiment method was used to determine the optimal values for a shape changeable furniture. For the m-chair's- which can be used as a chair, floor bed, and table, four design parameters- bending axis material surface roughness, density of body material, width of the surface plane, and the number of bending axis were evaluated on basis of the performance time of shape changing where the optimal value of influential parameters were determined for a minimum reshaping time using Minitab. This method can be implemented for unique product design. But for further study, different form changing times should be considered individually.

Keywords: Full factorial DOE analysis, Two-level four-factor DOE, Minimization optimization model, Shape-changeable furniture design.

1 | Introduction

Product design is a dynamic cycle which use arithmetic, fundamental science, design methodologies for addressing required issues. The process consists of several investigations, testing and assessment to bring out the result align with ideal and desired target [1].

In recent years with the development in product design, the use of multipurpose furniture is increased significantly. The major reason for converting single furniture into multiple functional furniture is preferred by the users as it offers optimal use in a confined living space. Therefore,

Corresponding Author: mobasshirazamanpropa@gmail.com.

10.22105/RIEJ.2021.286958.1226

allowing using the space in an optimal condition by maximizing space utilization and improving the livelihood condition of the user. If a single piece of furniture can be used for multiple functional units it will also reduce the user expense of buying multiple furniture units [2].

One of the new trends for furniture design development is the shape-changing furniture that can change form from one to another and materials characteristics and geometry is directly related to the reshaping capability of the furniture [3]. For furniture design, user satisfaction is directly related to the space-saving aspect and user-centered design [4]. The furniture must have easy-touse quality and aesthetic aspects [2]. Most of the product development is carried on the market survey and customer requirements. For suppose designing a multifunctional laptop table design house of quality was used and contemplating the customer need and market similar product the design parameters were determined, where a few new features were added with the basic features [5]. Rajan et al. [6] showed a multi-functional table design based on customer demand and software modeling parameters, however, the table was only for multiple types of table use. But reshape-able products are based on the integration of different furniture units. Although the market has data related to an individual unit, in most cases data is not available for the integrated furniture. As a result, possible customer feedback is also unpredictable. The only way does a statical study on this type of product is to choose the parameters which can provide an optimized result for a major user interface. On the other hand, design can be only implied as user-oriented if the major feature of the design is easily assessable and understandable by the user. For multi-functional furniture, the reshaping feature has the most significant purpose [7]. Hence, user satisfaction will only be obtained when the reshaping could be done with ease and if the reshaping is an easy process the user would be able to fluently implement the feature and reform the furniture in an alternative shape. On that account, the unique product development design of the experiment can easily pave the way.

Design of Experiments (DoE) is a statistical tool now and then used for optimization and robust design [8]. The full factorial DoE is one of the most used statistical analyses, where the interactions of different levels of factors screening process been conducted. If the number of factors is k and 2 is the level number used, then the possible combination for full factorial DoE will be n^k [9].

Research with DoE method can be used to improve the existing product's quality and optimization of the performance parameter, as well as for developing a whole new product. Some of the recent applications of DoE method were for improving the thermal performance of gas ovens by adjusting the parameters and interacting with those parameters [10], pharmaceutical drug development for improving quality and posit an optimal product [11], optimization of Electrophoretic Deposition (EPD) process parameters for PEEK base coatings [12], metabolomic related studies [13], for energy performance measurement [14] and so on. In practice is it common to find the use of DoE for optimization [15] as well as for product and process improvement [16].

In this paper, the full factorial DoE design was conducted and the influential parameters were determined. Furthermore, the optimal solutions for the influential parameter, for which the best response output obtained had been defined. In end, cost estimation for the prototype model was also demonstrated. This paper would pave a way to establish a multi-functional and reshape-able furniture design without customer survey and market benchmarking. The objective of this paper is to selecting optimal parameter values for unique multi-functional furniture design using full factorial DoE, to determining parameters that show an effect on reshaping time.

2 | Methodology

In this paper, a full factorial DoE method was used to determine the best possible parameters for the key performance selection for product design. In this article, 4 independent parameters were considered as factors with one dependent key performance evaluating parameter. Minitab 2020 version was used to determine the combinations, regression analysis, cube plot diagram and model solution establishment.

2.1 | Selection of Factors and Levels

The key performance indicator for the reshape able furniture was how easily it was be changed from one shape to another and the much easy the process the less time is likely to take to carry the process. So here the time needed (*T*) for reshaping was taken as a dependent variable and the parameters that were directly related to this performance were taken as independent variables. The four independent variables were bending axis material surface roughness (*R*), the density of body material (*D*), the width of the surface plane (*W*), and the number of bending axis (*N*) as they have a direct ergonomic effect on material handling.

Two levels (low and high) were assigned for all four factors, as shown in *Table 1*. The axis was a cylindrical metal pipe shape and the low rough surface was for Stretched steel (0.015* 10-3 m), high value for weld steel (0.045* 10-3 m) [17]. The furniture is a wooden base and two different types of wood material density were taken. The martial density was determined by measuring the weight/mass of 1 cubic unit if material using standard weight scale. Other measured value which was determined using slide-calipers was width of surface plane. The number of bending axis or joint axis is shown in *Fig. 1*.

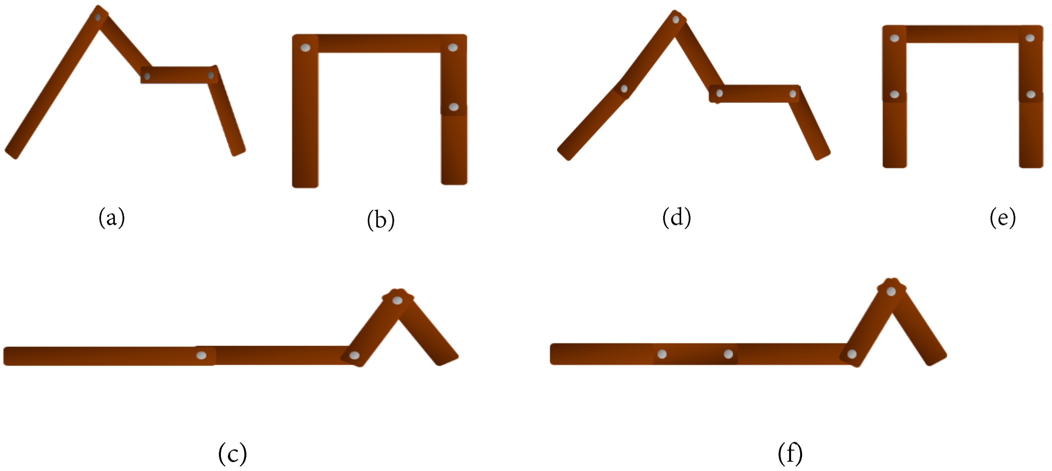


Fig. 1. Three joint chair-table-floor bed form and four joint chair-table-floor bed form respectively (side view).

Table 1. Factor's symbols and levels.

Factors	Symbols	Low	High
Bending axis material absolute surface roughness (ε in mm)	R	0.015 [17]	0.045 [17]
Density of body material (kg/m^3)	D	1200	2000
Width of the surface plane (m)	W	0.4	0.45
Number of the bending axis	N	3	4

2.2 | Response Determination for Possible Combinations

There were 4 factors, hence, the number of combinations was 2^4 or 16, (*Table 2*) which was taken randomly arranging the parameters [9].

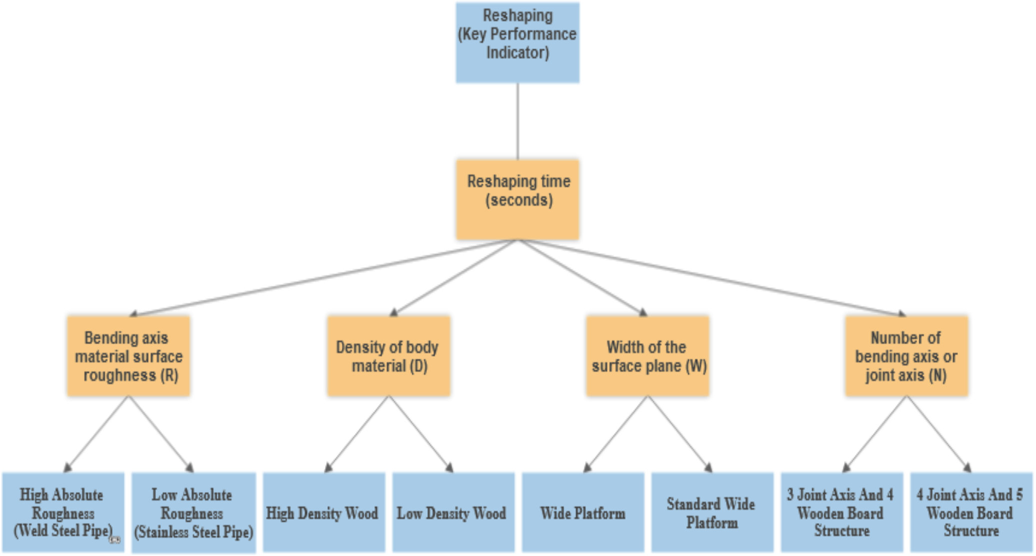


Fig. 2. Diagram showing parameters for DoE.

Table 2. Design summary.

Factors:	**4**
Runs:	16
Blocks:	1
Base Design:	4, 16
Replicates:	1
Center pts (total):	0

The combination was made with all possible factor interactions when all terms were free from aliasing. For two-level full factorial DoE total of 16 possible combinations were possible without an additional center point combination. Total 48 trials were conducted combining the time estimation for bed to chair, bed to table, chair to table, chair to bed, table to chair, and table to bed shape-changing, az shown in *Table 3*.

Table 3. Trial data.

StdOrder	RunOrder	CenterPt	Blocks	R [17]	D	W	N	T 1	T 2	T 3
1	1	1	1	0.015	1200	0.40	3	50.1	49.3	51.60
12	2	1	1	0.045	2000	0.40	4	64.7	65.3	66.00
15	3	1	1	0.015	2000	0.45	4	58.2	59.1	57.60
9	4	1	1	0.015	1200	0.40	4	57.0	58.5	58.40
16	5	1	1	0.045	2000	0.45	4	66.1	68.1	63.90
13	6	1	1	0.015	1200	0.45	4	59.0	56.0	56.10
10	7	1	1	0.045	1200	0.40	4	59.0	60.7	57.30
4	8	1	1	0.045	2000	0.40	3	54.9	57.0	53.00
7	9	1	1	0.015	2000	0.45	3	53.5	53.4	53.70
2	10	1	1	0.045	1200	0.40	3	52.8	51.1	55.10
8	11	1	1	0.045	2000	0.45	3	56.1	56.0	56.00
14	12	1	1	0.045	1200	0.45	4	59.9	58.3	59.00
5	13	1	1	0.015	1200	0.45	3	50.3	51.0	49.50
11	14	1	1	0.015	2000	0.40	4	59.0	59.0	59.00
3	15	1	1	0.015	2000	0.40	3	53.2	51.5	53.24
6	16	1	1	0.045	1200	0.45	3	54.0	52.9	55.00

2.3 | Determine Standard Deviation and Mean for All Combinations

As the trails for combinations were showing different values, for standardizing the response in factorial analysis the Standard Deviations (SD) and means were employed.

Table 4. Mean and SD of trails.

StdOrder	RunOrder	CenterPt	Blocks	R [17]	D	W	N	Mean	SD
1	1	1	1	0.015	1200	0.40	3	50.3333	1.16762
12	2	1	1	0.045	2000	0.40	4	65.3333	0.65064
15	3	1	1	0.015	2000	0.45	4	58.3000	0.75498
9	4	1	1	0.015	1200	0.40	4	57.9667	0.83865
16	5	1	1	0.045	2000	0.45	4	66.0333	2.10079
13	6	1	1	0.015	1200	0.45	4	57.0333	1.70392
10	7	1	1	0.045	1200	0.40	4	59.0000	1.70000
4	8	1	1	0.045	2000	0.40	3	54.9667	2.00083
7	9	1	1	0.015	2000	0.45	3	53.5333	0.15275
2	10	1	1	0.045	1200	0.40	3	53.0000	2.00749
8	11	1	1	0.045	2000	0.45	3	56.0333	0.05774
14	12	1	1	0.045	1200	0.45	4	59.0667	0.80208
5	13	1	1	0.015	1200	0.45	3	50.2667	0.75056
11	14	1	1	0.015	2000	0.40	4	59.0000	0.00000
3	15	1	1	0.015	2000	0.40	3	52.6467	0.99324
6	16	1	1	0.045	1200	0.45	3	53.9667	1.05040

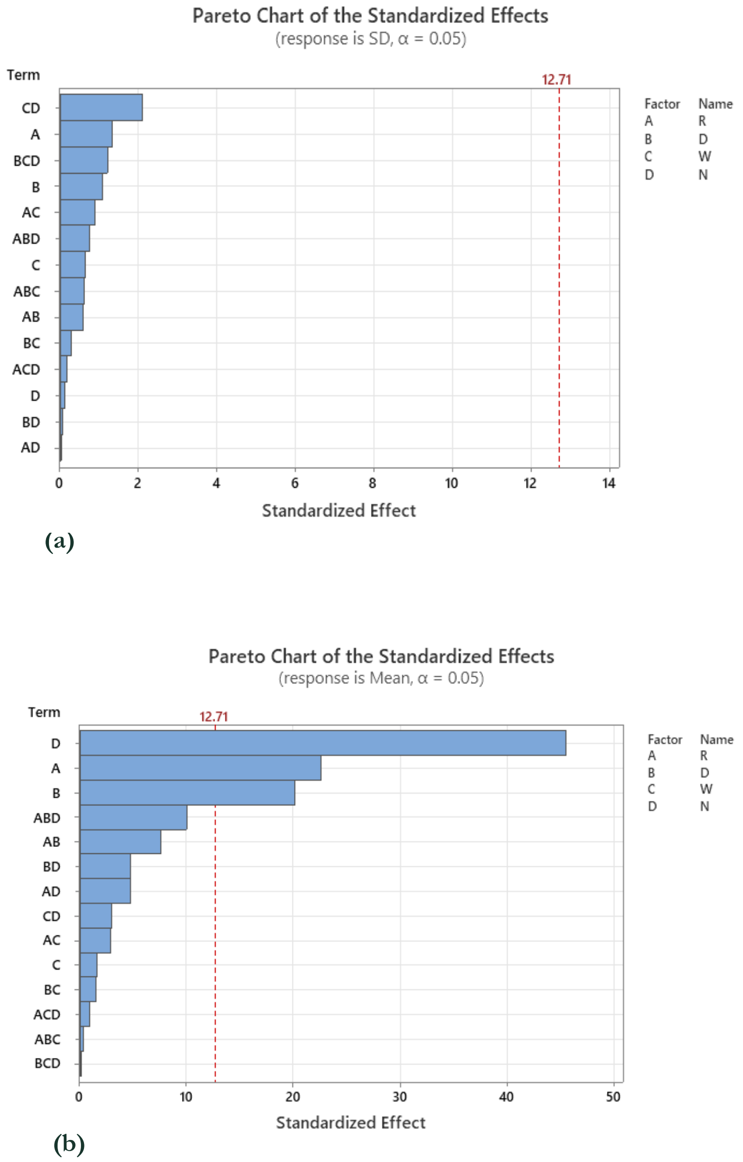
2.4 | Factorial Regression Analysis and Interpretation

The regression was enacted for SD and mean with *Eq. (1)* and *Eq. (2)*. The regression equations are in uncoded units.

$$\begin{aligned}&SD=-92+126R+0.0793D+203W+22.2N-0.482R*D-2386R*-158*N-0.178D*W-0.0207D*\\&N-47.0W*N+0.79R*D*W+0.0472R*D*N+192R*W*N+0.0456D*W*N,\end{aligned}\tag{1}$$

$$\begin{aligned}&Mean =-23.8 + 1455\,R + 0.0109\,D + 52\,W + 26.6\,N - 0.736\,R*D - 480\,R*W - 537\,R*N +\\&0.0258\,D*W- 0.00498\,D*N - 26.7\,W*N - 0.189\,R*D*W + 0.2614\,R*D*N +\\&396\,R*W*N -0.0023\,D*W*N.\end{aligned}\tag{2}$$

For DoE, SD and mean values were considered as a response (independent variable); the degree of freedom 3. *Fig. 3(a)* shows the Pareto chart for SD and none of the factors are affecting the time. Interpretation could be done the same for p-values (p-value > 0.05) as shown in *Table 5*. In *Fig. 3(b)*, bending axis material solute surface roughness (*R*), the density of principle material (*D*), and the number of joint axes (*N*) affected the mean values and for *R*, *D*, and *N* p-value is less than 0.05 as shown in *Table 6*.



(a)

(b)

Fig. 3. Pareto chart for standard effect on SD and mean of reshaping time respectively.

Table 5. Coded coefficient for factorial regression: SD versus R, D, W, N.

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		1.046	0.189	5.54	0.114	
R	0.501	0.251	0.189	1.33	0.411	1.00
D	-0.414	-0.207	0.189	-1.10	0.471	1.00
W	-0.248	-0.124	0.189	-0.66	0.630	1.00
N	0.046	0.023	0.189	0.12	0.922	1.00
R*D	0.226	0.113	0.189	0.60	0.656	1.00
R*W	-0.339	-0.169	0.189	-0.90	0.534	1.00
R*N	-0.012	-0.006	0.189	-0.03	0.980	1.00
D*W	0.104	0.052	0.189	0.27	0.830	1.00
D*N	0.029	0.015	0.189	0.08	0.951	1.00
W*N	0.791	0.396	0.189	2.10	0.283	1.00
R*D*W	0.237	0.118	0.189	0.63	0.643	1.00
R*D*N	0.283	0.142	0.189	0.75	0.591	1.00
R*W*N	0.072	0.036	0.189	0.19	0.880	1.00
D*W*N	0.456	0.228	0.189	1.21	0.440	1.00

Table 6. Coded coefficient for factorial regression: means versus R, D, W, N.

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		56.6550	0.0783	723.26	0.001	
R	3.5400	1.7700	0.0783	22.60	0.028	1.00
D	3.1517	1.5758	0.0783	20.12	0.032	1.00
W	0.2483	0.1242	0.0783	1.59	0.358	1.00
N	7.1233	3.5617	0.0783	45.47	0.014	1.00
R*D	1.1817	0.5908	0.0783	7.54	0.084	1.00
R*W	0.4517	0.2258	0.0783	2.88	0.213	1.00
R*N	0.7433	0.3717	0.0783	4.74	0.132	1.00
D*W	0.2400	0.1200	0.0783	1.53	0.368	1.00
D*N	0.7483	0.3742	0.0783	4.78	0.131	1.00
W*N	-0.4650	-0.2325	0.0783	-2.97	0.207	1.00
R*D*W	-0.0567	-0.0283	0.0783	-0.36	0.779	1.00
R*D*N	1.5683	0.7842	0.0783	10.01	0.063	1.00
R*W*N	0.1483	0.0742	0.0783	0.95	0.517	1.00
D*W*N	-0.0233	-0.0117	0.0783	-0.15	0.906	1.00

2.5 | Multiple Regression Analysis with of Influential Parameters

Furthermore, *R*, *D*, and *N* were employed as factors for modeling and the simplified multi-linear regression equation for mean values were:

$$\text{Mean}=21.88 + 118.0\ R + 0.003940\ D+ 7.123\ N. \tag{3}$$

The coefficient of the factors showed significance on the response (p-value<0.05, R^2 =92.94%).

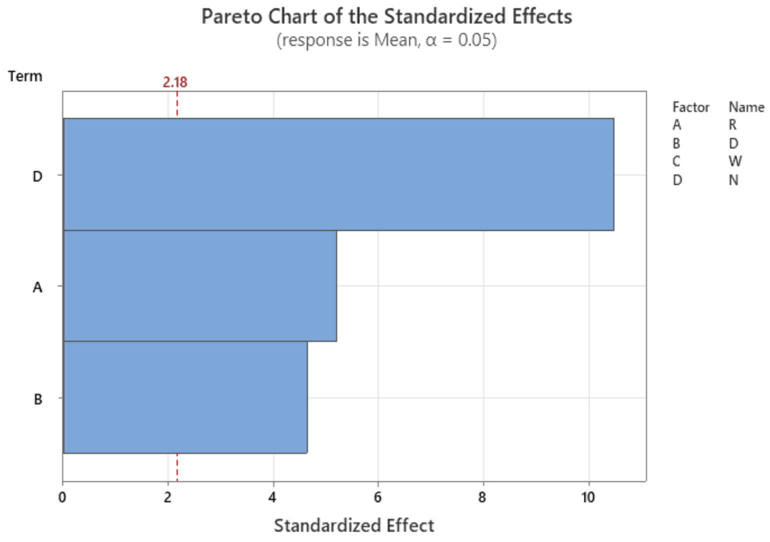


Fig. 4. Pareto chart for mean for D and N.

Table 6. Coded coefficient for factorial regression: means versus D and N.

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		56.655	0.340	166.49	0.000	
R	3.540	1.770	0.340	5.20	0.000	1.00
D	3.152	1.576	0.340	4.63	0.001	1.00
N	7.123	3.562	0.340	10.47	0.000	1.00

Fig. 4 showed the Pareto chart of standard effect on mean of reshaping time in terms of *R*, *D*, and *N*. And from the Pareto chart all three factors affected the mean value of the trials.

3 | Result

Optimal values were defined for *R*, *D*, and *N*, as *W* did not have a particular effect on reshaping time. Form the Minitab model, for reshaping time minimization approach was taken and the upper bound was 1 minute, which means the reshaping time could not be more than 1 minute.

3.1 | Cube Plot for (Fitted Means) for Mean Values

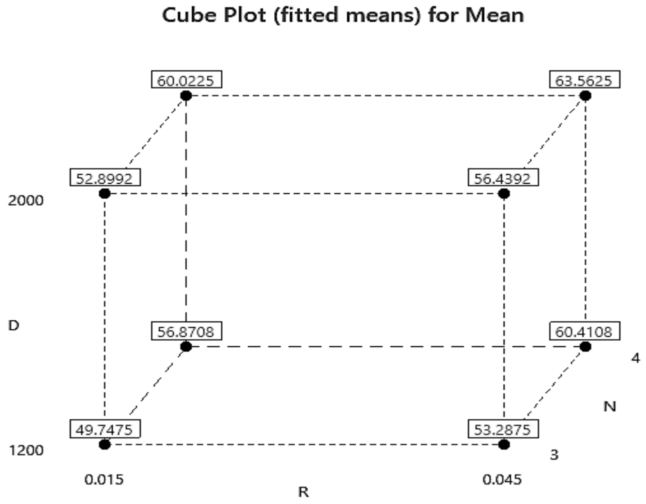
3D cube plot (fitted means), showed for the low-level values of *R*, *D*, and *N*, the minimum value could be invenit. From there in the point split pattern the time increased. Cube plot drawn from minitab showed for which level change of factor which minimum value to expect.

3.2 | The Optimal Values of Influential Factors for Time Minimization

3.2.1 | Model parameters

Target value= 50.2667 seconds.

Upper bound = 60.0 seconds.



Factors= R, D, N.

Fig. 5. Fitted means Cube plot for mean values vs R [17], D, and N.

3.2.2 | Model solution

Bending axis material surface roughness, *R*= 0.015 ε in mm [17].

The density of body material, *D*= 1200 kg/m^3.

Number of bending axis, *N*= 3.

In *Fig. 6*, Mean minimum time (mean fit) = 49.7475 seconds.

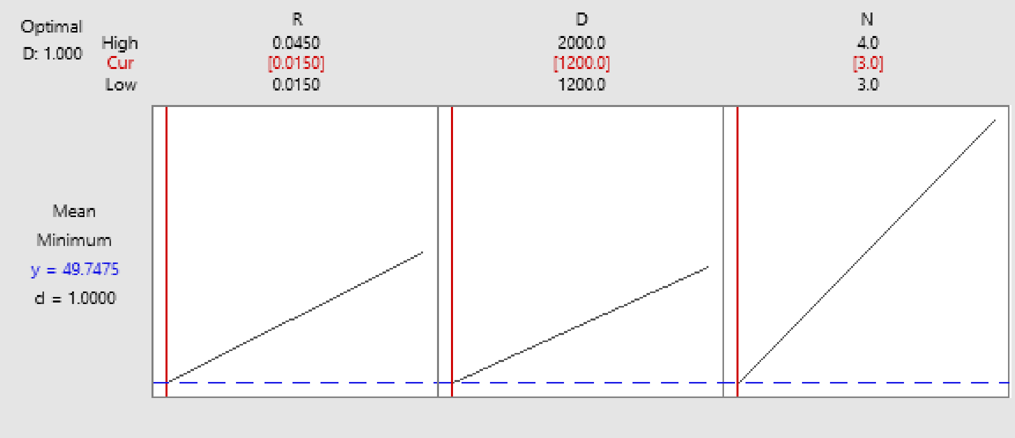


Fig. 6. Optimal solution graph [17].

3.2.3 | Multiple response prediction

Standard error, SE fit= 0.681.

For confidence interval 95% CI range = (48.265, 51.230).

For prediction interval 95% PI range = (46.432, 53.063).

3.3 | Cost Estimation

The mainframe was a wooden structure and 3 joint parts were added using a weld steel pipe.

Fig. 7. Multi-functional furniture side view in the folded position (1,2,3 joint position).

Table 7. Cost estimation for the prototype is given below.

Cost of labor= (3*200) BDT [200 BDT / day] =	600 BDT
Wood price=	800 BDT
Metal pipe price=	180 BDT
Utility cost=	100 BDT
Total cost=	1680 BDT

4| Conclusion

In this article, a multi-functional furniture's design parameters were determined using DoE full factorial two levels four-factor analysis. The furniture was convertible into chair to table to bed and vice-versa. Hence the reshaping time was taken as the independent variable and factors considered for performance enhancement were bending axis material surface roughness, the density of body material, the width of the surface plane, and the number of bending axis. From model established in minitab it is clear that the width of the surface plane did not show an effect in the performance time, whereas, bending axis material surface roughness, the density of body material, and the number of bending axis had a significant effect. Thereafter optimal solution was determined based on the factors for the minimum time needed to reshape the furniture form. To accustom this minimum time of approximately 49 seconds design should contain 3 joint axes and, bending axis material surface roughness 0.015 ε in mm the wood material density 1200 kg per cubic meter [17]. For Wooden frame width up to 0.45-meter, width did not have any effect on the reshaping time. A cubic plot also showed the effect of the factor value on reshaping mean fit time.

4.1| Future Research Scope and Drawbacks

For the early stage of this study, only a two-level full factorial design was carried on without additional center point combination, which remains the condition for further study with parameter combination with corner point replication and multiple level factorial analysis. Also, this study did not consider the table-chair, chair-bed, and bed- table reshaping time individually. A thorough analysis regarding this would remain for future development.

References

[1] Kroes, P. (2009). Foundational issues of engineering design. In *Philosophy of technology and engineering sciences* (pp. 513-541). North-Holland. https://doi.org/10.1016/B978-0-444-51667- 1.50023-9

[2] Nasser, F. (2013). *Multifunctional furniture for underprivileged communities: A milestone in sustainable development* (Master theses, Purdue University). Retrieved from https://docs.lib.purdue.edu/cgttheses/26/

[3] Grønbæk, J. E., Korsgaard, H., Petersen, M. G., Birk, M. H., & Krogh, P. G. (2017, May). Proxemic transitions: designing shape-changing furniture for informal meetings. *Proceedings of the 2017 CHI conference on human factors in computing systems* (pp. 7029-7041). https://doi.org/10.1145/3025453.3025487

[4] Nirmal, U., Kiat Ng, P., Jee, K. S., & Anton, E. (2018). Product and market observations on furniture technological developments. *International journal of engineering & technology*, *7*(3.7), 558-562.

[5] Habib, A., Taher, G. A., & Saha, M. (2013). Multifunctional computer table. *IJRET: International journal of research in engineering and technology*, *2*(10), 536-544.

[6] Rajan, A. P., Elavarasan, D., Balaji, S., Dinesh, A., & Gowtham, K. (2019). Design and fabrication of multifunctional furniture. *International journal of research in engineering, science and management*, *2*(5), 442-447.

[7] Hsueh, S. L., & Kuo, C. H. (2016). Factors in an interdisciplinary curriculum for the students of industrial design designing multifunctional products. *Eurasia journal of mathematics, science and technology education*, *12*(4), 1075-1089.

[8] Davim, J. P. (Ed.). (2016). *Design of experiments in production engineering*. Basel, Switzerland: Springer International Publishing.

[9] Rafidah, A., Nurulhuda, A., Azrina, A., Suhaila, Y., Anwar, I. S., & Syafiq, R. A. (2014). Comparison design of experiment (doe): Taguchi method and full factorial design in surface roughness. *Applied mechanics and materials*, *660*, 275-279.

[10] Arcos, J. I. L., Camacho, R. G., Campos, P. H. D. S., Da Silva, C. E. S., & de Paiva, A. P. (2017, October). Improve the product design process, with CFD and DOE approach. *Proceedings of the international conference on industrial engineering and operations management* (pp. 164-172). Bogota, Colombia.

[11] Beg, S., Swain, S., Rahman, M., Hasnain, M. S., & Imam, S. S. (2019). Application of design of experiments (DoE) in pharmaceutical product and process optimization. In *Pharmaceutical quality by design* (pp. 43-64). Academic Press.

[12] Rehman, M. A. U., Bastan, F. E., Haider, B., & Boccaccini, A. R. (2017). Electrophoretic deposition of PEEK/bioactive glass composite coatings for orthopedic implants: a design of experiments (DoE) study. *Materials & design, 130*, 223-230.

[13] Jacyna, J., Kordalewska, M., & Markuszewski, M. J. (2019). Design of experiments in metabolomics-related studies: An overview. *Journal of pharmaceutical and biomedical analysis, 164*, 598-606.

[14] Ghiaus, C., & Alzetto, F. (2019). Design of experiments for Quick U-building method for building energy performance measurement. *Journal of building performance simulation, 12*(4), 465-479.

[15] Alagumurthi, N., Palaniradja, K., & Soundararajan, V. (2006). Optimization of grinding process through design of experiment (DoE)—a comparative study. *Materials and manufacturing processes, 21*(1), 19-21.

[16] Montgomery, D. C. (1992). The use of statistical process control and design of experiments in product and process improvement. *IIE transactions, 24*(5), 4-17.

[17] Engineering ToolBox. (2003). *Roughness & surface coefficients*. Retrieved January 15, 2021 from https://www.engineeringtoolbox.com/surface-roughness-ventilation-ducts-d_209.html