DEVELOPMENT OF A MATHEMATICAL MODEL TO PREDICT THE TASK TIME AND PARAMETERS OPTIMIZATION FOR ERGONOMICALLY DESIGNED SETUP USING STATISTICAL DESIGN OF EXPERIMENTS

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Abstract: *An important part of many quality improvement and quality development programs is an evaluation of the effect of process variables upon performance. The product quality is depending on number of independent factors. Their effects on dependent factors are evaluated through empirical investigation. In practice, a small number of controllable variables contribute to a vital share of the effect of the product quality. These variables do not necessarily produce a constant effect on the product. The question would therefore arise as to how efficiently and economically the contribution of each of these factors can be assessed individually and also collectively to produce the total effect on the product performance. An approach that fulfills these requirements is available in the statistically designed experiments. The statistically designed experiment permits simultaneous consideration of all the possible factors that are suspected to have a bearing on the problem under consideration. Even a limited number of experiments would enable experimenter to uncover the vital factors on which further trails would lead the researcher to track down their most desirable combination which will yield the expected results. Scanning a large number of variables is one of the objectives that a statistically designed experiment would fulfill in many problem situations. The purpose of this study is to develop a mathematical model to predict the task time taken by the operator to assemble the needle and thread by varying the working environmental conditions like temperature, light and noise. The adequacies of the model are then evaluated using MINITAB statistical software and analysis of variance (ANOVA) technique. The model developed is checked for its adequacy. Results of confirmation experiments showed that the model can predict the optimum task time with reasonable accuracy.*

Keywords: *Design of Experiment, ANOVA, Experiments, Treatment, Replication.*

1. INTRODUCTION

Productivity is one of the most important factors affecting the overall performance of any organization, from small enterprises to entire nations. Sarode, A. P., & Shirsath, M. studied the factors affecting employee work environment & it's relation with employee productivity [1]. Increased attention has been paid to the relationship between the work environment and productivity since the 1990s. Lan, L., Wargocki, P., & Lian, Z stated that Quantitative measurement of productivity loss due to thermal discomfort must estimated separately [2]. Laboratory and field studies show that the physical and chemical factors in the work environment may have a notable impact on the health and performance of the occupants, and consequently on productivity. Niemelä, R., and Hannula studied the effect of air temperature on labor productivity in call centers [3]. Seppanen, O., Fisk, W. J., & Lei, Q. H. (2006). Effect of temperature on task performance in office environment [4]. Seppanen, O., Fisk, W. J., & Lei, Q. H. studied the Effect of temperature on task performance in office environment [5]. A common allegation is that improving the work environment results in productivity gain. This relationship, however, has been insufficiently explored. Some researchers discovered that these elements affected both the psychological and physiological welfare of the workers, causing such conditions as eyestrain, fatigue, headache, back pain, and nausea. Suresh & Saurabh Dalela studied the i mpact of climate on human efficiency while working [5].

This paper focuses on the optimization of temperature, noise and light level to raise the productivity on the assembly activity of thread and needle. A mathematical model to predict the task time has been developed and parameters are optimized for an ergonomically designed setup using statistical Design of Experiments.

2. EXPERIMENTAL DETAILS

The preliminary stage involved designing of the experimental set-up where-in it involved the designing of a light-varying experimental setup along with this; a method study table was designed as per the standards (for both male and female) by using AutoCAD software.

Once the designing was completed both the set-up were fabricated as per the design specifications and the setup were installed. Now that the table is ergonomically designed and the parameters such as temperature, light, noise can be varied, the experiments were designed based on the concept of DOE. The experiments taken into consideration is the assembly of Needle and thread used in the garment industry.

Since the assembly of needle and thread requires high concentration and the factors of temperature, light, noise plays a vital role in such experiments. Two trained volunteers were taken into consideration, and the experiments was carried out in a normal office work-area adapted for experiments. Two thermal conditions were created by setting the temperature in office between 32°C to 36°C, the noise levels between 80 dB to 90dB, artificial lighting rate between 750 Lux to 1000 Lux. The room was ventilated by 100% outdoor air.

The volunteers were recruited based on the following criteria: familiarity with the needle and thread experiment, impartiality to the room in which the study was carried out, and absence of color blind, asthma, allergy, hay-fever and chronic diseases. During the week preceding the experiment, subjects received a 4-hr. session at 32°C to practice neuro behavioral tests and other tasks that were subsequently used in the experiment. Both subjects completed all experimental sessions.

3. METHODOLOGY INVOLVED THE FOLLOWING STEPS

- Design the experimental set up to perform the experiments.
- Identifying important process control variables
- Finding upper and lower limits of control variables.
- Establishing the procedure to conduct the experiments.
- Selection of optimization parameter.
- Development of design matrix.
- Conducting experiment as per design matrix.
- During the course of the experiment the noise (decibels) and the light intensity (lux) and temperature (degree Celsius) are varied according to the design matrix.
- Recording response i, e, Task time in minutes
- Developing of mathematical model
- Determining the co-efficient of the regression model using MINTAB statistical software.
- Checking the adequacy of the developed model
- Presenting the effects of process parameters in graphical form and analyzing the results

3.1 Design the Experimental Set up to Perform the Experiments

The preliminary stage involved designing of the experimental set-up where-in it involved the designing of a light-varying experimental setup along with this; a method study table was designed as per the standards (for both male and female) by using AutoCAD software is as shown in the Figure 1.

3.2 Identifying Important Process Control Variables

The three controllable factors like temperature, light and noise and their levels were selected

Table 1: Factors and Level

Sl. No.	Factors	Unit	Notations	Lower Limit	Basic Level	Upper Level	Variation interval
1	Temperature	°C	A	32	33	34	1
2	Light	Lux	B	750	875	1000	125
3	Noise	dB	C	80	85	90	5

Fig 1: The Experimental Set Up

as shown in the Table 1.

The design matrix for 3 factors, 2 levels and 2 replications is developed using DOE feature of MINITAB statistical software and shown in the Table 2.

Table 2: Design Matrix Fractional Factorial Design with Resolution V

Std. Order	Run Order	Center Pt	Blocks	A	B	C
16	1	1	1	1	1	1
4	2	1	1	1	1	-1
12	3	1	1	1	1	-1
13	4	1	1	-1	-1	1
15	5	1	1	-1	1	1
3	6	1	1	-1	1	-1
9	7	1	1	-1	-1	-1
10	8	1	1	1	-1	-1
14	9	1	1	1	-1	1
8	10	1	1	1	1	1
7	11	1	1	-1	1	1
5	12	1	1	-1	-1	1
6	13	1	1	1	-1	1
2	14	1	1	1	-1	-1
1	15	1	1	-1	-1	-1
11	16	1	1	-1	1	-1
Note: + 1 indicates Upper limit and -1 indicate Lower level in the design matrix						

3.3 Selection of Optimization Parameter

Optimization parameter i.e., task time (minutes) is the reaction (response) to the action of the factors (Temperature, Light and noise) determining the behavior of the system being studied.

3.4 Conducting Experiment as per Design Matrix

During the course of the experiment the noise (decibels) and the light intensity (lux) and temperature (degree Celsius) are varied according to the design matrix and corresponding task time is noted down in the Table 3.

After the experiment was performed, next step was to analyze and interpret the results so that necessary actions could be taken accordingly. The analysis of the experiment is to identify the factors which affect the task time. In this case MINITAB software was used to analyze the data from the experiment.

3.5 Statistical Analysis and Interpretation of Results

Prior to carrying out the statistical analysis, first step was to check the data for the normality assumptions is shown in the Figure 4.0

A Normal probability plot of residuals was constructed using the MINITAB software. It can be seen from the Figure 2 that all the points on the normal plot are significant except the Factor C.

Table 3: Design Matrix with Response (Task Time)

Std Order	Run Order	Center Pt	Blocks	A	B	C	Task time (Min)
16	1	1	1	1	1	1	4.1
4	2	1	1	1	1	-1	3.49
12	3	1	1	1	1	-1	3.42
13	4	1	1	-1	-1	1	4.02
15	5	1	1	-1	1	1	3.56
3	6	1	1	-1	1	-1	2.59
9	7	1	1	-1	-1	-1	3.18
10	8	1	1	1	-1	-1	4.45
14	9	1	1	1	-1	1	2.55
8	10	1	1	1	1	1	3.46
7	11	1	1	-1	1	1	3.17
5	12	1	1	-1	-1	1	4.39
6	13	1	1	1	-1	1	3.22
2	14	1	1	1	-1	-1	4.4
1	15	1	1	-1	-1	-1	3.23
11	16	1	1	-1	1	-1	2.42

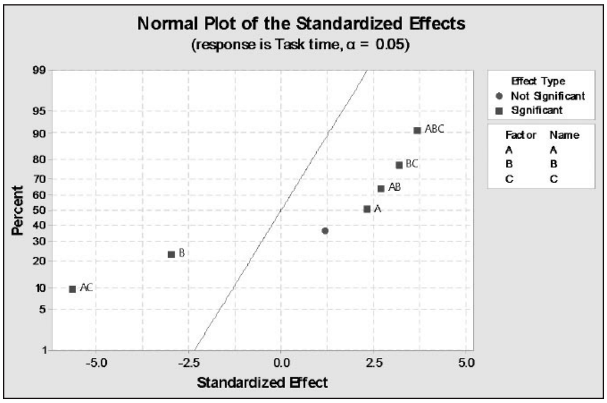

Fig 2. Normal Plot

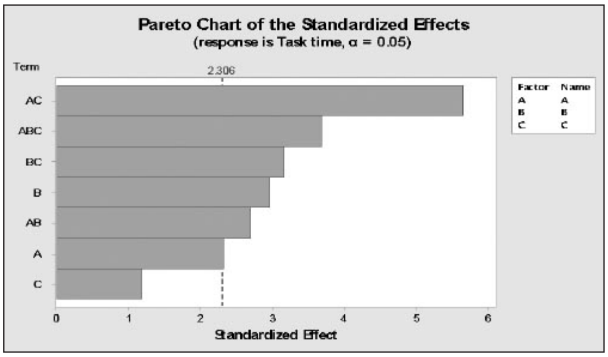

Fig 3. Pareto Plot

3.6 Pareto Plot

The next step is to identify the most significant main and interaction effect which influence the task time USING Pareto chart using MINITAB statistical software is shown in Figure 3.

Pareto Chart shows that all the main effects and interaction effects are significant except factor C.

4. DEVELOPMENT OF MATHEMATICAL MODEL TO PREDICT THE TASK TIME

Determining the co-efficient of the regression model using MINTAB statistical software

Factorial Regression: Task time versus A, B, C

Analysis of Variance was carried out and output of the statistical software is shown in Table 4.

R^2: Co-efficient of determination indicates how much variation in the response is explained by the model. The higher the R^2, the better thr model fits the design.

Adjusted $R^{2:}$ Adjusted R^2 is a statistic adjusted for the size of the model, which is number of

Table 4: ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	5.8055	0.82936	11.19	0.001
Linear	3	1.1561	0.38537	5.20	0.028
A	1	0.4001	0.40006	5.40	0.049
B	1	0.6521	0.65206	8.79	0.018
C	1	0.1040	0.10401	1.40	**0.270**
2-Way Interactions	3	3.6444	1.21479	16.38	0.001
A*B	1	0.5366	0.53656	7.24	0.027
A*C	1	2.3639	2.36391	31.88	0.000
B*C	1	0.7439	0.74391	10.03	0.013
3-Way Interactions	1	1.0050	1.00501	13.55	0.006
A*B*C	1	1.0050	1.00501	13.55	0.006
Error	8	0.5931	0.07414		
Total	15	6.3986			

Table 5: Model Summary

S	R-sq	R-sq (adj)	R-sq (pred)
0.272293	90.73%	82.62%	62.92%

Table 6: Coaded Values

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		3.4781	0.0681	51.09	0.000	
A	0.3163	0.1581	0.0681	2.32	0.049	1.00
B	-0.4038	-0.2019	0.0681	-2.97	0.018	1.00
C*	**0.1612**	**0.0806**	**0.0681**	**1.18**	**0.270**	**1.00**
A*B	0.3662	0.1831	0.0681	2.69	0.027	1.00
A*C	-0.7687	-0.3844	0.0681	-5.65	0.000	1.00
B*C	0.4313	0.2156	0.0681	3.17	0.013	1.00
A*B*C	0.5013	0.2506	0.0681	3.68	0.006	1.00
C* insignificant factor, Factors with P-value less than 0.05 indicates significant effect on response (Task time)						

factors. The adjusted R^2 can decrease non-significant terms that are added to the model.

Predicted R^2: Predicted R^2 value is calculated by systematically removing each observation from the data set, estimating the regression equation, and determining how well the model predicts the removed observation. Model summary and Coded Coefficients are shown in the Table 5 and Table 6. Main effects of process parameters on Task time. From figure 4, it is evident that the effect that parameter A (temperature) has on mean task time increases when A changes from low level (-1) to high level (1). Effect that

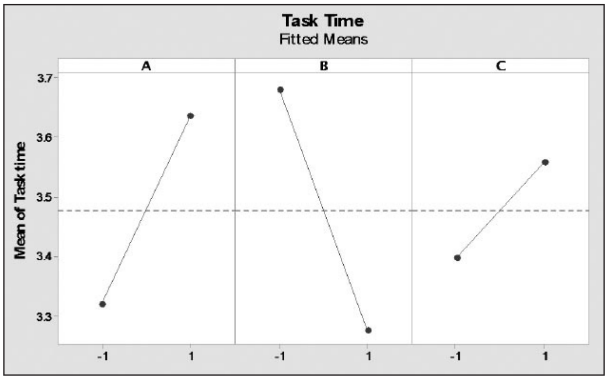

Fig 4. Main Effect Plot

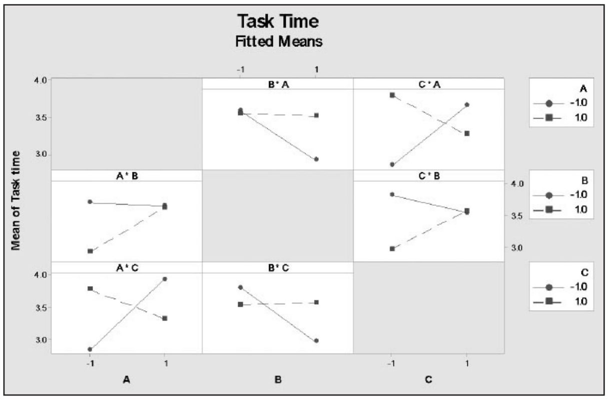

Fig 5. Interaction Effect of Process Parameters

parameter B (Light) has on mean task time decreases when B changes from low level (-1) to high level (1). Effect that parameter C (noise) has on mean task time increases when C low level (-1) to high level (1).

Interaction effects of process parameters on Task time

From figure 5, the interpretation of interaction between A and B is that when factor A is at it's low level (-1) the mean response time of factor B does not show any significant increase or decrease when it changes from low level to high level, when factor A is at it's high level (1) the mean response time of factor C decreases when it changes from low level to high level.

When factor B is at its low level (-1) the mean response time of factor A does not show any significant increase or decrease when it changes from low level to high level. When factor B is at it's high level (1) the mean response time of factor C decreases when it changes from low level to high level.

When factor C is at it's low level (-1) the mean response time of factor A decreases when it changes from low level to high level. When factor C is at it's high level (1) the mean response of B does not show any significant increase or decrease when it changes from low level to high level.

5. REGRESSION EQUATION FOR TASK TIME

Response (Task Time) can be computed using the Model.

Task Time = 3.4781 + 0.1581 A - 0.2019 B + 0.1831 A*B - 0.3844 A*C + 0.2156 B*C+ 0.2506 A*B*C

Task Time = 3.4781 + 0.1581 (Lower Level) - 0.2019 (Upper Level) + 0.1831 (lower level) (Upper level) - 0.3844 (lower level) (lower level)+ 0.2156 (upper level) (lower level) + 0.2506 (lower level) (Upper level) (lower level).

Task Time = 3.4781 + 0.1581 (-1) - 0.2019 (+1) + 0.1831 (-1) - 0.3844 (+1) + 0.2156 (-1) + 0.2506 (-1).

Task Time = 3.4781 - 0.1581 - 0.2019 - 0.1831 - 0.3844 - 0.2156 - 0.2506

Task Time = 2.3 Minutes

6. RESULT

Optimum parameters for accomplishing the task in minimum time are shown in the Table 7.

Table 7: Optimum Values for the three Factors

Sl. No.	Factors	Unit	Notations	Optimum Values
1	Temperature	°C	A	32
2	Light	Lux	B	1000
3	Noise	dB	C	80

7. CONCLUSION

1. Experiments conducted using DOE concepts were applied to develop regression models using response surface methodology to predict the optimum parameters to yield the best task response time.
2. The effect of parameter C individually on the mean response time is insignificant.

3. The interaction figure shows that parameter B is not significantly affected by the variation in levels of parameter A or C whereas interaction between parameters A and C have significant impact on the mean response time of each other.

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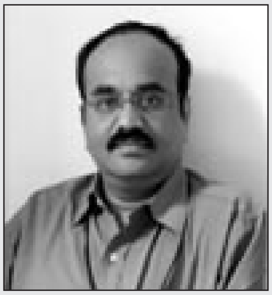

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