Optimization Physical Environment Effects on Work Productivity for Assembly Operator with Response Surface Methodology

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Abstract. The work environment greatly affects the level of work productivity of a person, it affects the increase of production, means and equipment production, occupational safety and health, and atmosphere of the work environment itself. The atmosphere of this working environment can be the lighting and temperature. This study discusses the optimization of lighting and temperature levels on the performance of the assembly operator with Response Surface Methodology. Experiment design using Central Composite Design (CCD). The experiment was conducted at the Industrial Engineering Design Laboratory. The range for lighting is 350 lux - 700 lux and the temperature is between 24°C - 27°C. The experiments performed were the assembly of a light sleeper for 10 minutes. Output is the number of completed assemblies. The results showed that the optimal working environment conditions for lighting were 700 lux and temperature 24°C. While the most influential variable on the work of the operator is the lighting with coefficient value of 0.026.

Keywords: work productivity, lighting, temperature, optimization, response surface methodology

1. Introduction
Condition of a good work environment if humans can carry out its activities with optimal health [1]. Optimal working environment is defined as the comfort that is needed by someone to be able to work more productively [2]. With good health, human beings are able to adapt to various situations and conditions of the physical environment. Physical factors that can affect the working environment include temperature, humidity, vibration, lighting, noise and more [3]. Non-conformance with working environment can be seen in the impact of time[4]. It also happened at Industrial Engineering Design Laboratory, there is a Climatic Room. Climatic space as a practicum does not yet have a good level of comfort. The impact is the practice has not run effectively and efficiently.

Several previous studies on the work environment are "Measuring of Working Physical Environment and Workstation at Central Post Office of Samarinda Center" [5]. The research is discussed about the determination of administrative waiting room service in accordance with the standard of comfort and health and has a room layout that suits the needs of work. While research using Response Surface Methodology is:
1. Optimizing Influential Factors on Candle Quality in UD X with Response Surface Methodology [6]. The research was conducted on candle product to get experimental design by combining factor and level to get optimum wax quality.

2. Determination of Physical Fatigue Patterns in Active Smokers Using Response Surface Methodology [7]. This study identifies physical fatigue patterns in active smokers at light workloads, medium workloads, and heavy workloads with temperature and light factors.

3. Determination of Parameter Setting Machine on Corrugation with Response Surface Methodology [8]. This study was conducted to obtain the optimum level of factors affecting bursting strength.

4. Determination of Condition of Optimal Physical Work Environment using Surface Response Method [9]. This research was conducted to optimize the working environment factor. Working environmental factors studied are noise, lighting and temperature, with the aim of improving operator performance.

Given the importance of the physical environment of a working system, the authors need to research how the influence of the physical environment on work productivity in the Climatic Space Laboratory with Response Surface Methodology. The focus of this study is on lighting and temperature factors. Previous studies conducted experiments by matching the color of resistors, with the subject of research on 10 students who had been trained before. While in this study will develop previous research by adding assembly process to the assembly operator, but the number of research subjects only 3 people only, due to limited capacity Climatic Space Laboratory.

2. Response Surface Methodology

Response Surface Methodology (RSM) is a collection of statistics and mathematical techniques that are useful for developing, improving, and optimizing processes, where responses are influenced by several factors (independent variables). The main idea of this method is to know the effect of the independent variable on the response, to get the model of relationship between the independent variable and the response and to get the condition of the process that produces the best response.

According to [10], Surface Response Methods are the set of mathematical and statistical methods used to see the relationship between one or more quantitative variables of treatment with a response variable that aims to optimize the response in an experiment. This method is useful for developing, improving, and optimizing processes. Its application is particularly important in the areas of designing, developing and formulating new products, as well as on improving the design of existing products. According to [11] Response Surface Methodology is a combined method of mathematical techniques and statistical techniques, used to create models and analyze a y response that is influenced by some independent variables.

3. Methods

The location of this research was conducted in Climate Room of Industrial Engineering Design Laboratory. The object of research is the physical work environment at the level of lighting and temperature, while the subject of this study on 3 students who have been trained previously. The design of experiments conducted is the operator to do the light sleeping assembly for 10 minutes in accordance with the specified product specifications. The result is a number of light sleeping assemblies. The lighting standard used in this study is 350 lux - 700 lux. [12] According to the Decree of the Minister Health of Indonesia No. 1405 of 2002 [13], lighting is the amount of exposure to an area of work required to carry out the activity effectively. Minimum lighting required by type of activity as follows:

| Type of activity level                  | Lighting level (lux) | Information          |
|----------------------------------------|----------------------|----------------------|
| Work is rough and not continuous       | 100                  | Storage room & equipment room |
Rough and persistent work 200 Work with machines and rough assembly
Routine work 300 Administration room, control room, machine work & assembly
The work is rather smooth 500 Making drawings or working with office machines, inspection work or work with machines
Fine work 700 Making drawings or working with office machines, inspection work or work with machines
The work is very subtle 1500 not cause shadow Engraving by hand, inspection of machine work and assembly is very smooth
Detailed work 3000 no shadow Inspection work, assembly is very smooth

Source: Kepmenkes No.1405 Tahun 2002.

The standard temperature used in this study is 24°C to 27°C, the range is taken because at that temperature is a comfortable temperature to work.

**Table 2. Convenient Temperature according to Technical Energy Conservation**

| Number | Description       | Temperature Effective (°C) | Threshold (°C) |
|--------|-------------------|-----------------------------|----------------|
| 1      | Cool comfort      | 20 – 22,8                   | 24             |
| 2      | Comfortable optimal | 22,8 – 25,8               | 28             |
| 3      | Warm comfort      | 25,8 – 27,1                 | 31             |

Source: Teknis Konservasi Energi Dinas PU

4. Analysis and Experiment Laboratory,
The experimental data was analyzed by software and manual. Data analysis is done in 2 calculation phase, that is calculation of regression test and calculation to get maximum value from variable.

4.1. Determining the research variables

**Table 3. Research Variables**

| Variable   | Symbol | Original | Code |
|------------|--------|----------|------|
| Lighting   | $N_1$  | $X_1$    |      |
| Temperature| $N_2$  | $X_2$    |      |

4.2. Calculation of Regression Model Test
The steps of calculating the regression model test are as follows [14]:
   a. Determination of second order equation coefficients
   b. Determination of correction factor
Correction Factor = \( \frac{(\sum Y)^2}{n} \) \hfill (1)

c. Determination of Total Squares Total
\[
\text{Total Squares Count} = \sum Y^2 - FK \hfill (2)
\]
d. Calculation of the Number of Error Squares
\[
\text{Number of Error Squares} = \sum Y^2 - CF - \beta^\top X - \text{Total Squares Count} \hfill (3)
\]
e. Calculation of the sum of squares of Pure Error
\[
\text{Sum of Squares of Pure Error} = \left( \sum Y^2 \right) - \frac{(\sum Y)^2}{n} \hfill (4)
\]
f. Determination of the Quantity of Square of the Model
\[
\text{Quantity of Square of the Model} = \text{Number of Error Squares} - \text{Sum of Squares of Pure Error} \hfill (5)
\]

**Test Lack Of Fit (deviation from model)**

Hypothesis:
Ho: No Lack of Fit;
H1: There's Lack of Fit
Significant level: \( \alpha = 0.05 \)
Test Statistic = \( f_{\text{count}} = \left( \frac{\text{TS Quantity of Square of the Model}}{\text{TS sum of squares of Pure Error}} \right) \)

**Overall Test (Regression Test)**

Hypothesis:
Ho: All 5g independent variables do not affect the dependent variable
H1: At least one independent variable affects the variable
Significant level: \( \alpha = 0.05 \)
Test Statistic = \( f_{\text{count}} = \frac{\text{TS Regression}}{\text{TS the Number of Error Squares}} \)

**Partial Test**

Testing of lighting predictor regression coefficient (N) 2 to (N) n
Hypothesis:
Ho: \( b_2 = 0; \) H1: \( b_2 \neq 0 \)
Critical region: \( -t_\alpha \frac{1}{2} \leq t_{\text{count}} \leq t_\alpha \frac{1}{2} \)
Test Statistic = \( t_{\text{count}} = \text{coefficient} / \left( \text{SE}_\text{coefficient} \right) \)

Calculation to obtain the maximization value of the variable
a. Determination of factor level (coding for each factor)
b. Determine the relationship between code variables and the original variables
c. Determining the level of factors corresponding to values
d. Point determination that optimizes response function
Next it is necessary to check whether the stationary point is maximum by checking sufficient conditions. From the regression equation that has been obtained can be derived Hessian matrix.

5. Analysis and Discussion

The data that has been collected from the experimental results is processed with the help of software and manuals. Data processing in this research is divided into 2 stages of calculation, the calculation of regression test and calculation to obtain the maximum value of the variable.
Table 4. Mean Experiment Rates Two Factors of Uniformity (K = 2)

| Variable          | Symbol | Range And Level |
|-------------------|--------|-----------------|
| Lighting (lux)    | N₁     | X₁ 350 525 700  |
| Temperature (°C)  | N₂     | X₂ 24 25.5 27   |

Combination treatment as much as 9 as in table. The RSM design used is CCD.

Table 5. CCD Design and Observation Results

| Number | Variable Code | Independent Variable | Y  |
|--------|---------------|-----------------------|----|
| 1      | -1            | 350                   | 6  |
| 2      | 1             | 700                   | 5  |
| 3      | -1            | 350                   | 3  |
| 4      | 1             | 700                   | 4  |
| 5      | 0             | 525                   | 3  |
| 6      | 0             | 525                   | 3  |
| 7      | 0             | 525                   | 2  |
| 8      | 0             | 525                   | 4  |
| 9      | 0             | 525                   | 3  |

Figure 1. Design of RSM Central Composite Design

To determine the value of Xᵀ then, X₀ (Dummy Variable) = 1 because dummy variable serves to estimate parameter β₀

\[
Xᵀ = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
-1 & 1 & -1 & 1 & 0 & 0 & 0 & 0 & 0 \\
-1 & -1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}
\]

After determining the parameter β₀, then the Xᵀ.X matrix obtained as follows:

\[
Xᵀ.X = \begin{bmatrix} 9 & 0 & 0 \\
0 & 4 & 0 \\
0 & 0 & 4 \end{bmatrix}
\]
With X',Y matrix as follows:

\[
\begin{bmatrix}
10.163 \\
0.105 \\
-0.916
\end{bmatrix}
\]

Next determine the value of \( \beta^\wedge = (X^T.X)^{-1}(X^T.Y) \) where value \((X^T.X)^{-1}\) is as follows:

\[
(X^T.X)^{-1} =
\begin{bmatrix}
0.111111 & 0 & 0 \\
0 & 0.25 & 0 \\
0 & 0 & 0.25
\end{bmatrix}
\]

Value \( \beta^\wedge=(X^T.X)^{-1}.(X^T.Y) \) obtained for:

\[
\begin{bmatrix}
b_0 \\
b_1 \\
b_2
\end{bmatrix} =
\begin{bmatrix}
0.111111 & 0 & 0 \\
0 & 0.25 & 0 \\
0 & 0 & 0.25
\end{bmatrix} \begin{bmatrix}
10.163 \\
0.105 \\
-0.916
\end{bmatrix} =
\begin{bmatrix}
1.129 \\
0.026 \\
0.229
\end{bmatrix}
\]

Thus the equation of the second order response can be suspected as follows:

\[
Y = 1.129 + 0.026 X_1 - 0.229 X_2
\]

Determination of correction factor

Correction factor = \( \left( \frac{\Sigma Y^2}{n} \right)^2 = \left( \frac{10.163}{9} \right)^2 = 11.476 \)

Determination of Total Squares

Total of squares = \( \Sigma Y^2 - CF = 103.282 - 11.476 = 91.086 \)

With degrees of free (df) = \( n - 1 = 8 - 1 = 7 \)

Determine the quadratic amount of the regression

To determine the value of the sum of the squares of regression is as follows:

\[
= \Sigma Y^2 - CF - \beta^\wedge . X^T =
\]

\[
= 91.086 - 1.129 - 0.026 - 0.229 = 90.677
\]

With degrees of free (df) regression = \( k - f = 3 - 1 = 2 \)

Calculation of the Amount of Error Squares

To determine Number of Error Squares as follows:

\[
= (\Sigma Y^2 - CF) - (\Sigma Y^2 - CF - \beta^\wedge . X^T)
\]

\[
= 91.086 - 90.677 = 1.129
\]

With degrees of free (df) Error = df. Total – df. Regression

\( = 8 - 2 = 6 \)

Calculation of Amount of Error Pure Squares

\[
= 13.746 - \frac{(10.163)^2}{5} = -6.911
\]

With degrees of free (df.) Error Pure = the number of repetitions on X1 and X2 - 1

\( = 5 - 1 = 4 \)
Determination of the deviation Quantity of the Model

\[ = 1,129 - (-6,911) = 8,040 \]

With degrees of free (df) deviation of the model

\[ = \text{db. error} - \text{db. pure error} = 6 - 4 = 2 \]

Then obtained:

Total Squares Regression = \( \frac{90,677}{2} = 45,338 \)

Total Squares Error = \( \frac{1,129}{6} = 0,188 \)

Total Squares Model = \( \frac{8,040}{2} = 4,020 \)

Total Squares the sum of squares of Pure Error = \( \frac{6,911}{4} = 1.728 \)

F Regression = \( \frac{45,338}{0,188} = 240,906 \)

F Square Model = \( \frac{4,020}{-1.728} = -2.327 \)

\[ R^2 = \frac{91,086}{90,677} = 1.012 \]

**Test Lack Of Fit (deviation of model)**

Hypothesis: Ho: No Lack of Fit; H1: There is Lack of Fit

Level of significance: \( \alpha = 0.05 \) df1 = 2 df2 = 4 Ftable = 7.71

Critical region: When \( F_{\text{count}} > F_{\text{table}} \) then Ho is rejected; When \( F_{\text{count}} < F_{\text{table}} \) then Ho is accepted

Test Statistics: \( F_{\text{count}} = -2.327 \)

**Conclusion**: Since \( F_{\text{count}} < F_{\text{table}} \) is -2.237 < 7.71 then Ho is accepted which means no Lack of Fit (no deviation model).

**Test Overall (Regression test)**

Hypothesis:

Ho: All Independent Variables do not affect the dependent variable

H1: At least one independent variable affects the variable

Significant Level: \( \alpha = 0.05 \) df1 = 2 df2 = 6 Ftable = 5.79

Critical Area: When \( F_{\text{count}} > F_{\text{table}} \) then Ho is rejected; When \( F_{\text{count}} < F_{\text{table}} \) then Ho is accepted

Test Statistics: \( F_{\text{count}} = \frac{45,338}{0.188} = 240,906 \)

**Conclusion**: Since \( F_{\text{count}} > F_{\text{table}} \) is 240,906 > 5.79 then Ho is rejected which means there is at least one independent variable affecting the variable.

**Partial Test**

Testing of lighting predictor regression coefficient (N) 2 to (N) n

Hypothesis: Ho: b1 = 0; H1: b1 ≠ 0

Significance Level: \( \alpha = 0.05 \) df = n-2 = 9-2 = 7 \( t_{\alpha} \)

Critical Area: If \( F_{\text{count}} > F_{\text{table}} \) then Ho is rejected; When \( F_{\text{count}} < F_{\text{table}} \) then Ho is accepted

Test Statistics: \( t_{\text{count}} = \frac{\text{coefficient}}{SE_{\text{coefficient}}} = \frac{0.026}{0.109} = 0.241 \)
Conclusion: Ho rejected

Testing of temperature predictor regression coefficient ($b_2$)

Hypothesis: $H_0: b_2 = 0$; $H_1: b_2 \neq 0$

Significance level: $\alpha = 0.05$; $df = n-2 = 9-2 = 7$; $t_{a/2} = 0,025$

Critical Area: if $-t_{a/2} \leq t_{\text{calculation}} \leq t_{a/2}$ then Ho is accepted;
if $t_{\text{count}} < -t_{a/2}$ or $t_{\text{count}} > t_{a/2}$ then Ho rejected

Test Statistics: $t_{\text{count}} = \frac{\text{coefficient}}{\text{SE}_\text{coefficient}} = \frac{-0.209}{0.109} = -2.094$

Conclusion: Ho accepted

Determination of factor level (coding for each factor)

Lighting factor ($n_1$) = 350 lux ($x_1$) = -1 and 700 lux ($x_1$) = 1
Temperature factor ($n_2$) = 24°C ($x_2$) = -1 and 27°C ($x_2$) = 1

Determining The Levels Of The Corresponding Factor With The Center Point

Lighting factor ($n_1$) with center point $\frac{350+700}{2} = 525$ (coding $X_1=0$)
Temperature factor ($n_2$) with center point $\frac{24+27}{2} = 25.5$ (coding $X_2=0$)

Determining X1 and X2 Which Optimizes the response function

| Replicate | N1  | N2  | Y   | $y=\ln(Y)$ |
|-----------|-----|-----|-----|------------|
| 350       | 24  | 6   | 1.792|
| 700       | 24  | 5   | 1.609|
| 350       | 27  | 3   | 1.099|
| 700       | 27  | 4   | 1.386|
| 525       | 25.5| 3   | 1.099|
| 525       | 25.5| 3   | 1.099|
| 525       | 25.5| 2   | 0.693|
| 525       | 25.5| 4   | 1.386|

| Level Factor | low(-1) | 0 | high(+1) |
|--------------|---------|---|----------|
| n1           | 350     | 525| 700      |
| n2           | 24      | 25.5| 27       |

| Response results | Rounding |
|------------------|----------|
| $Y_1$            | 4.733    | 5       |
| $Y_2$            | 13.833   | 14      |
| $Y_3$            | 4.046    | 4       |
| $Y_4$            | 13.146   | 13      |
From above table obtained the optimal point is $Y_2 = 13.833$.

Based on the results of calculations that have been done then can be drawn conclusions for data processing as shown in the table below:

| Sources of Diversity | DB   | JK   | KT   | $F_{\text{count}}$ | $F_{\text{table (5%)}}$ |
|----------------------|------|------|------|---------------------|-------------------------|
| Regression           | 2    | 90.677 | 45.338 | 240,906            | 5.79                    |
| Error                | 6    | 1.129 | 0.188 |                      |                         |
| SDM                  | 2    | 8.04  | 4.02  | -2.327              | 7.71                    |
| GM                   | 4    | -6.911 | -1,728 |                      |                         |

With the results of tests that have been done then we get the following equation:

$$Y = 1.129 + 0.026 X_1 - 0.229 X_2$$

From the result of determination of point $X_1$ and $X_2$ that optimize the response function then get the value of $Y_1$ to $Y_9$ is $Y_1 = 5$, $Y_2 = 14$, $Y_3 = 4$, $Y_4 = 13$, $Y_5 = 9$, $Y_6 = 9$, $Y_7 = 9$, $Y_8 = 9$, $Y_9 = 9$. And the most optimal $Y$ is $Y_2 = 14$.

6. Conclusion

Based on the results of the analysis and discussion done, then in this study it can be concluded that the stationary point that maximizes the response (the number of truths that occur) obtained from the data processing is $X_1 = 0.026$ and $X_2 = -0.299$.

The stationer dot obtained by the lighting value of 700 lux and the temperature of 24°C with the expected maximum response to the output is 14.

In this study the most influential variable on operator work is lighting with coefficient value of 0.026.
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