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# The Optimization of Environmental Factors at Manual Assembly Worstation by Using Taguchi Method

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**Abstract:** The objective of this study was to determine the dominance effects of environmental factors such as Illuminance, humidity and WBGT on the operators' productivity at Malaysian automotive industry. A case study was carried out at an automotive components assembly factory. The environmental factors examined were the Illuminance (lux), humidity and WBGT of the surrounding workstation area. Two sets of representative data including the illuminance, humidity and WBGT level and production rate were collected during the study. The production rate data were collected through observations and survey questionnaires while the illuminance level was measured using photometer model RS 180-7133, the humidity and WBGT level were measured by using quest temp thermal environment monitor. Taguchi Method was utilized to find the sequence of dominant factors that contributed to the productivity of operator at that specified production workstation. The study reveals that the dominant factor contributed to the productivity was illuminance, followed by humidity and WBGT.

**Key words:** Illuminance, relative humidity, WBGT, productivity, optimum

## INTRODUCTION

Ergonomics has traditionally been used to improve the workers' performance by discovering the factors that contribute to their performance. Many organizations are forced to consider effects of environmental factors towards their workers' performance in terms of safety and efficiency (Ismail *et al*., 2009). In recent years, there has been increasing interest in the automotive industry. Automotive industry is a booming industry which encompasses similar areas of activities (Yazdani *et al*., 2009) in Malaysia. Over the years production of car has also showed an increasing trend where in 1999, almost 254,000 cars produced but doubled (442,000 cars) in 2007 with employing of 47,000 workers in Malaysia (OICA, 2007). Improving workers' productivity, occupational health and safety are major concerns of industry, especially in developing countries. However, these industries are featured with improper workplace design, ill-structured jobs, mismatch between workers' abilities and job demands, adverse environment, poor human-machine system design and inappropriate management programs (Shikdar and Sawadeq, 2003). Light, noise, air quality and the thermal environment were considered factors that would influence the acceptability and performance on the occupants of premises (Olesen, 1995). Dua (1994) stated that lower emotional health is manifested as psychological distress, depression and anxiety, whereas lower physical health is manifested as heart disease, insomnia, headaches and infections. These health problems could lead to organizational symptoms such as job dissatisfaction, absenteeism and poor work quality.

According to the Fisk and Rosenfeld (1997), productivity was one of the most important factors affecting the overall performance to any organization, from small enterprises to entire nations. Increased attention had focused on the work environment and productivity since the 1990s. Laboratory and field studies showed that the physical and chemical factors in the work environment could have a notable impact on the health and performance of the occupants and consequently on the productivity. Workplace environmental conditions, such as humidity, indoor air quality and acoustics have

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significant relationships with workers' satisfaction and performance (Marshall *et al.*, 2002; Fisk, 2000). Indoors air quality could have a direct impact on health problems and leads to uncomfortable workplace environments (Juslen and Tenner, 2005; Fisk and Rosenfeld, 1997; Marshall *et al.*, 2002).

Shikdar and Sawaqed (2003) pointed out that there was high correlation between performance indicators and health, facilities and environmental attributes. In the other words, companies with higher health, facilities and environmental problems could face more performance related problems such as low productivity and high absenteeism. Employees with complaints of discomfort and dissatisfaction at work could have their productivity affected, result of their inability to perform their work properly (Leaman, 1995).

Staffan and Knez (2001) had investigated on how noise, air temperature and illuminance combine or interact in their effects on cognitive performance. The results from Staffan and Knez study showed that they worked faster in noise but at the cost of lesser accuracy. Interactions were found between noise and heat on the long-term recall of a text and between noise and light on the free recall of emotionally toned words. In metal industry, Bommel *et al.* (2002) conducted a study on the effect of increasing the illuminance based on increased task performance, reduction of rejects and the decreased number of accidents. The result of the study revealed that the increasing of illuminance from the minimum required of 300 lux (minimum) to 500 lux could lead to an increase of productivity from 3 to 11% based on realistic assumptions that the increase of illuminance from 300 lux to 2000 lux would increase the productivity from 15 to 20% (Bommel *et al.*, 2002). Juslen and Tenner (2005) described the mechanisms involved in enhancing human performance by changing the lighting in the industrial workplace through visual performance, visual comfort, visual ambience, interpersonal relationships, biological clock, stimulation, job satisfaction, problem solving, the halo effect and the change process.

Robust design is an engineering methodology for obtaining product and process conditions, which are minimally sensitive to the various causes of variation to produce high-quality products with low development and manufacturing costs (Park, 1996). Taguchi's parameter design is an important tool for robust design. It offers a simple and systematic approach to optimize design for performance, quality and cost. Two major tools used in robust design are (Park, 1996; Unal and Dean, 1991; Phadke, 1989):

- Signal to noise ratio, which measures quality with emphasis on variation
- Orthogonal arrays, which accommodate many design factors simultaneously

Taguchi's approach is totally based on statistical design of experiments (Park, 1996) and this can economically satisfy the needs of problem solving and product or process design optimization (http://www.vkroy.com/up-doe.html). By applying this technique one can significantly reduce the time required for experimental investigation, as it is effective in investigating the effects of multiple factors on performance as well as to study the influence of individual factors to determine which factor has more influence, which less (Park, 1996.; http://www.vkroy.com/up-doe.html). Some of the previous works that used the Taguchi method as tool for design of experiment in various areas including metal cutting are listed in the references (Lin, 2002; Tsui, 1999; Zhang and Wang, 1998; Si and Tong, 1997; Kopac, 2002).

The most important stage in the design of an experiment lies in the selection of control factors. As many factors as possible should be included, so that it would be possible to identify non-significant variables at the earliest opportunity. Taguchi creates a standard orthogonal array to accommodate this requirement. Depending on the number of factors, interactions and levels needed, the choice is left to the user to select either the standard or column-merging method or idle-column method, or etc. Two of the applications in which the concept of S/N ratio is useful are the improvement of quality through variability reduction and the improvement of measurement. The S/N ratio characteristics can be divided into three categories when the characteristic is continuous (Park, 1996):

Nominal is the best characteristic:

$$S/N = 10\log\frac{\bar{y}}{s^2_{\ y}} \quad (1)$$

Smaller the better characteristics:

$$S/N = -10\log\frac{1}{n}\left(\sum y^2\right) \quad (2)$$

Larger the better characteristics:

$$S/N = -10\log\frac{1}{n}\left(\sum\frac{1}{y^2}\right) \quad (3)$$

where, $\bar{y}$ is the average of observed data, $s_y^2$ is variance of y, n is number of observations and y is the observed data. For each type of the characteristics, with the above S/N ratio transformation, the higher the S/N ratio the better is the result.

## MATERIALS AND METHODS

**Selection of location and subjects:** The study is conducted on a selected work station in the automotive industry where it refers mainly towards the assembly section or the manual production line where human energy are involve for in the manufacturing activity. This study was conducted on September 2009.

Figure 1a-d shows the work sequences for the complete assembly of body switch backdoor. Process (a) and (b) is the process to insert the contact spring into the body switch. For the process (c), the wire is inserted into the part and taping. Lastly the body switch is done with a soldering process.

Figure 2 show the flow process at body switch backdoor assembly. The production is desired to be the repeated production of the same component throughout the entire shift and this is to ensure on the consistency of the data collected towards the data analysis later. Priority of study will be given to the work station where the environmental factors will sponsor the most towards effect of the productivity. One automotive vendor has been selected as a place of study. A line producing a product over a period of time and under the effects of certain relative humidity, illuminance and WBGT was chosen. There are three process involve in order to complete the body switch. Worker 1 starts with the process 1 and pass the complete part to the operator 2 to do the process 2. Worker 1 completed the process 1 until the certain quantity and move to process 3. After achieve the target for the process 3, worker 1 back to process 1. The process rotate until 3.15 pm, where all the process stops and start to bundling and packaging.

This criterion is essential in order to obtain the which factors contribute utmost to the worker productivity based on output of assemblies among operators. The production line was consist of 5 woman operators. The task is to assemble an automotive parts which is known as body switch backdoor. The standard production rate determined by the previous feasibility study to assemble a complete door check was 392 units for every hour of production.

**Experimental method:** The Taguchi design of experiment was employed in this experiment with two factors at two levels each. The fractional factorial designs used was a standard $L_8$ orthogonal array (Park, 1996). This orthogonal array was chosen because of its minimum number of experimental trials. Each row of the matrix represented one trial. However, the sequence in which those trials were carried out was random, the factors and levels identified in this study were shows in Table 1.

Table 1 shows the factors and levels used in the experiment, for the illuminance factor, the range of illuminance level has be chosen whether below 500 lux for discomfort level and more than 500 lux for comfort level (Bommel *et al*., 2002; Juslen and Tenner, 2005). A relative humidity factor consists of two level which is below 75% for the comfort level and more than 75% for discomfort level (Tsutsumi *et al*., 2007). Lastly for WBGT factor, it

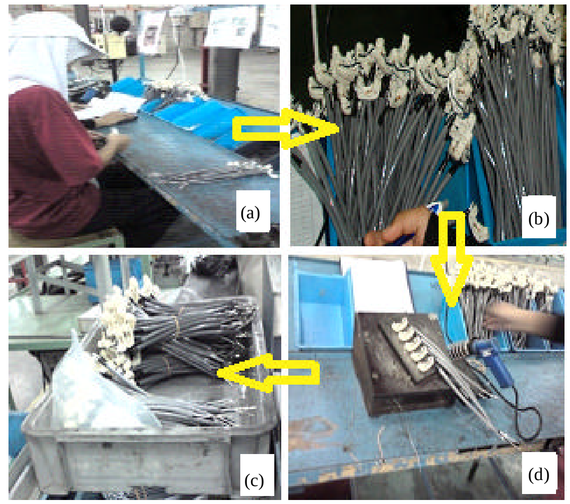


Fig. 1: (a-d) Production sequence for the complete assembly of body switch backdoor

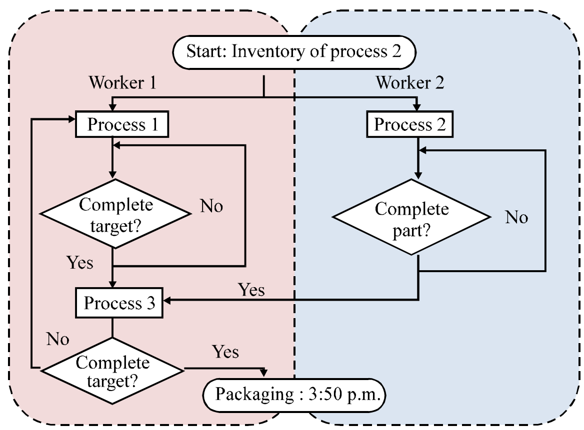


Fig. 2: The flow process at body switch backdoor assembly

Table 1: Factors and levels used in the experiment

| Symbol | Factors | Unit | Level 1 | Level 2 |
|---|---|---|---|---|
| A | Illuminance | lux | <500 | >500 |
| B | Relative Humidity | (%) | <75 | >75 |
| C | WBGT | °C | <27 | >27 |

Table 2: Experimental Layout Using an $L_8$ Orthogonal Array

| | Factor levels | | |
|---|---|---|---|
| Experiment No. | Illuminance (A) | Relative humidity (B) | WBGT (C) |
| 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 2 |
| 3 | 1 | 2 | 1 |
| 4 | 1 | 2 | 2 |
| 5 | 2 | 1 | 1 |
| 6 | 2 | 1 | 2 |
| 7 | 2 | 2 | 1 |
| 8 | 2 | 2 | 2 |

consists of two levels which are below than 27°C for comfort level and more than 27°C for discomfort level (Niemelä *et al*., 2002).

**Orthogonal array experiments:** To select an appropriate orthogonal array for experiments, the total degree of freedom needs to be determined. The degree of freedom are defined as the number of comparisons between factors that need to be determine which level is better and specifically how much better. In the present study, since each factor has two levels therefore, there are three degrees of freedom. In this study an $L_8$ orthogonal array is used and shown in Table 2.

Table 2 shows the standardize Taguchi method under $L_8$ orthogonal array. Each factor consists of two levels which are level 1 for the minimum value and level 2 for the maximum value.

## RESULTS AND DISCUSSION

The result of this study was based on the case study conducted on the production line in the automotive vendor factory. The hypotheses for this study was the production rate have a direct relationship with the illuminance, humidity and WBGT level. The levels of illuminance, humidity and WBGT were taken to identify their effect on the worker performances. The objective of the experiment is to obtain the optimize the environmental parameters (WBGT, illuminance and humidity) in order to obtain the better results for production rate (high value) and therefore the optimum characteristic of environment should be quantify.

**Linear relation analysis:** Figure 3 represents the linear regression model between production rate and illuminance level. The linear regression model obtain is Production Rate = 1.75 Illuminance-694. Based on Fig. 3, the production rate were improved with the increase of the

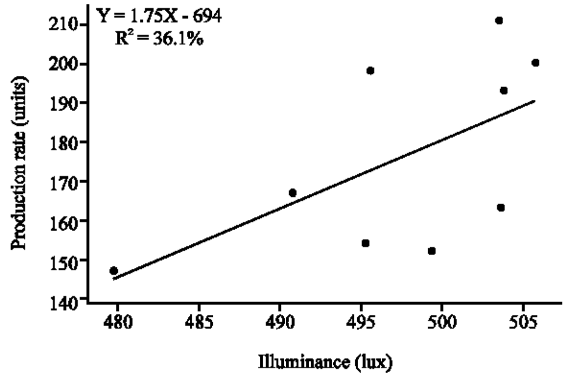


Fig. 3: Results of production rate versus illuminance level

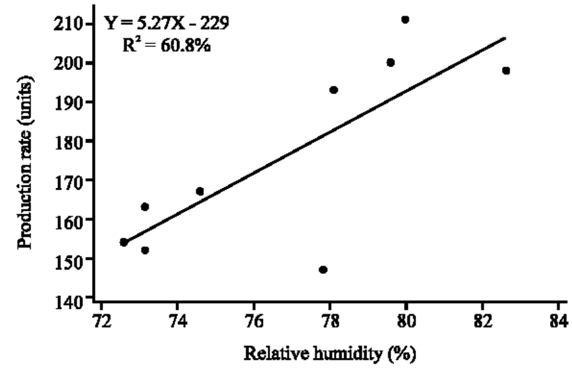


Fig. 4: Results of production rate versus relative humidity

illuminance (lux). The results obtained for the illuminance is in-line with the finding from Bommel *et al*. (2002) and Juslen and Tenner (2005) where the increasing of illuminance levels lead to an increase in productivity. The same trend is observed for the relative humidity (%) and the productivity as shown in Fig. 4.

Figure 4 represents the linear regression model between production rate and relative humidity. The linear regression model obtain is Production Rate = 5.27 Relative Humidity-229. The positive trend on the effect of relative humidity towards productivity is in-line with the finding by Tsutsumi *et al*. (2007) where they had found the subjective performance was at the same level under four different levels of relative humidity. However, Tsutsumi *et al*. (2007) reported their subjects were more tired at 70% RH after relative humidity (%) step change.

Figure 5 represents the linear regression model between production rate and WBGT. The linear regression model obtain is Production Rate = -24.8 WBGT + 876. The trend obtained for illuminance and relative humidity towards productivity is different compared to the relation of Wet Bulb Globe Temperature (WBGT) and productivity. Figure 5 shows by increasing the Wet Bulb

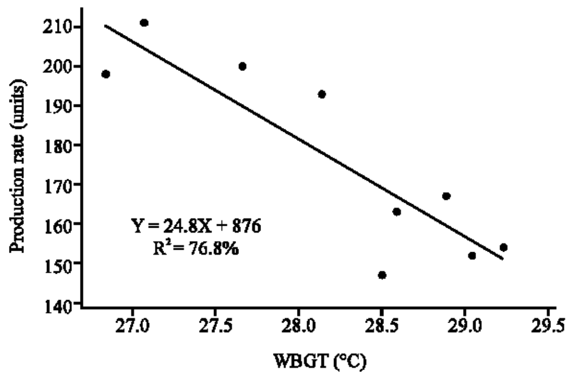


Fig. 5: Results of production rate versus WBGT

Globe Temperature will reduce the performance and productivity of the operators. It is encouraging to compare this figure with that found by Niemelä *et al.* (2002), who reported that productivity decrease of 2.2% per °C when the temperature increased above 25°C. The findings for Wet Bulb Globe Temperature is contradicted with finding of Fisk and Rosenfeld (1997) where by increasing the air ventilation will significantly increase the performance of the operators. The productivity increase cause by the WBGT could be related to the attention and cognitive aspect of the operators, which has been studied by Staffan and Knez (2001). They found that the combination of air temperature and illuminance level had a significant effect on cognitive performance.

**Taguchi approach:** Taguchi recommends analyzing the means and S/N ratio using conceptual approach that involves graphing the effects and visually identifying the factors that appear to be significant, without using ANOVA, thus making the analysis simple (Park, 1996). It shows that the relative humidity is the most significant factor in controlling the production rate, followed by the illuminance and WBGT. The $L_8$ orthogonal array for environment parameters and production rate were show in Table 3.

Table 4 shows the mean S/N ratio for each factor at two levels. From this table, the highest value for each mean S/N ratio for each factor can be identified clearly. The optimum condition for the production rate are at level 1 (less than 500 lux) of illuminance, level 1 (less than 75%) of humidity and level 2 of WBGT (more than 27°C).

**Analysis of Variance (ANOVA):** The purpose of ANOVA is to investigate which of the factors significantly affect the workers' productivity. Table 5 shows the results of analysis of variance. Statistically F-test can be used to determined which factors have significant effect on the workers' productivity. The sequential sums of squares (Seq SS) measure the reduction in the residual sums of squares provided by each additional term in the model. The adjusted sums of squares (Adj SS) measure the reduction in the residual sums of squares provided by each term relative to a model containing all the other terms. The F value for each factor is then a ratio of the MS to the mean square of error. The larger the F value, the greater the effect on the performance characteristics (productivity of workers) due to change of operating factors. Usually, when F>4 it means that the change of operating factors has a significant effect on the quality characteristics.

Table 3: Experimental result for productivity and S/N ratio

| Experiment No. | Illuminance (A) (lux) | Relative humidity (B) (%) | WBGT (C) (°C) | Production rate (units) | S/N ratio dB |
|---|---|---|---|---|---|
| 1 | <500 | <75 | <27 | 198 | 45.93 |
| 2 | <500 | <75 | >27 | 211 | 46.49 |
| 3 | <500 | >75 | <27 | 200 | 46.02 |
| 4 | <500 | >75 | >27 | 193 | 45.71 |
| 5 | >500 | <75 | <27 | 163 | 44.24 |
| 6 | >500 | <75 | >27 | 152 | 43.64 |
| 7 | >500 | >75 | <27 | 154 | 43.75 |
| 8 | >500 | >75 | >27 | 167 | 44.45 |

Table 4: Response Table for signal to noise ratios (larger is Better)

| | | Mean S/N ratio (dB) | | |
|---|---|---|---|---|
| Symbol | Factors | Level 1 | Level 2 | Rank |
| A | Illuminance | 46.04 | 44.02 | 1 |
| B | Relative Humidity | 45.07 | 44.98 | 2 |
| C | WBGT | 44.99 | 45.07 | 3 |

Table 5: Results of the analysis of variance for S/N ratios

| Symbol | Factors | df | Seq SS | Adj SS | Adj MS | F-value | p-value |
|---|---|---|---|---|---|---|---|
| A | Illuminance | 1 | 8.131 | 8.131 | 8.131 | 43.61 | 0.003 |
| B | Relative humidity | 1 | 0.016 | 0.016 | 0.016 | 0.09 | 0.781 |
| C | WBGT | 1 | 0.014 | 0.014 | 0.014 | 0.08 | 0.795 |
| Error | | 4 | 0.746 | 0.746 | 0.186 | | |
| Total | | 7 | 8.908 | | | | |

From the results of the ANOVA presented in Table 5, it can be seen that only illuminance is statistically significant. However, each factor contributes to the quality characteristics and the rank order is illuminance (rank 1), relative humidity (rank 2) and WBGT (rank 3) respectively. Therefore, based on the S/N ratio and ANOVA analysis, the optimal parameters for achieving optimum productivity in terms of environmental factors are illuminance level at level 1 (<500lux), relative humidity at level 1 (<75%) and WBGT at level 2 (>27°C).

From the literature, only a few studies have been conducted in the area to establish a dominant environmental parameter contributed to the worker productivity. The authors believe the study had achieved the objective in order to establish the dominant environmental parameters contributed to the productivity.

The finding from the current investigation corresponds to the result found by Bommel *et al.* (2002) and Juslen and Tenner (2005) where the increasing of illuminance levels lead to an increase in productivity. This also accords with our earlier observations, which showed that the production rate and illuminance level has positive significant relationship (Ismail *et al.*, 2007). The two dominant factors obtain in this study will provide a guideline to assist engineers to determine the illuminance and relative humidity level during the feasibilities study to allow assembly production line achieves the optimum output.

The finding also will be useful to engineers in design the lighting systems in order to improve the comfort in the workstation area and control the productivity of workers. The dominant environmental parameter obtain in this study is only applicable to present the current condition for the selected area of assembly workstation at Malaysian automotive industries. From the results of the study also concluded that there is relationship between illuminance, humidity and WBGT level with production rate. Therefore the findings from this study are in line with the previous study that indicated illuminance and WBGT play an important role in controlling the production rate because the both factors will contributed to the comfort level of worker (Shikdar and Sawadeq, 2003; Olesen, 1995; Dua, 1994).

## CONCLUSIONS

Past research on the modeling relationship of workplace environmental factors to the productivity or performance is very limited. In addition they are characterized by a short time perspective, not enough engineering data regarding the lead time, expected output capacity or perception with emphasis on survey methods, statistical analysis, satisfaction and the preferences measurement. This study was done to prove empirically the previous perception studies, which based on the role of environmental factors to productivity. It is hoped that this study would be beneficial to the automotive manufacturing industries in Malaysia.

The research findings are restricted to the Malaysian workplace environment, where the awareness among workers on improving productivity is still low. The results might vary for tests carried out for different sample sizes, types of industries and countries. The study could be more extensive if the fraction of defect rate for the product is included in the analysis. Nevertheless the authors believed the modeling of production rate, as a time series data is more than adequate to understand the affect of environmental factors towards productivity.

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