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Optimizing Humidity Level and Illuminance to Enhance Worker Performance in an Automotive Industry

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Abstract: The objective of this study is to determine the optimum values of environmental factors such as relative humidity (%) and illuminance (lux), on the operators' productivity at Malaysian automotive industry. Production of automotive parts is among the largest contributor to economic earnings in Malaysia. The dominant work involve in producing automotive part were manual assembly process. Where it is definitely used a manpower capability. Thus, the quality of the product heavily depends on worker's comfort in the working condition. Humidity and illuminance level can give significant effect on the worker performance. Humidity level, illuminance level and productivity rate were observed in automotive factory. An automotive manufacturing firm was chosen to observe the relative humidity level, illuminance level and worker's productivity rate. The data were analyzed using Artificial Neural Network's (ANN) analysis. Artificial Neural Network's (ANN) analysis technique is usual analysis method used to form the best linear relationship from the collected data. It is apparent from the linear relationship, that is the optimum value of production (value˜1) is attained when relative humidity is 54.86% RH and lighting value is 146.386 lux. Optimum value production rate (value˜1) for one manual production line in that particular company is successfully achieved. Through ANN's system, optimum environmental factor manage to be predicted.

Key words: Optimum, productivity, humidity, illuminance

INTRODUCTION

Automotive Industry in Malaysia contributes large profit and investment. According to the released automotive data by Malaysia Automotive Associations (MAA) in 2007, 441 678 vehicles were installed in manufacturing plants within Malaysia where 403 245 are passenger vehicles and 38 433 are commercial vehicles. This number increase every year. Due to that, demand of vehicle components (car/lorry/bus) rising, therefore productivity of the component should be increase. More than 30% of these components are fitted and done manually. For components which require observation and human touch such as installation engine car must be done manually. It uses a manpower capability. Thus, the quality of the product heavily depends on worker's comfort in the working environment. One major issue in early Shikdar and Sawaqed (2003) research concerned is about 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. It means that the comfort level for workers do their job is not been considered in the first place. Tarcan *et al*. (2004) indentified irritated, sore eyes and throat, hoarseness, stuffy congested nose, excessive mental fatigue, headache and unusual tiredness were all signs of the negative workplace environmental conditions.

Light, noise, air quality and the thermal environment were considered factors that would influence the acceptability and performance on the occupants of premises (Dua, 1994; Olesen, 1995). Environmental factors surrounding the work area such as illumination, temperature, ventilation, noise and vibration must also be taken into consideration to increasing motivation level of

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the workers (Ismail *et al*., 2008). 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. Those factors can affect the comfort level of the production operators to perform their jobs. When comfort level at workplace increase, the productivity increase too. Ettner and Grzywacz (2001) published a study in which they described that the work environments were associated with perceived effects of work on health. Workplace environmental conditions, such as humidity, indoor air quality and acoustics have significant relationships with workers' satisfaction and performance (Atmaca *et al*., 2007; Tarcan *et al*., 2004). These factors need to be adjusted to get the best ratio will increase the rate of comfort in workplace.

Relative humidity is a quantity of water content in the air and should be control to ensure the environmental comfort for maintain the productivity in industry (Huanga *et al*., 2008). In another major study, Atmaca and Yigit (2006) found that by increasing the relative humidity rate would result the skin temperature and wettedness increase at high operation temperature. With low relative humidity level can cause the development of dry eyes, possibly more among elderly than young people, although the immediately perceived indoor air quality may be favorable (Wolkoff and Kjærgaard, 2007). Dry air in office workplaces has been the target for discomfort complaints and a number of symptoms in the skin and the mucous membranes, such as eye irritation (Gavhed and Klasson, 2005). However, if the value of relative humidity and air velocity are controlled within the optimum ranges, the negative effects could be kept to a minimum and thermal comfort remain higher (Hashiguchi and Tochihara, 2009). Ventilation system is an important component for controlling environmental temperature and plays a key role in comfort level of working environment.

One of the major factor contribute to the productivity at the body assembly production line is illuminance (Ismail *et al.* 2008, 2009a, b). The term Illumination is used by Golmohammadi *et al.* (2009) to refer to the cumulative energy incidents on a surface in a certain time, whereas the term Illuminance is refer to the instantaneous incident energy. The correlation between illuminance and productivity is weak, but statistically significant (Jusle´n *et al*., 2007). This indicates that there is a connection between lighting level and productivity. Sasaki *et al.* (2006) pointed out that noise of the lighting can improve the signal detection in human visual perception. Illuminance and the use of lights and blinds seemed to have little effect on self-reported productivity. There was evidence of continual changes in the use of artificial lights and blinds to adapt light levels in the offices, probably to increase the satisfaction of occupants (Nicol *et al*., 2006). The combination of colour temperature and illuminance that best preserved the positive mood and enhance the performance in the problem-solving and free recall tasks (Knez, 1995).

Productivity may be classified as ratio of some output with some input (Bain, 1982). Productivity is relationship of output in an particular organization with its input (Belcher, 1987). To measure productivity, Eq. 1 can be used. Output can be in term of results or efficiency, whereas input can in source or effectiveness.

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Results}}{\text{Source}} = \frac{\text{Efficiency}}{\text{Effectiveness}} \quad (1)$$

Productivity is relationship between goods output or service with employee input or non-human resource in production which will consider employee total working hours, machine total hours operating etc (Buehler and Shetty, 1981). Productivity basically consist of three basis which are the production input, production output and effectiveness of product distribution from inputs to output (Bhattasali and Bhattasali, 1972). Artificial Neural Network (ANN) is a calculation system for sets of data in nonlinear experiment that uses system neurons with ability mapping linear line (Hao *et al*., 2008). ANN operating similarly like human brain function to resolve problems which involve mathematical calculation (Zhou *et al*., 2008). Hayati (2007) defines the Artificial Neural Network as an interconnection of simple processing element that use simple biological neuron as it functionality. The ANN consists of input layer, layer hiding and output layer. ANN is a system that can build an accurate input-output experiment system (Liau, 2008). In this study, Relative Humidity (RH) index is used to represent room humidity. RH is percentage of water vapor pressure in air with saturated water vapor pressure at certain temperature. In this paper, the RH value will be obtained by using Eq. 2:

$$\text{RH} = \frac{\rho}{\rho^*} \times 100 \quad (2)$$

Where:

ρ = Water vapor pressure in air
ρ^* = Saturated water vapor in air at certain temperature
RH = Relative humidity

MATERIALS AND METHODS

A Malaysian based automotive company had been selected as a place of study. The study at the field had been conducted on 5 and 12 June 2009. This experiment is conducted for two working days (two shift days). This study was carried out in a 200 m^2 area production set which was equipped with air conditioner cooling system. During the study, one operator was chosen to become a subject. The operator will work as usual day and ascertained measurement equipments will not restrict the operator movement to do work. Equipment would be mounted near to the operator and the maximum range of equipments is three meters. All factors will be recorded for 10 min time interval in one shift job.

Before starting data collecting process, the equipments must be calibrated. This calibration's process would be vital to determine the accuracy of data. This process is carried out by using computerize method to make sure the calibration process followed the standard perception. After calibration, these equipments are prepared to take readings at the study field. After completed data observation, these equipments will be calibrated again to make sure the quality of the data and facilitate equipment in data collection in future.

After the data was observed and recorded, the data were analyzed using ANN's process to get a straight line graph of production rate versus relative humidity. This analysis will be conducted repeatedly to get the best reading. After getting best variation data, optimum value would be determined (Fig. 1).

In this study, productivity is deliberating real output value with target output. From Eq. 1, productivity will be calculated with ratio of real output (input) to target output (output). Below is calculation for productivity, productivity will be calculated with use Eq. 3.

Target output per shift	= 1400 units
Time for one shift	= 9 h
Interval period	= 1.15 h
Real time work	= (9-1.15) h
	= 7.45 h
Target output for 10 min	= 30.107 units

$$\text{Productivity} = \frac{\text{Real output}}{30.107} \tag{3}$$

Relative humidity in this study is measured base on percentage amount of water vapor that exists in a gaseous mixture of air and water vapor in unit %RH. For illuminance level in this study measured in unit lux. This relative humidity and illuminance level was carried out using Quest-Thermal Environment Monitor equipment as shown in Fig. 2. This equipment use equation 1 to calculate relative humidity in the study field. For each 10 min, relative humidity, illuminance level and production rate being recorded. To confirm either the optimum value has achieved acceptable range or not, the regression value (R) must be within the scale of 0.5 to 1. Two

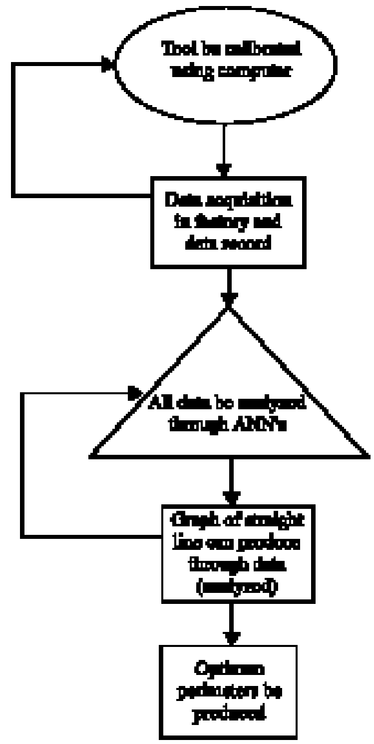

Fig. 1: Flow process for the study

Fig. 2: Quest-thermal environment monitor

proportion factors tested in this study. Firstly the proportion factor between production rate values after ANN analysis verses production rate before ANN analysis and secondly the proportion factor between production rate values after ANN analysis versus relative humidity and illuminance level values.

RESULTS AND DISCUSSION

After relative humidity, illuminance level and production rate were obtained, that data will be trained using ANN analysis to get the relative humidity level and production rate to obtained linear relationship. Through ANN analysis, relative humidity and illuminance values have been set to be constant, but dependent variable factor (production rate) been trained and altered. The production rate will be coordinated to get significant value.

First day experiment: During the experiment parameters such as relative humidity, illuminance level, real production level and target production had been carried out and recorded. By using Eq. 1, the productivity for the first day of experiment can be obtained. The readings were recorded for 10 min intervals time, starting from 9:40 a.m. to 4:00 p.m. There have idle time in the operation due to the worker's rest time and maintaining machine.

Relative humidity: Figure 3 shows the graph plotted between original value of production rate (shaped 'o') together with production rate value after ANN analysis (shaped '*') versus relative humidity value for first day experiment. Observe that original value of production rate scattered randomly versus relative humidity value. But after ANN analysis, production rate value give linearly reducing pattern at relative humidity 47-50% RH and 52-54% RH. The data are divided into three parts which are the training part (Fig. 4a), validity part (Fig. 4b) and test part (Fig. 4c). This three training part will contribute to R value for proportion factor between production rate value after ANN analysis versus production rate before ANN analysis.

For first day experiment, the R value is 0.52951 (Fig. 4d) for proportion factor between production rate value after ANN analysis versus production rate before ANN analysis. This shows that production rate relationship after ANN analysis compared with production rate before analysis is a bit strong. Whereas for proportion factor between production rate values after ANN analysis versus relative humidity values obtain R value is 0.5217. The strength of relationship between

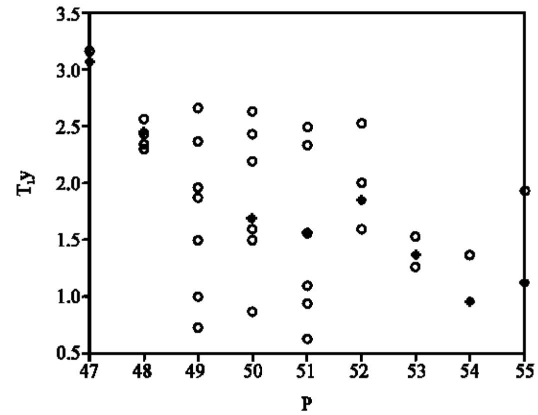

Fig. 3: Production rate graph verses relative humidity value

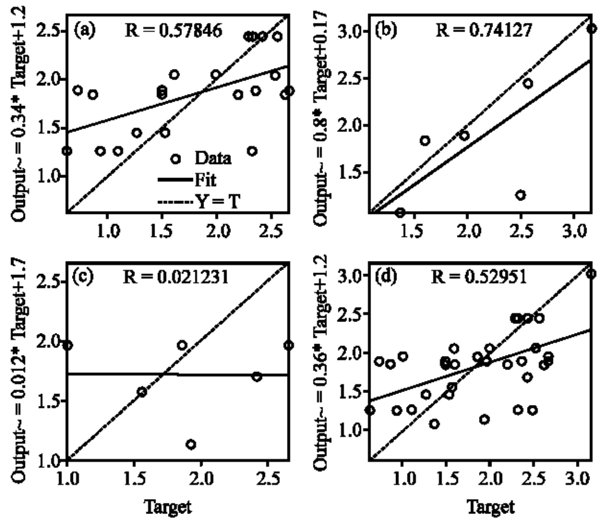

Fig. 4: Production rate graph before ANN analysis versus production rate after ANN analysis for (a) training department, (b) validity, (c) test and (d) total

production rates after ANN analysis on relative humidity is fairly high.

With result of both proportion factor giving R value exceeds 0.5, this observation can conclude that the production rate after ANN analysis versus relative humidity is proportional quite linear. Through this relationship, the optimum production value (value~1) will be achieved when relative humidity value is 53.6582%RH. This finding is in agreement with Tsutsumi *et al*. (2007) findings that the best relative humidity for doing task while working is between 40 to 50% RH. This result is consistent with ASHRAE Standard 62-2001 Ventilation for Acceptable Indoor Air Quality, which states that a relative humidity range of 25 to 60% RH is optimal for human

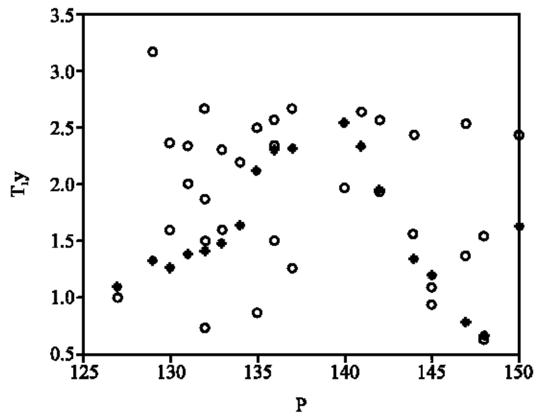

Fig. 5: Production rate graph verses illuminance level value

working conditions. According to an article provided by the Minnesota Blue Flame Gas Association, relative humidity ranges between 20 and 60% RH are comfortable for humans. The Engineering ToolBox has suggested that human comfort requires the relative humidity to be in the range of 25-60% RH. For relative humidity above 60% RH, workers will feel uncomfortably damp.

Illuminance level: Figure 5 shows the graph plotted between original value of production rate (shaped 'o') together with production rate value after ANN analysis (shaped '*') versus lighting value for first day experiment. Observe that original value of production rate scattered randomly versus lighting value. But after ANN analysis, production rate value give linearly increasing pattern at illuminance level 125140 lux and decreasing 140-150 lux. The data are divided into three parts which are the training part (Fig. 6a), validity part (Fig. 6b) and test part (Fig. 6c). This three training part will contribute to R value for proportion factor between production rate value after ANN analysis versus production rate before ANN analysis.

For first day experiment, the R value is 0.29087 (Fig. 6d) for proportion factor between production rate value after ANN analysis versus production rate before ANN analysis. This shows that production rate relationship after ANN analysis compared with production rate before analysis is a bit strong. Whereas for proportion factor between production rate values after ANN analysis versus lighting values give R value is 0.3040. The strength of relationship between production rates after ANN analysis on lighting level is fairly week.

With result of both proportion factor giving R value below 0.5, this observation can conclude that the production rate after ANN analysis versus lighting level

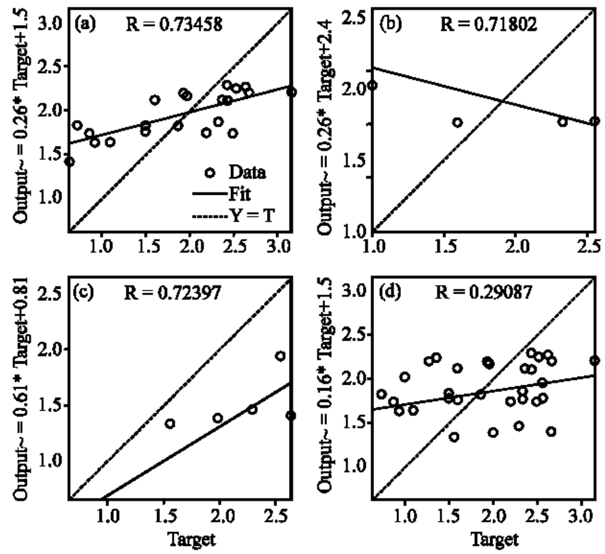

Fig. 6: Production rate graph before ANN analysis versus production rate after ANN analysis for (a) training department, (b) validity, (c) test and (d) total

is proportional linear with low strength. Through this relationship, the optimum production value (value˜1) will be achieved when lighting value is 146.386 lux. It is encouraging to compare this figure with that found by Cajochen *et al.* (2000), who found that exposure to lighting level in range of 90 hingga 180 lux can increasing the awareness at night time. Although, Cajochen *et al.* (2000) did his experiment at night day, but his result can support this optimum level for lighting because this experiment been done in close room and had similar with night condition. The Engineering ToolBox has suggested that illuminance for working areas where visual tasks are only occasionally performed is 100-150 lux.

Second day experiment: The reading recorded for 10 min intervals time starts from 9.40 a.m. to 4.50 p.m. There have idle time in the operation due to the worker's rest time and maintaining machine.

Relative humidity: For second day of experiment, Fig. 7 shows the graph of original production rate value (shaped 'o') together with production rate value after ANN analysis (shaped '*') versus relative humidity value for first day experiment. From the graph in Fig. 7, production rate value before ANN analysis scattered by fairly random with relative humidity values. After ANN analysis (shaped '*'), production rate value scattered randomly, the data still shows a reduction pattern although it not reduce linearly.

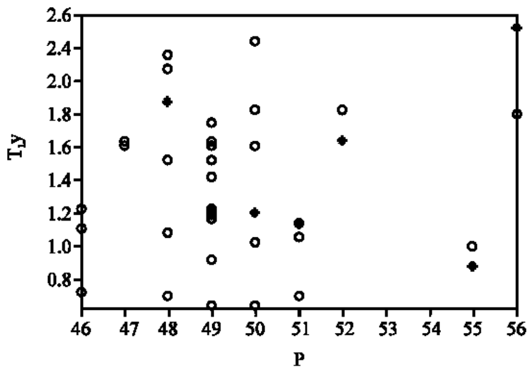

Fig. 7: Production rate graph verses relative humidity value

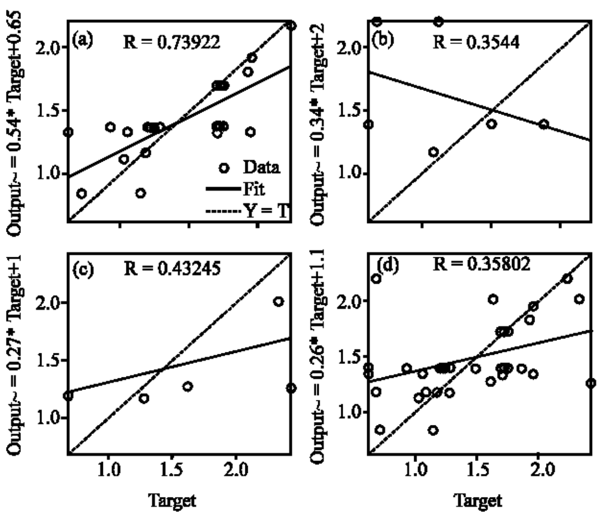

Fig. 8: Production rate graph before ANN analysis versus production rate after ANN analysis for (a) training department, (b) validity, (b) test and (d) total

For the second day experiment, the proportion factor between production rate values after ANN analysis versus production rate before ANN analysis had R value is 0.35802 (Fig. 8d). This shows that the production rate relationship after ANN analysis compared with the production rate before analysis is weak. Whereas for proportion factor between production rate values after ANN analysis versus relative humidity values gives R value is 0.3781. The strength of relationship between production rates after ANN analysis versus relative humidity is pretty weak. Although the value is pretty weak but that is the best value for the data of relative humidity for that day. The data are divided into three parts which are the training part (Fig. 8a), validity part (Fig. 8b) and test part (Fig. 8c). This three training part will contribute to R value for proportion factor between

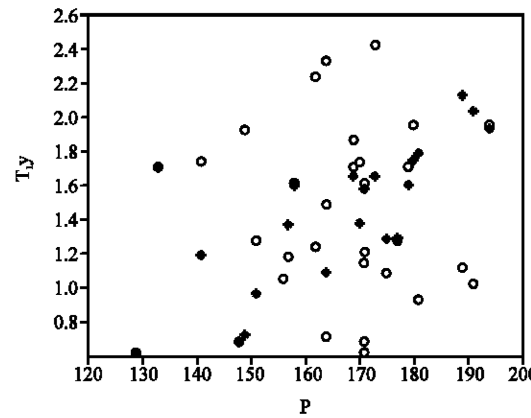

Fig. 9: Production rate graph verses illuminance level value

production rate value after ANN analysis versus production rate before ANN analysis.

With the result for both proportion factor value, R which exceeded 0.5, this observation can conclude that the production rate after ANN analysis versus relative humidity is proportional quite linear. Through this weak relationship, the optimum value of production (value˜1) can be achievable when the relative humidity value is 54.86% RH. This finding is in agreement with Tsutsumi *et al.* (2007) findings that the best relative humidity for doing task while working is between 40 to 50% RH. This result is consistent with ASHRAE Standard 62-2001 Ventilation for Acceptable Indoor Air Quality, which states that a relative humidity range of 25 to 60% RH is optimal for human working conditions (ASHRAE Handbook, 2005). According to an article provided by the Minnesota Blue Flame Gas Association, relative humidity ranges between 20 and 60% RH are comfortable for humans. The Engineering ToolBox has suggested that human comfort requires the relative humidity to be in the range of 25-60% RH. For relative humidity above 60% RH, workers will feel uncomfortably damp.

Illuminance level: Figure 9 shows the graph of original production rate value (shaped 'o') together with production rate value after ANN analysis (shaped '*') versus lighting value for first day experiment. From the graph in Fig. 9, production rate value before ANN analysis scattered by fairly random with lighting values. After ANN analysis (shaped '*'), production rate value scattered randomly, the data still shows a reduction pattern although it not reduce linearly.

For the second day experiment, the proportion factor between production rate values after ANN analysis versus production rate before ANN analysis had R value

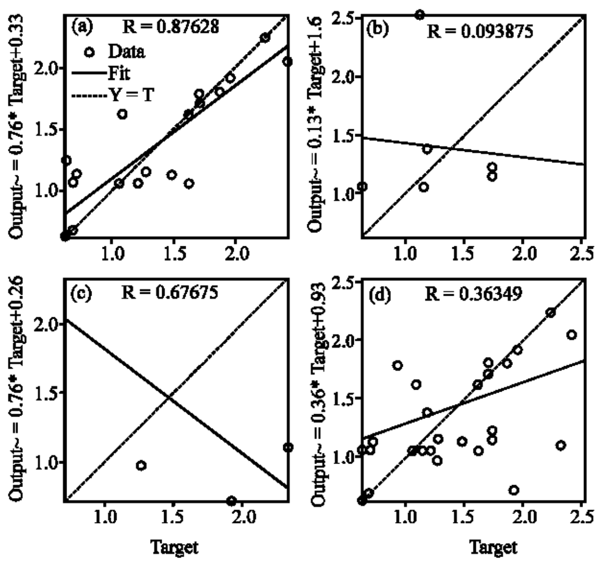

Fig. 10: Production rate graph before ANN analysis versus production rate after ANN analysis for (a) training department, (b) validity, (b) test and (d) total

is 0.36349 (Fig. 10d). This shows that the production rate relationship after ANN analysis compared with the production rate before analysis is a bit strong. Whereas, for proportion factor between production rate values after ANN analysis versus lighting values gives R value is 0.2348. The strength of relationship between production rates after ANN analysis versus illuminance level is pretty weak. Although the value is pretty weak but that is the best value for the data of illuminance level for that day. The data are divided into three parts which are the training part (Fig. 10a), validity part (Fig. 10b) and test part (Fig. 10c). This three training part will contribute to R value for proportion factor between production rate value after ANN analysis versus production rate before ANN analysis.

With the result for both proportion factor value, R which exceeded 0.5, this observation can conclude that the production rate after ANN analysis versus illuminance level is proportional quite linear. Through this weak relationship, the optimum value of production (value˜1) can be achievable when the lighting value is 155.8 lux. It is encouraging to compare this figure with that found by Cajochen *et al.* (2000), who found that exposure to lighting level in range of 90 hingga 180 lux can increasing the awareness at night time. Although Cajochen *et al.* (2000) did his experiment at night day, but his result can support this optimum level for lighting because this experiment been done in close room and had similar with night condition. The Engineering ToolBox has suggested that illuminance for working areas where visual tasks are only occasionally performed is 100-150 lux.

CONCLUSION

The objective of the study to interpret optimum humidity level to seek the optimum value production rate (value˜1) for one manual production line in that particular company is successfully achieved. The predicated optimum values were analyzed by ANN's system with regression value, R within acceptable range and strong. Through ANN's system, optimum environmental humidity level can be predicted. As the result, data of relative humidity in first day of experiment will be considered as data for this experiment because it has higher regression value. The optimum value of production can be obtained (value ˜1) when the relative humidity value is 54.86% RH. For comfortable relative humidity value is between 40 to 50% RH. For illuminance level in first day of experiment will be considered as data for this experiment because it has higher regression value. The optimum value of production can be obtained (value ˜1) when the illuminance value is 146.386 lux. It is encouraging to compare this figure with that found by Cajochen *et al.* (2000), who found that exposure to lighting level in range of 90 hingga 180 lux can increasing the awareness at night time.

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