Lighting Quality Improving Work Thoroughness of Sorting Operators

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Abstract. This study observes work thoroughness of sorting operators in quality control station at drinking bottle industry. Operators sort the bottles manually using naked eyes to decide whether the bottles have some defects or not. Dirty bottles, cracked, chipped or have water volume that is different from other bottles will be taken by operators. The low light intensity in quality control station causes high numbers of defect bottles to pass the inspection. The standard of Government of Indonesia Health Ministerial Decree No 1405 The Year 2002 that work performed continuously needs 200 lux of lighting. Illuminance level measurement is conducted for five days at 09.00, 11.00, 13.00, and 15.00 o’clock using lux meter on four measurement points using a grid of 1m x 1m. In this study, the average light intensity in quality control station 1 and 2 is 59.30 lux and 52.15 lux. The number of defective products that pass the inspection in a quality control station for 5 days of observation is 2,676 bottles or 55.47% from the total defect products, while the number allowed by the company is only 5%. The correlation between illumination factor in quality control station 1 and defect products that pass the inspection is calculated moment Pearson correlation product and the results are \( \hat{y} = 292,885 - 1,317x \) and \( r = -0.3147 \), while in quality control station 2 the results are \( \hat{y} = 524,077 - 4,919x \) and \( r = -0.6329 \). The higher illumination level, the lower the number of defective products that pass the inspection, which means operators’ work thoroughness improve.

1. Introduction
This study is conducted at a beverage factory, which main products are sarsaparilla drink and soda water, to identify the relation between defect products inspected and lighting quality. Indonesian beverages industries have already been using automation for the production process, yet workers still performed inspection manually. A quality control station, workers inspect the products using naked eyes and taking the defect products if the products do not meet the criteria set by the company. Workers at quality control station 1 are in charge of observing bottles already washed in sterilization machine whether bottles are clean, have no crack and dent. A quality control station 2, workers are in charge of observing the result from workers at quality control station 1 whether the bottles are clean, have no crack and dent, and the water inside is clean and the volume is different. Types of defects at a quality control station in the beverage industry the dirty bottle, cracked bottle, dented bottle, unclear bottle, different volume water. The quality control station 1 and 2 work results are the focus of this study, as work detail at two stations are higher than other work stations, so appropriate illuminance is needed as recommended. However,
the number of defect products that pass the inspection is still higher 5%, which is the number allowed by the company. There is an indication that low illuminance leads to a decrease in thoroughness, affecting the number of defect products passing the inspection. The measured lighting in quality control station is 72 lux, and this is lower than the standard number set by the government, i.e. 200 lux.

Lighting is one of the most important work environment factors and is of a risk factor, meaning that if light intensity does not adequate, productivity will decrease. Dim lighting at work area causes workers to maximize their vision, leading to eye strain, muscle strain, and nerve strain, which result in eye fatigue, mental fatigue, headache, decrease in concentration, thinking speed, and intellectual ability. Work environment factors that affect workers productivity are noise, lighting, color, air quality. Air quality comprised of temperature, humidity, ventilation, and cleanliness. Inadequate lighting significantly affects workers physically and psychologically, that can be noticed from a health problem that occurs such as a headache, etc [1].

Low illuminance causes activity can not be performed correctly, therefore more windows should be added to let more natural light enters the room. Adding more lamps must be done accordingly with work characteristics performed in a certain room [2]. Work environment affects comfortability, health, morale, efficiency, and work productivity [3]. Lighting at the work environment affects work performance, productivity, and quality. Bad lighting causes low productivity, eye strain, headache, and increase accident number. Lighting improvement in the work environment can be done by designing artificial lighting [4,5]. Light color, light intensity, and colored text significantly affect the answer regarding reading understanding, which means affect visual work [6]. An energy-efficient light bulb will consume the lowest wattage, yet producing a high intensity of visible light. Fluorescent tube and Compact Fluorescent Lamp (CFL) are the energy-saving light bulb of phosphorescent type [7].

Illuminance designed without glare and using efficient lighting will improve workers comfort level because danger can be detected immediately [8]. Lighting has an effect on workers mental load, where the lighting level below standard will affect work performance and disrupt visual ability. Even though this will not cause eyes problem permanently, it will increase workload, speed up tiredness, make workers take more rest, reduce work time, reduce work satisfaction, decrease production quality, increase error frequency, disrupt concentration, and reduce worker productivity.

Humans need lighting to identify an object visually and this comprises of 90% work activity, especially for works requiring sharp vision. Eyes ability to see an object with clear, quickly, without an error is greatly affected by lighting in the work environment [9]. Workers complain of visual fatigue and eye strain is a hidden danger [10]. Visual fatigue and eye strain will affect thoroughness and work quality of workers [11]. A sustainable act to improve productivity, efficiency, and workers skill in an industry should also consider workers comfort. There is a relation between illuminance and productivity. Lighting greatly affects workers’ visual perception when handling the process on a production floor. White light increases eyes strain more than other color lights [12]. High color temperature inhibits melatonin secretion and helps increase workers response speed and the opposite is true for low color temperature [13]. Blue light usage is better than white light to alleviate visual fatigue, eye strain, inability to focus, concentration disruption, and blurred vision [14]. Substitution of lights is not only concerned with reducing the burden, but there must be policies and regulations related to the negative impacts caused [15].

2. Method
Illuminance at the production floor is measured using lux meter for 5 days at 09.00-16.00, divided into several intervals during the 1st shift. Each measurement represents a certain time interval with the condition that the 1st measurement conducted at 09.00 represents the time interval of 08.00-10.00, the 2nd measurement conducted at 11.00 represents the time interval of 10.00-12.00, the 3rd measurement conducted at 13.00 represents the time interval of 12.00-14.00, and the 4th measurement conducted at 15.00 represents time interval of 14.00-16.00. Defect products that pass the inspection are calculated twice, the 1st time window represents defect products that pass the inspection at 08.00-12.00 and the 2nd time window defect products that pass the inspection 13.00-16.00. Measured points are chosen using a
reference of SNI 16-7062-2004 regarding light intensity measurement in workspace using certain size grids according to an area that will be measured its illuminance [16]. Production floor has 2 quality stations, quality control station 1 and quality control station 2, both with an area of 9.92 m². Since both areas are less than 10 m², a grid with a size of 1 m x 1 m is used so that there are 4 points of measurement. There are 4 points measured in both quality control station 1 and 2 as shown in figure 1.

Illuminance data and the number of defective products that pass the inspection will be tested its normality using Kolmogorov-Smirnov and its sufficiency. Regression equation and correlation coefficient test are used to predict defect products that pass the inspection based on illumination level and relation degree between illumination level with a quality control station work result. The correlation coefficient is calculated to know whether there is a correlation between illuminance variable with quality control work result.

3. Results and Discussions

In these parts, the results of average illuminance, defect products that pass the inspection, regression equation, and correlation coefficient will be discussed. The result of the Kolmogorov Smirnov test on illuminance and defect products that pass the inspection at quality control station shows that data is distributed normally, since $D_{\text{max}} > D_\alpha$. The result of the sufficiency test on illuminance and defect products that pass the inspection at quality control station shows that $N' < N$, which means the data is sufficient.

3.1. The average illuminance in a quality control station

Illuminance measured at quality control station 1 and 2 is performed at 4 points. Measurement conducted at 09.00, 11.00, 13.00, and, 15.00 o’clock for five days shows that the average illuminance at quality control station 1 is 59.30 lux and at quality control station 2 is 52.15 lux. Recapitulation of average illuminance at quality control station 1 is shown in table 1.

| Quality Control Station | Time | Day-1 | Day-2 | Day-3 | Day-4 | Day-5 | Average |
|-------------------------|------|-------|-------|-------|-------|-------|---------|
| 1                       | 09.00| 54.90 | 57.59 | 58.05 | 56.82 | 60.11 |         |
|                         | 11.00| 55.45 | 57.03 | 60.52 | 62.23 | 57.78 |         |
|                         | 13.00| 67.08 | 57.27 | 60.22 | 62.40 | 57.65 |         |
|                         | 15.00| 67.89 | 58.13 | 59.60 | 58.56 | 56.47 |         |
| Average                 |      | 61.33 | 57.51 | 59.60 | 60.01 | 58.01 | 59.30   |
| 2                       | 09.00| 50.36 | 55.55 | 52.33 | 49.12 | 50.12 |         |
|                         | 11.00| 52.61 | 55.93 | 52.81 | 49.18 | 50.38 |         |
|                         | 13.00| 52.92 | 56.68 | 53.16 | 49.25 | 50.27 |         |
|                         | 15.00| 53.01 | 56.53 | 53.12 | 49.00 | 50.41 |         |
| Average                 |      | 52.23 | 56.18 | 52.86 | 49.14 | 50.30 | 52.15   |
The comparison between illuminance at quality control station 1 and 2 on the same day implies that illuminance at quality control station 1 is higher, yet the value is far below the standard illuminance for the corresponding work, 200 lux, as set by Indonesian Government Health Ministerial Decree No 1405 The Year 2002 [17]. Illumination on the production floor is affected by lamp wattage, lamp distance toward the work field, and room area.

3.2. Calculation of Defect Products That Pass The Inspection
Defect bottles that pass the inspection at quality control station during 5 days of observation are 2,676 bottles, while the total number of defect bottles at both quality control station 1 and 2 is 4,824 bottles. Therefore, the percentage of defect bottles that pass the inspection at a quality control station is 55.47%. This number is very large compared to the allowed number of 5% and this, of course, inclicts a financial loss to the company.

3.3. Relation Between Illuminance and Defect Products That Pass The Inspection
Regression is a measuring tool that can also be used to measure whether there is a correlation between variables or not. Regression analysis is performed to predict the average value of dependent variables based on independent variables value known. This correlation aims to measure the relation degree between two variables or more. Work results data used from both station is defect products that pass the inspection. Data distribution of dependent and independent variables at quality control station 1 and 2 and the corresponding regression line are shown in figure 2.

Regression line equation of illuminance and defect products that pass the inspection at quality control station 1 is \( \hat{y} = 292,885 - 0.3174x \) and Pearson correlation test result gives correlation coefficient value (r) of -0.3174 (figure 2a). This value means there is a low inverse relation between illuminance and defect products that pass the inspection at quality control station 1. In other words the higher illuminance at quality control station 1, the lesser defect products that pass the inspection.

Regression line equation of illuminance and defect products that pass the inspection at quality control station 2 as shown in figure 2b is \( \hat{y} = 524,077 - 4.919x \) and Pearson correlation test result gives correlation coefficient value (r) of -0.6329. This value means there is a strong inverse relation between illuminance and defect products that pass the inspection at quality control station 1. In other words the higher illuminance at quality control station 1, the lesser defect products that pass the inspection. In order to obtain optimum illuminance (x), assume \( \hat{y} = 0 \) in a regression equation, then we obtain \( x = 222.39 \) lux at quality control station 1 and \( x = 106.54 \) lux at quality control station 2.

Illuminance needed at quality control station 1 differs from Illuminance needed quality control station 2, as workers at quality control station 1 are older than at quality control station 2, affecting eyes ability to observe drink bottles. Correlation coefficient values between illuminance at quality control with defect products that pass the inspection are calculated and the obtained values are \( r_{qc1} = -0.3174 \)
and $r_{qc} = -0.6329$. Both values show an inverse relation between illuminance at a quality control station and the number of defective products that pass the inspection. The higher the illumination level becomes, the lesser defect products that pass the inspection. Lighting quality improvement at quality control station can minimize defect products that pass the inspection.

3.4. The Reflectance of Object Materials

The reflectance of object materials measured is the wall, ceiling, and machine (washer machine and conveyor). The reflectance of object materials at quality control station is varied, where the wall, ceiling, washer machine, and conveyor have larger reflectance number than the recommended. It is shown in figure 3.

Based on the graph in Figure 3a to 3d there are two material objects whose material reflectance values exceed the recommended values, namely the reflectance figures of the wall and the washer and conveyor machine. Wall material is made of bright ceramic, increasing its reflectance number. There is a lamp installed on the wall at a sorting area, causing reflectance number of washer machine and conveyor to increase. However, ceiling reflectance number still meets the recommended range, i.e. 85.6%, with material made of the white ceiling. Floor reflectance number is still far below the recommended range, i.e. 16.7%. The reason is the floor is dirty and enclosed by puddles so that light can not be well-reflected. Cleaning the floor regularly and building good drainage water will make floor surface clean. Therefore water flowing from the washer machine will not make floor filled by puddles and slippery, allowing workers to work comfortably.

3.5. Type and Number of Lamps Mapping

The actual number of lamps on production floor does not the needed number and the type of lamp used is also not suitable for indoor usage, as it has closed luminaire that is more suitable for outdoor usage. Data used to calculate the number of light bulb on production floor are room length (L) 6.2 m; room width (W) 3.2 m; room height (H) 10 m; coefficient of reflectance for ceiling ($\rho_c$) 0.86; coefficient of
reflectance for wall ($\rho_w$) 0.72; coefficient of reflectance for floor ($\rho_f$) 0.17; distance from luminaire plane to ceiling ($h_c$) 0.25 m; distance from work plane to floor ($h_f$) 0.75 m; distance from luminaire plane to work plane ($h_r$) 7 m. The division of the cavity is shown in figure 4.

![Figure 4. Cavity distribution at quality control station](image)

The coefficient of Light Loss Factor (LLF) is 0.71, based on the Ballast Factor (BF) of 1; the coefficient of Voltage Variation (VV) is 1; the coefficient of Luminaire Surface Depreciation (LSD) is 1; the coefficient of Luminaire Ambient Temperature (LAT) is 1; the coefficient of Lamp Lumen Depreciation (LLD) 0.85; the coefficient of Room Surface Dirt Depreciation (RSDD) is 0.92; the coefficient of Luminaire Dirt Depreciation (LDD) is 0.95; the coefficient of Lamp Burnout (LBO) is 0.95. The minimum standard number of lumen required is 14,708 lumen based on E 200; area (A) 19.84 m$^2$; Effective Floor Cavity reflectance ($\rho_{fc}$) 0.84; coefficient of utilization (CU) 0.38; light loss factor (LLF) 0.71.

Changing type and number of lamp used on the production floor will meet the standard requirement of lumen on all production floor. Currently, 8 Compact Fluorescent Lamp (CFL) lamps of 18 Watt are used, each producing only 1100 lumen, so that in total only give 8800 lumen. The recommended type of lamp to be used is Fluorescent Tube, each producing 3350 lumens, therefore only 5 bulbs are needed. This Fluorescent Tube can consistently produce a high number of the lumen and prevent the lamp from fading its color, which makes it suitable to be used in the beverage company. Lighting layout is set using the uniformity principle, by arranging lamp based on spacing criteria determined. Quality Control Station has an area of 19.84 m$^2$ and if 5 light bulb is to be used, the maximum distance between each light bulb is 1.99 m with the layout as shown in figure 5.

![Figure 5. Arrangement of proposed lights on the production floor](image)
4. Conclusions
This article aims to understand the effect of lighting on workers thoroughness during a manual inspection on defect products at a quality control station. The main parameters of this study are average illuminance, defect products that pass the inspection, regression coefficient, and correlation coefficient. The average illuminance at quality control station is far below the standard value set by The Indonesian Government of Health Ministerial Decree Number 1405 The Year 2005, i.e. 200 lux. The number of defective products that pass the inspection at quality control station during 5 days of observation reaches 55.47% of the total defect products, far higher than the company allowed number. The illuminance at quality control station 1 has a low and medium inverse relation with defect products that pass the inspection, meaning that the higher illuminance becomes the lesser defect products will pass.

References
[1] Sarode AP, Shirsath M 2012 International Journal of Science and Research (IJSR)3 (11) 2735-2737
[2] Bella L, Spada G, Pearce A, Fragliasso F 2015 Energy Procedia78 3138-3143
[3] Ajala EM 2012 The African Symposium12 (1) 141-149
[4] L Espinoza LA, Najera JM 2010 Research Journal of the Costa Rican Distance Education University (Online Edition)2 (1) 63-68
[5] Anizar, Erwin 2017 IOP Conf. Ser.: Mater. Sci. Eng. 180 012122
[6] Lin CC, Huang KC 2014 International Journal of Applied Science and Engineering12 (3) 193-202
[7] Chumaidy A 2017 Sinusoida19 (1) 1-8
[8] Pal N, Krishnan SV, Sadhu PK 2013 International Journal of Engineering Science & Research Technology2 (2) 240-247
[9] Dey AK, Mann DD 2011 Journal of Agricultural of Safety and Health7 (2) 91-110
[10] Osuke GO, Okolie STA, Anyaeche CO 2015 International Journal of Innovative Science & Technology2 (7) 34-37
[11] Seegehalli PJ 2016 International Journal of Computer Sciences and Engineering (IJCSE)8 (3) 94-100
[12] Kumar R, Pandey S, Jana P, Panghal D 2016 International Journal of Electrical, Electronics, and Data Communication4 (2) 9-12
[13] Jiandong Z, Shuo M 2016 International Journal of Signal Processing, Image Processing and Pattern Recognition9 (6) 437-446
[14] Viola AU, James LM, Schlangen LJM, Dijk DJ 2008 Scand Journal Work Environ Health34 (4) 297-306
[15] J Ogunyemi, I.A. Adejumobi 2018 Lautech Journal of Engineering and Technology12 (2) 33-40
[16] Indonesian National Standard 2004 Lighting Intensity Measurement at Work Place
[17] The Government of Indonesia Health Ministerial Decree No 1405 The Year 2002, 2002, Health Requirements of Work Environment at Office Complex and Industry