IOP Conference Series: Materials Science and Engineering

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To cite this article: Iwan Aang Soenandi and Vincent Ardian 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **508** 012100

IOP Conf. Series: Materials Science and Engineering **508** (2019) 012100 doi:10.1088/1757-899X/508/1/012100

Fatigue recovery mathematical modelling for increasing productivity of a medium-workload worker in Indonesia

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Abstract. Due to high demand for workers and limited technology management in Indonesia, the industries need to focus on increasing worker's productivity in this labour-intensive system. Such system has the inclination to use workers to actuate the economic cycle. But in employing human workers, we will face the problem of fatigue. This research identifies factors affecting fatigue recovery of workers and obtained the mathematical model for it. The model was built using the experimental design method that involved three workers with age ranging from 20 to 22 years and obtained that variable of activity, treatment and operator have closely related to fatigue recovery. The mathematical model was obtained as equation of Y=-13,856+15,515X1+2,736X2+3,674X3 with X1 is variable of activity, X2 is variable of treatment and X3 is variable of operator. The results of this research would become an indicator for the manufacturing industries in Indonesia to increase labour's productivity.

1. Introduction

Every human has differences in body characteristics, power, and endurance [1]. From previous research stated that age affects muscle recovery time. For example, younger people (25±3 years old) recovers faster from fatigue than older people (71±4 years old) [2]. Also, in one of previous studies, we found that problem of fatigue is generally characterized by a reduced desire to work due to the monotony [3], intensity and duration of physical labour and the environment [4]. Fatigue is an endurance mechanism to prevent negative health conditions. So the body needs rest for recovery [5]. From previous observations, rate of body recovery is usually high in the first 15 seconds, even though there are no significant differences after two minutes of recovery [6]. As the basis of this research, a good regulation for the worker i.e. fatigue recovery is the key to maintain productivity [7]. The aim of this study is to set up a mathematical model for assessing recover time using variable that closely related to fatigue of the worker. The model was used to relate fatigue problem with job specification in repetitive movements with types of treatment to see the effect of recovery process. The measurement is based on the worker's heart rate through experimental studies. This research proposed the mathematical model based on how to estimate the recovery time and how to integrate it to the mathematical equation. First we describe the background and objectives this research in Section 1. Next, in section 2, the experimental design of the research is explained. Next, the results and its discussion are shown in section 3. Finally, in section 4 the conclusion showed the overall findings of the paper.

2. Experimental Design

2.1 Subject

We chose three men as volunteer with age ranging from 20 to 22 years, height ranging from 1.55 to 1.7 m, and weight ranging from 60 to 70 kilograms with the previous job criteria as medium workload daily worker and assured that none of them had a history of musculoskeletal problems.

2.2 Apparatus and data collection

The subjects executed three types of trial, and each day there are different types of treatment. In the first trial, each subject were simulating a different type of job for 10 minutes with non-treatment. The next day, subjects were changing different work and simulating it for 10 minutes with drinking water treatment. On the third day, subjects were changing work for 10 minutes with drinking milk and bread consumption treatment. On the fourth day, subjects were simulating work for 10 minutes with hot compress treatment. There were blood pressure tests before the trials were started. Furthermore, the Automatic Blood Pressure Monitor with pulse monitor was used to measure the worker's pulse. To find the recovery time during the time breaks, the worker's pulse has been measured to see the duration of worker's fatigue recovery.

2.3 Treatment selection

a.) The selection of treatment for drinking water for worker based from WHO that for man in ages from 19 – 70+ in daily consumption is 3.7 L. In this study the first treatment for each man deployed a drinking treatment with 150mL of water for 10 minutes simulation or ±450mL of water in 30 minutes after doing the work. The selection of treatment for drinking water for worker was based on WHO recommendation that for man in age 19 – 70, the daily consumption is 3.7 L. In this study the first treatment for each man was drinking 150mL of water for 10 minutes or ±450mL of water in 30 minutes after doing the work.
b.) The second treatment is using a bread and milk for consumption. The other research has used a ± 500mL milk for two hours during extension training. In this study we used ±80mL in 10 minutes, then each man spent a total of ±240mL of water in 30 minutes in each activity. Bread was chosen for an alternative carbohydrate consumption and was consumed at 30 – 40 grams in 10 minutes for one activity. In total, each man consumed 120 grams of bread for 30 minutes activity.
c.) Warm compress therapy was used to recover from physical activities and the temperature was set at 40°- 45°C.
d.) The room temperature was set at 16 - 20°C, as OSHA has established the maximum temperature for medium workload to be 26.7°C (80°F).

2.4 Experiment procedures

This study was held in the industrial engineering laboratory of Krida Wacana Christian University, a private university in West Jakarta. The data was collected in thirty days, consisting of different treatment levels per day. The experiments of doing each task was doing in 90 minutes totally for each day. All the experiment procedures was shown in Figure 1.

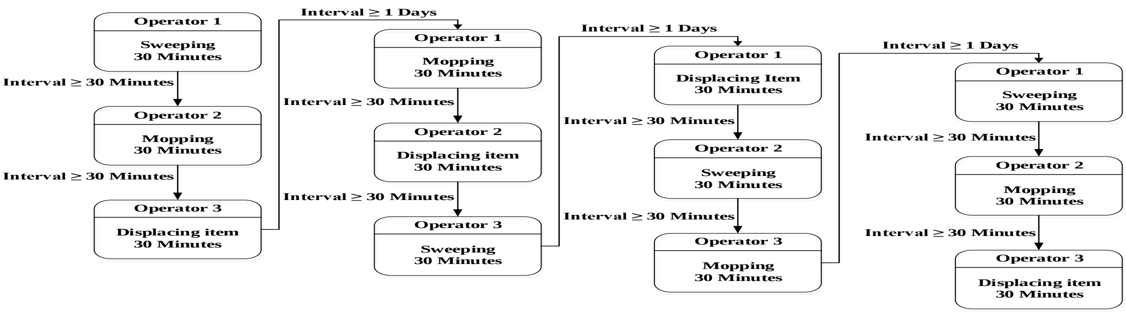

Figure 1. Experiment procedures

IOP Conf. Series: Materials Science and Engineering **508** (2019) 012100 doi:10.1088/1757-899X/508/1/012100

3. Result and discussion

3.1 ANOVA Tests of Between-Subjects Effects

The result of ANOVA was shown in table 1. With significance level of 5%, the outputs from interaction factors: activity-treatment, activity-operator, and treatment-operator had a sig value more than 0.05. This meant those factors had not affected the result of fatigue recovery. For other factors separately such as activity, treatment, operator, and combination of the activity-treatment operator had a sig value lower than 0.05. With this result, we concluded these factors had affected the result of fatigue recovery.

Table 1. Results of ANOVA

Dependent Variable: Recovery process

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	26650.696[a]	35	761.448	5.700	.000
Intercept	106226.356	1	106226.356	795.221	.000
Activity	17403.211	2	8701.606	65.141	.000
Treatment	2291.890	3	763.963	5.719	.001
Operator	1079.541	2	539.771	4.041	.022
Activity *treatment	754.562	6	125.760	.941	.471
Activity * Operator	351.837	4	87.959	.658	.623
treatment * Operator	1038.155	6	173.026	1.295	.270
Activity * treatment * Operator	3731.499	12	310.958	2.328	.014
Error	9617.822	72	133.581		
Total	142494.874	108			
Corrected Total	36268.518	107			

3.2 Calculation of multiple linear regression

Accuracy model was used to measure how much impact the independent variable of the dependent variable. Mathematical modeling for recovery process is stated in Table 2. The measurement of accuracy model (R^2) for fatigue recovery is 63.3%. In this study the accuracy model is under expectation but we are convinced that the equation model of fatigue recovery is representing the related variable such as activity, treatment and operator based on result of ANOVA in Table 1.

Table 2. Mathematical modeling of recovery time

Model	Independent Variable	Accuracy Model (R^2)
Y = -13,856+15,515X1 +2,736X2+ 3,674X3	X1= variable activity X2= variable treatment X3= variable operator	0.633

Based from regression model in Table 2, we obtained that fatigue recovery time increased due to work time, in the same treatment and workload, it means that the longer is work time needed more time to recover the stamina of the worker

3.3 Calculation of recovery process time

The results of calculation for each activity has shown us that every activity has a different treatment for the best recovery for worker. First, for sweeping the floor activities the best treatment for the worker was applied warm water compress with ±9.8 minutes. Second, for mopping the floor activities the best treatment was drunk water (±150 mL) with ±29.75 minutes. Third, for displacing item activities, the best treatment was eating bread and drank milk (±80mL) consumption with ±39.07 minutes.

From result of calculation average time told us that on sweeping the floor activity, warm water compress has a faster time to other treatment. Next, for sweeping the floor activity, drank water has a faster time to other treatment. The last, for lifting (5 - 10 Kilograms) activity, ate the bread and drank milk (±80mL) consumption has a faster time other treatment. So, we can conclude that all treatment has an effect on all activities related to recovery time.

3.4 Calculation of productivity

The calculation of productivity is needed to see whether the treatment can improve the productivity of the operator doing their job. We measured the productivity in this case is the output of total repetition divided by available time of work (in this case we assumed 90 minutes). We hoped the results of the work assessment can show which treatment is better for increasing productivity. In Table 3 showed the example of productivity calculation for lifting task. By this calculation we showed the differences between each treatment that related to productivity. In this lifting task warm compress obtained highest productivity number as 2.33 repetition/minutes.

Table 3. Example of Productivity Calculation

Operator	Treatment for recovery of medium workload				
	Lift (Repetition)				
	Replication	Drink	Eat Bread and Drink Milk (±80mL)	Warm Compress (40° - 45° C)	Without Treatment
1	1	13	18	18	13
	2	19	16	15	15
	3	14	16	17	15
2	1	15	17	24	15
	2	13	19	28	15

	3	14	19	32	16
3	1	14	17	19	16
	2	16	18	27	16
	3	17	17	30	12
Output (Total Repetition)		135	157	210	133
Input (Minutes)		90	90	90	90
Productivity Results (Repetition/Minutes)		1.5	1.74	2.33	1.48

Based on Figure. 2 showed that the effect of treatment in medium workload such as sweeps, mop, and lift. The treatment of warm compress is always obtained highest productivity (repetition/minute). As this result, we conclude that warm water compress is the best treatment for increasing the productivity.

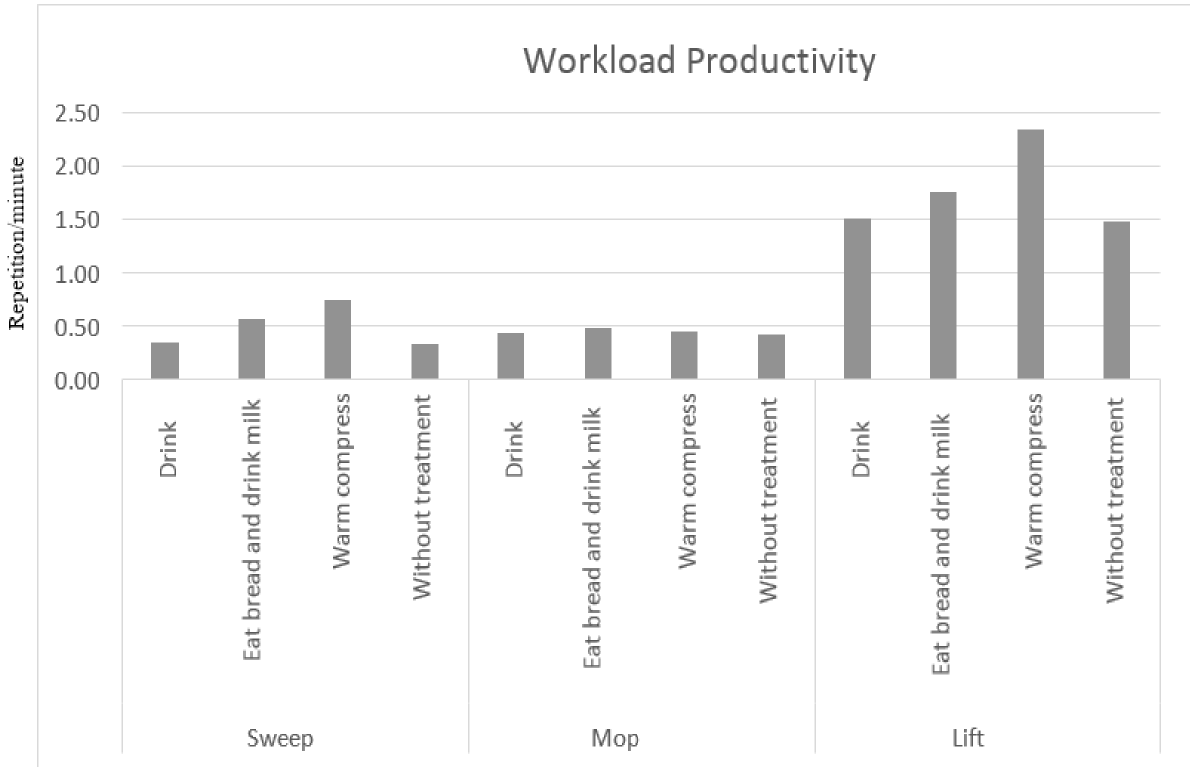

Figure 2. Productivity of medium-workload graph

4. Conclusion

Based on analysis results and discussion on this research. This research conclude that treatment factors giving a significant influence on muscle recovery. But, based on the calculation of average process recovery time and the productivity value obtained same results. Finally, this research obtained the equation of fatigue recovery as Y = -13,856+15,515X1+2,736X2+ 3,674X3. This equation described when workers gave each treatment, the process of fatigue recovery faster than non-treatment. By comparing the pulse measurement of the worker, the calculation of productivity value showed us that warm compress (40 - 45°C) are giving workers more productivity from other treatment. So we can choose warm water compress (40 - 45°C) better than other treatment. This study, therefore recommends warm water compress (40 - 45°C) to workers. For further research, should researchers can consider other factors potentially influential, as effect of gender (male and female) and increasing the number of operators and more repetitive task to get more accurate data**.**

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