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Design of Worker Rotation for a Precast Concrete Pole Factory Based on Mental Workload

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ABSTRACT

This study examines the effect of temperature and noise on workers' mental workload and evaluate the effectiveness of job rotation in mitigating these impacts. The manufacturing plant has a temperature of 35.86 degrees Celsius from the pile formation process and a noise level of 89.32 dBA from the process of releasing piles from the mould. High temperatures and noisy work environments cause workers to feel stressed and fatigued, leading to longer task completion times. The factory implements 2 work shifts per day, but if the daily production target is not met, there will be additional work shifts. Who will work in this irregular addition of work shift is also unclear. The extra shift workers come from the second shift workers of that day and the first shift workers the following day. Additional working hours increase the mental workload for the workers. This problem can be solved through job rotation. This research is classified as explanatory research with the object of study being the work environment and workers of the pile manufacturing factory. The mental workload is measured using the subjective workload assessment technique (SWAT). The novelty of this research lies in the design of work rotation based on mental workload, where in 2 shifts, workers rotate every four hours.

1. INTRODUCTION

Workload is the frequency of the average worker's activities that must be completed within a certain period. There are two types of workloads experienced by workers, namely physical workload and mental workload. Workload is influenced by several factors, namely external factors and internal factors. External factors are those that originate from outside the body, including the layout of tools and facilities, work organization, and work environment. Meanwhile, internal factors are those that originate from within the human body, including gender, age, motivation, and satisfaction. Hence, it can be said that the work environment is closely related to workers and is a factor that influences human workload [1]. The work environment will affect how employee perform their tasks to achieve the company's targets [2]. Poor work environment increases the mental workload of workers, resulting in fatigue and stress [3]. ISO 10075 categorizes conditions that produce mental workload, including task requirements, office organization, structural social factors, and workplace environmental characteristics. Specifically, ISO 10075 highlights the role of environmental variables such as lighting, climate conditions related to temperature, humidity, air movement, noise, atmospheric conditions, and pollutants [4]. The factors of the physical environment and mental workload will affect workers in performing their tasks [5-7].

This research discusses the work environment factors in a precast concrete pile factory that processes raw materials into precast concrete in the form of piles. The pile factory workers complained about the high temperature and noise conditions in the work environment, making them feel uncomfortable and quickly fatigued. The factory has 6 work areas, namely reinforcing, pouring concrete, prestressing, mould spinning, steam curing, and mould stripping. Initial measurements of temperature and noise levels conducted in those 6 areas recorded the highest temperature of 36.69 degrees Celsius in the steam curing area, followed by the mould stripping area at 35.81 degrees Celsius. The high temperature in that area comes from the spinning machine, which generates heat for the formation of piles, and high-temperature steam is used in the steam curing process for concrete hardening. The highest noise level is found in the mould stripping work area at 92.7 dBA, followed by the reinforcing area at 90.2 dBA. The process of transferring, assembling rebar, and opening the mold, which is done by striking the iron against the mold to release the product from the mold, produces that high-pitched sound. These two work areas are quite close, which also increases the noise level beyond the threshold value. This noise threshold value is 85 dBA and this is a value for 8 hours of work without using personal protective equipment [8].

Interviews with workers revealed that hearing impairments and communication difficulties are causing more stress in their work. This has resulted in longer completion time for tasks, often causing them to miss the daily production target. Workers normally work for 8 hours in one shift, but if the daily production target is not met, additional work shifts are added [9]. They complain about the frequent addition of work shifts, causing longer working hours. This is due to the pile factory implementing a make-to-order production system, resulting in fluctuating demand and when demand is high and not met, additional work shifts are added. The additional work shifts use inconsistent workers, some workers are from the second shift on that day and some are from the first shift for the following day. As a result, workers have more than 8 working hours for 5 working days a week [10].

Previous research has discussed the issue of mental workload caused by environmental factors and work shifts. However, generally, studies on these two factors are discussed separately and not examined together [11-14]. The solution provided by these researchers generally involves regular inspections of environmental factors and more rest hours for workers. Based on the problems that have been outlined, a solution is needed to address the issue of irregularly scheduled additional work shifts. This research proposes the Subjective Workload Assessment Technique (SWAT) method to analyze the mental workload experienced by workers [15]. The procedure for implementing the SWAT method consists of two stages: scale development and the assessment stage [16]. Based on the obtained results, a worker rotation design will be implemented to minimize the mental workload experienced by workers. The work rotation design also aims to balance the workload value received by workers.

2. LITERATURE REVIEW

Mental workload is a critical aspect in understanding human performance, particularly in modern work environments that are often characterized by high pressure and demands. Mental workload can be defined as the level of cognitive effort required to complete a specific task, often involving decision-making, problem-solving, and information processing. Humans have a limited cognitive capacity, divided into several domains such as visual, auditory, and motor. When workload exceeds this capacity, overload occurs, leading to decreased performance, stress, and even mental fatigue. Factors such as complex task characteristics, prolonged working hours, and high levels of uncertainty are key contributors to mental workload.

Additionally, individual factors such as cognitive capacity, experience, training, and psychological condition also play a role in determining the level of mental workload. Tasks with high levels of difficulty tend to increase cognitive processing, while experience and training help individuals to reduce the burden through higher work efficiency [16]. Psychological stress can also impair cognitive capacity, thereby diminishing an individual's ability to manage mental workload effectively.

Work environment factors, such as noise, lighting, temperature, and workspace layout, greatly affect mental workload. High noise can disrupt concentration and inappropriate lighting will increase visual fatigue [17, 18]. Additionally, extreme workspace temperatures, either too hot or too cold, have been shown to impair cognitive function [19]. Ergonomic workspace design also plays an important role in creating a work environment that supports cognitive efficiency [20].

The workload is the difference between a worker's ability and the demands of the job they face, categorized into small, medium, and large workloads. The workload analyzed on outsourcing company workers using the SWAT and CVL methods, which include the dimensions of time, effort, and stress, revealed that the highest workload is influenced by the time dimension. The solution provided includes adding more workers and providing nutritious snacks [21]. Recent studies reinforce the importance of appropriate interventions in managing mental workload. The use of artificial intelligence-based technology can reduce mental workload by up to 25% through better information management [22]. Dynamic lighting is useful in adjusting intensity based on the time of day and worker activity, thereby reducing mental fatigue by up to 18% [23]. In conclusion, understanding and managing mental workload effectively requires a holistic approach that takes into account individual factors, task characteristics, and the work environment, supported by current studies and implementation of relevant technologies.

Work shifts have a noticeable relation with fatigue, and workload has a significant relation with the fatigue of air traffic controllers, so the manager must monitor the workload to avoid workers experiencing more severe fatigue. It is recommended to regulate and maintain a balanced diet and nutritional intake and to schedule rest periods between work shifts [24]. The same thing also happens to nurses, where there is a strong relation between work shifts and work fatigue, and a moderate relation between mental workload and work fatigue. Hospitals are advised to periodically measure nurses' work fatigue levels and provide counseling and training related to work fatigue and its prevention [25]. Work fatigue occurs due to an imbalance between task demands and the work capacity of the employee. Meanwhile, mental workload is a multidimensional construct that refers to the ability of workers to meet the demands of information processing from existing tasks or systems. Mental workload is related to employee performance.

Fatigue is a natural signal given by the body due to a decline in bodily functions caused by work processes that will affect work capacity or endurance and can reduce a person's work productivity. The work environment is one of the considerations for employees in their jobs [26]. Employees will be able to perform their tasks well to achieve optimal results provided that an optimal work environment is given [27]. One of the environmental factors is noise, which is an unwanted sound that can disturb hearing and even reduce the hearing ability of someone exposed to it [28]. Continuous noise exposure may lead to hearing loss, increased heart rate, stress, and psychomotor disturbances. The noise threshold value is regulated in the Minister of Manpower Regulation No. 5 of 2018 concerning Occupational Health and Safety in the Workplace [8]. The working hours of the pile factory are 8 hours per day, and the permissible noise intensity is 85 dBA. Aside from noise, hot working conditions and heart pulse rate also affect fatigue levels. Noise and hot working conditions indirectly contribute to the fatigue level by increasing the working pulse rate [29].

Stress caused by suboptimal noise increases workers' mental workload. This mental workload is calculated using the subjective workload assessment technique (SWAT). The SWAT method is a scale-giving procedure designed for important tasks that significantly affect an individual's mental state and are related to varying task performance. The SWAT method consists of two stages: the scale creation stage and the event scoring stage [30]. The scale creation stage aims to train subjects in perceiving the workload represented by the combination of the three existing descriptors. The event scoring stage, which is performed using the SWAT program, involves assigning a score to the subjects' perception of the workload. The final value of mental workload can be categorized as low if it is between 0%-40%, moderate if it is between 41%-60%, and high if it is between 61%-100% [21]. The workload measured using the SWAT method includes time load, mental effort load, and psychological stress load. The assessment of this workload is then presented in the form of a SWAT card questionnaire. Respondents will be directed to arrange 27 combinations of SWAT cards based on the lowest mental workload to the highest mental workload [31].

3. RESEARCH METHODOLOGY

This research is an explanatory study that explains the cause-and-effect relation between the noise variable in the work environment and the mental workload of workers on the production floor. Activities related to measurement include measuring noise levels, creating noise mapping, and obtaining noise distribution on the production floor. The instrument used to measure noise in the workplace is a sound level meter. The noise levels measured in six work areas serve as input for calculating the equivalent noise level. The calculation of the equivalent continuous noise level (Leq) is performed to obtain the average noise level. Leq is the noise level of fluctuating noise over a certain period, equivalent to the noise level of steady noise over the same time interval. Next, noise mapping, which is used to determine noise distribution in the production area, is created using the Surfer software. This is a tool for contour map creation and three-dimensional modeling based on grids that plot irregular XYZ tabular data into a regular grid of quadrilateral points. In this context, the grid is a series of vertical and horizontal lines that in a surfer form a rectangle and are used as the basis for creating contours and three-dimensional surfaces. After obtaining the noise levels in each area, noise levels are then measured at several predetermined points as input data for the noise mapping method [32-34]. Through this noise mapping method, a contour map will be produced showing the distribution of noise levels on the production floor of the pile factory. The production floor itself, which has a dimension of 60 m × 20 m, is divided into 21 noise measurement points with approximately 10 m of distance between each point [35]. Noise level distribution in the work area can be determined through the noise mapping created. Each measurement point is equidistant from the others. The result of the measurement at each point serves as input to create the noise mapping using the Surfer software.

The next step was using SWAT cards to calculate workload. There were 27 possible combinations of SWAT cards consisting of three variables: Time Load (T), Psychological Stress (S), and Mental Effort (E) [21].

4. RESULT AND DISCUSSION

Noise measurements were conducted in the areas of reinforcing, pouring concrete, prestressing, mould spinning, steam curing, and mould stripping. Measurements with a sound level meter were conducted over 2 days with 2 replications, resulting in a total of 4 replications. The measurement period started at 1:00 PM until 2:30 PM, and the second replication from 2:30 PM until 4:00 PM. The noise measurement results show that all work areas had noise levels above 85 dBA, which was the established threshold value. Only the steam curing area during the first noise measurement had the lowest noise level, which was 85.72 dBA on the first day and 85.78 dBA on the second day. The noise levels in the work areas on the production floor of the pile factory are shown in Table 1.

Table 1. Noise level measurement result

Work Area	First Day (dBA)		Second Day (dBA)	
	1	2	1	2
Reinforcing	90.21	90.42	90.34	90.56
Pouring concrete	89.50	89.58	89.47	89.61
Prestressing	88.64	88.89	88.67	88.92
Mould spinning	88.28	88.75	87.30	88.78
Steam curing	85.72	86.10	85.78	86.23
Mould stripping	90.52	90.89	90.61	91.27

The reason that causes the noise level to be above the threshold point at the production floor needs to be found by analyzing the noise distribution level. Noise levels at the 6 working areas become the input for the calculation of equivalent continuous sound level (Leq). This Leq is a value of fluctuating noise level over a certain period which equals to steady noise level at a certain period. The results of Leq calculation at work areas are 90.38 dBA at the reinforcing area, 89.54 dBA at the pouring concrete, 88.78 dBA at the prestressing area, 88.53 dBA at the mould spinning area, 85.96 dBA at the steam curing area, and 90.83 dBA at the mould stripping area. Noise mapping on the production floor area is shown on Figure 1.

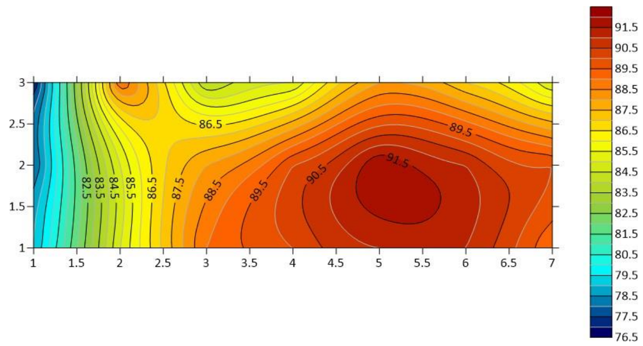

Figure 1. Noise mapping at work production area

Figure 2 shows the distribution of noise levels in the production work area of the pile factory, as determined by noise mapping integrated into the layout.

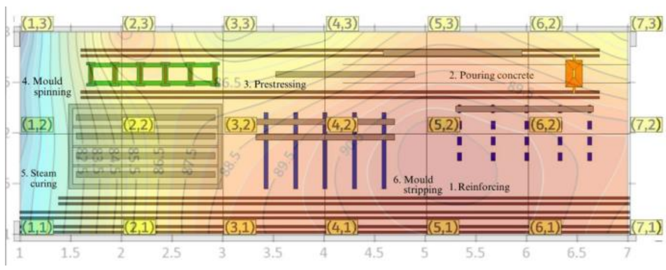

Figure 2. Distribution of noise in production work areas

The work areas around reinforcing and mould stripping have the highest noise levels (>90 dBA). The work area with the lowest noise level, although still above the noise threshold, is steam curing (85.96 dBA). Meanwhile, the other three work areas, namely pouring concrete, prestressing, and mould stripping, have noise levels above 88 dBA.

The measurement of workers' mental workload was conducted by sequencing SWAT card combinations for each job and processed with DOSBox 0.74 software to obtain respondent scores. SWAT has two methods for determining the scale used, namely the group scaling solution (GSS) and the individual scaling solution (ISS). The method used to establish the final SWAT scale is based on the Kendall coefficient value obtained from the input data from the SWAT card to the SWAT software. If the Kendall coefficient value is >0.75, GSS is used; if <0.75, ISS is used. The data processing results in the DOSBox software yielded a Kendall coefficient of 0.8677, so the scale determination method used is GSS. Prototyping was conducted to determine the highest workload category experienced by workers, with the workload categories including time (T). The group scale results using the SWAT software showed that mental workload is influenced by 51.78% by the time load factor (T), 25.85% by the effort load factor (E), and 22.36% by the stress load factor (S). The workload factor that most affects workers is the time load (T), followed by the stress load factor (S). The prototyping results indicate that the workload category perceived by workers is in the time (T). The value of the event scoring area and the mental workload of workers as shown in Table 2.

Table 2. Even scoring values in different work areas and the mental work load values

Work Area	T	E	S	Mental Work Load Value
Reinforcing	3	1	3	74.1%
Pouring concrete	2	2	3	73.8%
Prestressing	3	1	2	62.7%
Mould spinning	2	3	1	59.5%
Steam curing	1	3	2	36.8%
Mould stripping	3	3	1	77.6%

The work environment affects the level of mental workload experienced by workers. The non-optimal environmental factors in the workplace are temperature and noise, as it is stated that the optimal working environment temperature is 31℃ for 75% to 100% of the working time [8]. The lowest temperature is found in the concrete pouring area at around 35.83℃, and the highest in the steam curing area at around 35.89℃, due to the high-temperature steam used to achieve the concrete hardness standards. Meanwhile, the highest noise levels are found in the mould stripping and reinforcing areas, while the noise levels in the steam curing area are the lowest but still above the noise threshold value. The comparison between temperature, noise, and mental workload in the work area can be seen in Table 3.

Workers with the highest mental workload are those who work in the mould stripping area, followed by workers in the reinforcing, pouring concrete, and prestressing areas respectively. Workers in the mould spinning area have a moderate mental workload, while workers in the mould steam curing area have a low mental workload. The mental workload experienced by workers in the mould spinning and steam curing areas is lower than in other areas because the work in these two areas is assisted by machines. In addition, there are speed and machine work time regulations to meet the established product standards. Therefore, workers must perform their tasks according to this time regulation and they are not allowed to work faster or slower as it would damage the product quality standards. This can also be seen through the problems occurring in the work area, i.e., if the daily production target is not met, workers often have to work overtime to cover this target.

Table 3. Comparison of temperature, noise level, and mental workload

Work Area	Temperature (℃)	Noise Level (dBA)	Mental Workload (%)	Category
Reinforcing	35.84	90.38	74.1	High
Pouring concrete	35.83	89.54	73.8	High
Prestressing	35.86	88.78	62.7	High
Mould spinning	35.88	88.53	59.5	Medium
Steam curing	35.89	87.58	36.8	Low
Mould stripping	35.87	90.83	77.6	High

The noise levels in 6 production areas at the pile factory are all above 85 dBA, so work rotations are designed based on the calculation of maximum exposure time using the NIOSH equation. A recap of the maximum noise exposure time calculations at each noise point is presented in Table 4.

Table 4. Time exposure of maximum noise level

Work Area	Number of Workers (person)	Noise Level (dBA)	Duration (hour)
Reinforcing	4	90.38	2.30804
Pouring concrete	3	89.54	2.80241
Prestressing	4	88.78	3.34035
Mould spinning	3	88.53	3.53898
Steam curing	3	85.96	6.40856
Mould stripping	3	90.83	2.08012

The calculated value of the average exposure time allowed in 6 work areas is 3.41 hours; so, it is decided to rotate workers every 4 hours. So, they will work in an area at 08:00 PM until 12:00 PM and move to another area at 1:00 PM until 5:00 PM -with a break between 12:00 PM until 1:00 PM. This work rotation is done to move high-workload areas to low workload areas and vice versa. The work rotation is shown in Table 5.

Table 5. Worker’s rotation in production area

Worker Nth-	Work Time 08.00-12.00		Work Time 13.00-17.00	
1-4	Reinforcing	74.1%	Prestressing	62.7%
5-7	Pouring concrete	73.8%	Mould spinning	59.5%
8-11	Prestressing	62.7%	Reinforcing	74.1%
12-14	Mould spinning	59.5%	Pouring concrete	73.8%
15-17	Steam curing	36.8%	Mould stripping	77.6%
18-20	Mould stripping	77.6%	Steam curing	36.8%

Rotating workers between different areas does not lower their mental workload considerably because their workloads are still categorized as high. Some workers in prestressing, mould spinning, and steam curring also feel an increase in their mental workloads. Only workers in the mould stripping area experienced a significant reduction in mental workload, decreasing from 77.6% to 36.8% after moving to the steam curing area. Meanwhile, workers in the reinforcing area (74.1%) who moved to the prestressing area (62.7%) continued to have a high workload. Workers in the pouring concrete area (73.8%) who moved to the mould spinning area (59.5%) experienced a decrease in workload from high to moderate levels [21]. However, the minimal reduction in mental workload experienced by workers did not result in a decrease in fatigue, thereby keeping productivity levels low [26]. Therefore, overtime policy is expected to solve this problem. According to the Minister of Manpower and Transmigration regarding overtime work hours and pay, the maximum duration of overtime allowed for 1 day is 3 hours [36]. The overtime work policy stipulates that workers who work additional hours are neither from the previous shift nor from the next shift, so there will be no increase in mental workload for the workers. This overtime rule also saves any worker who may work continuously for long hours.

5. CONCLUSIONS

Temperature and noise levels affect the workload experienced by workers on the production floor at the pile factory. Both temperature and noise levels are above the safe threshold value. The temperature in work area is in the range of 35.830C-35.890C, while 310C is the threshold value. The lowest noise level is in the steam curing area at 85.96 dBA, and the highest noise level is in the mould stripping area at 90.83 dBA with a threshold limit of 85 dBA. Measurement of mental workload using the SWAT program shows that the most influential SWAT dimension is time load (T) at 51.78%, while the effort load (E) factor only influences 25.85% and the stress load (S) by 22.36%. Workers in 6 work areas experience different mental workloads, with the highest experienced by workers in the mould stripping area (77.6%), followed by the reinforcing area (74.1%), pouring concrete area (73.8%), prestressing area (62.7%), mould spinning area (59.5%), and steam curing area (36.8%).

Based on the measurement of mental workload and the most influential SWAT dimension being time, a job rotation design was implemented every four hours in one work shift so that the value of the worker's mental workload became more evenly distributed. However, it turned out that job rotation did not significantly reduce the mental workload of workers because the workers' mental workload was still categorized as high. Ideally, workers' mental workload after job rotation in the work areas should be reduced to below 40%. However, only one work area achieved this, namely the rotation from the mould stripping area (77.6%) to the steam curing area (36.8%). In contrast, job rotations in other work areas still resulted in high workloads, remaining above 60%. Thus, the implementation of overtime policies with workers who are not from the work shift becomes a choice.

This study has limitations as it was conducted only on workers in production line 1 of a precast concrete pile factory, making it not fully representative of conditions in other production lines or similar factories with different types of production. The job rotation design was solely based on mental workload without considering physical workload or workers' fatigue levels. Furthermore, the implementation of the job rotation design was tested over a limited period, so its long-term impact on productivity, efficiency, and workers' well-being could not be determined. Future research could integrate analyses of both physical and mental workloads to develop a more comprehensive job rotation design. Additionally, further studies could evaluate the long-term impacts of job rotation design on productivity, product quality, and job satisfaction. Comparative studies on workload-based job rotation designs across various industries could also be explored.

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