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ANALYSIS OF MENTAL WORKLOAD AND WORK FATIGUE OF FACTORY WORKERS USING NASA-TLX METHOD

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Abstract

This research is based on the rapid development of the manufacturing industry which shifts the demands of workers from pure physical activity to a high cognitive and mental load, thereby triggering work fatigue which has an impact on decreased productivity and increased risk of accidents. The purpose of this study was to measure and analyze the level of mental workload and work fatigue experienced by workers in various lines of the manufacturing industry (such as production, operator, and sewing divisions) using the multi-dimensional NASA-Task Load Index (NASA-TLX) method. This research method is quantitative descriptive with an in-depth survey and interview approach with several worker respondents from factory x. The results showed that the majority of factory workers experienced a level of mental workload in the medium category, with NASA-TLX scores ranging from 61.0 to 78.3. The most dominant dimensions of workload contributing to workers' mental fatigue are the level of effort, mental demand, and temporal demand due to strict production targets and repetitive work nature. The conclusion of this study emphasizes the need for K3 management policies to conduct periodic evaluations, restructuring work targets, organizing shift rotations, and providing adequate recovery time to maintain workers' cognitive health and sustainability of company productivity.

Keywords: Mental Workload, Work Fatigue, NASA-TLX

Introduction

In the era of modern industrialization that moves dynamically, Human Resources (HR) plays a very crucial role and cannot be completely replaced by machine automation. As the main asset of the organization, the performance and capabilities of workers are the driving force in achieving efficiency, innovation, and sustainability of the company's operations. The management of quality and human resource capacity in the industrial environment must be the main focus in order to maintain productivity stability and achieve competitive market competitiveness [21]. Based on Law No. 13 of 2003, every company is obliged to implement an Occupational Safety and Health (K3) system to protect workers from various risks in the workplace [15]. The optimal contribution of these workers depends heavily on how the work environment can minimize various work pressures that have the potential to reduce the cognitive and physiological functional capacity of humans themselves [21].

One of the critical factors that directly dictates the performance of workers on the production floor is workload and work burnout. Job fatigue is a condition of physical and psychological decline in the body's functional capacity that arises due to work activities that take place continuously without adequate recovery time [9]. An unbalanced workload, either overloaded or underloaded, has a linear correlation with decreased company productivity and health problems for workers [22]. When the demands of the task exceed the threshold of the worker's biological and psychological adaptation capacity, the body will experience chronic fatigue, decreased cognitive function, slowing down of the

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decision-making process, and perceptual inhibitions [16]. In the long term, this condition triggers the occurrence of various physical and mental health problems, an increase in absenteeism, and high human error which is the main trigger for work accidents in factories [26].

Previous related studies have shown the importance of psychological aspects in the work environment of the manufacturing industry. Several previous studies have focused on evaluation on purely physical workload using indicators of pulse rate or cardiovascular energy consumption [17]. However, as technology complexity, automation systems, and the demands of strict production targets on the factory floor increase, the concept of workloads has now shifted to the dominance of mental workloads [1]. Today's workers are faced with the need to process information intensively, monitor automated machines, maintain high accuracy in sorting defective products, and make quick decisions in a short period of time [10]. This mental workload refers to how much cognitive capacity and portion of information processing a worker's brain must allocate in order to complete its operational tasks efficiently [18].

Before this research was conducted, there was a real gap analysis in the literature and implementation of K3 in the field. Most convection plant and manufacturing management in Indonesia tends to ignore cognitive fatigue and focus only on visual physical safety, such as the provision of Personal Protective Equipment (PPE) and the prevention of mechanical accidents [25]. Integrated evaluations comparing the manifestations of interdivisional mental workloads (production, machine operators, and sewing) in several different sub-sectors of the manufacturing industry are still very limited [11]. As a result, macro ergonomics interventions are often mistargeted because they are not based on periodic mapping of the dimensions of specific cognitive load that workers experience [14].

The purpose of this scientific paper is to comprehensively analyze and map the level of mental workload and work fatigue faced by factory workers in various operational lines using the multidimensional instrument NASA-Task Load Index (NASA-TLX) [7]. Through this objective analysis, it is hoped that the dominant factors (main stressors) that trigger cognitive fatigue in workers can be found, so that the results of the research can be used as a valid scientific basis for the company's management in designing improvements to ergonomic work systems, shift rotation arrangements, optimization of rest time, and improving the psychological well-being of workers in line with the principle of fit the job to the man [20].

Method

This study uses a descriptive design with a cognitive ergonomics approach. The population and sample involved workers from various production lines in the factory such as machine operators, product inspection parts, and tailors in factory X. Data sources were obtained through questionnaires and direct interviews. The measuring tool used is the NASA-TLX instrument which consists of the weighting stage (paired comparison) and rating (scale 0-100). The data collection technique was carried out by self-assessment of workers on six dimensions of assessment, namely Mental Demand (MD), Physical Demand (PD), Temporal Demand (TD), Work Performance (Own Performance / OP), Level of Effort (EF), and Frustration Level (FR). Data analysis was carried out by calculating *the Weighted Workload* (WWL) value which was then classified into low to very high categories. The questionnaire contains six questions for rating and 15 paired weighting according to the NASA-TLX method. The following are the procedures for doing the questionnaire for rating and weighting.

1) Weighting

   This weighting asks respondents to circle one of the indicators (right or left) that has the most effect on the respondent's mental workload on their work.

No	Indikator Beban Mental		
1	MD (*Mental Demand*)	vs	PD (*Physical Demand*)
2	MD (*Mental Demand*)	vs	TD (*Temporal Demand*)
3	MD (*Mental Demand*)	vs	OP (*Own Performance*)
4	MD (*Mental Demand*)	vs	EF (*Effort*)
5	MD (*Mental Demand*)	vs	FR (*Frustation*)
6	PD (*Physical Demand*)	vs	TD (*Temporal Demand*)
7	PD (*Physical Demand*)	vs	OP (*Own Performance*)
8	PD (*Physical Demand*)	vs	EF (*Effort*)
9	PD (*Physical Demand*)	vs	FR (*Frustation*)
10	TD (*Temporal Demand*)	vs	OP (*Own Performance*)
11	TD (*Temporal Demand*)	vs	EF (*Effort*)
12	TD (*Temporal Demand*)	vs	FR (*Frustation*)
13	OP (*Own Performance*)	vs	EF (*Effort*)
14	OP (*Own Performance*)	vs	FR (*Frustation*)
15	EF (*Effort*)	vs	FR (*Frustation*)

Figure 1. Weighting

2) Pemberian Rating

In the rating questionnaire, respondents were asked to rate all six indicators of mental workload by circling a line that corresponds to the scale felt by workers in doing their work.

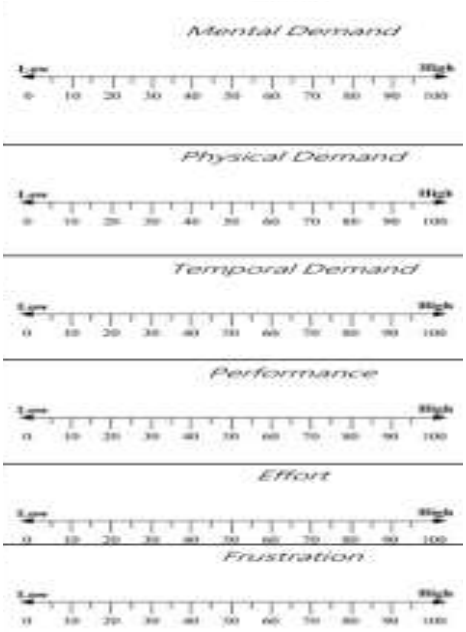


Figure 2. Rating

The NASA-TLX calculation went through several stages of assessment, namely:

a. The weighting was obtained from the selection between two dominant indicators in a paired comparison consisting of 15 pairs of indicators.
b. Ratings are obtained from the rating values given by respondents on each indicator.
c. Product Value Calculation Product = rating x weight factor
   The product is the value of each indicator.
d. Weighted Workload (WWL) calculation WWL = product ∑

e. Calculation of Score = WWL/15
   The divisor is calculated from the total weighting, which is a total of 15 pairs.
f. Interpretation of the Score
   Hart and Staveland in Mahfira and Andres (2018) explain the NASA-TLX theory and state that the score obtained can be interpreted by looking at Table 1 as follows:

Table 1. NASA-TLX Score Reting

Reting Shoes	Workload Categories	Remarks
0 – 50	Light/low	Safe conditions, workload is still below the optimal capacity of workers
51 – 80	Medium	The condition is alert, but it needs periodic evaluation so that it does not rise to be heavy.
81 - 100	Weight	Danger! Workers are vulnerable to stress or work accidents. Immediate action is needed to improve the work system.

Results

The findings of the field research revealed that the characteristics of work in a manufacturing plant environment provide significant cognitive and psychological demands on workers [2]. Based on operational data that has been processed from questionnaires and in-depth interviews with worker representatives in six manufacturing industry entities, a quantitative picture of the final score of the mental workload of NASA-TLX and its most dominant forming indicators [12] is obtained. All data is presented in the form of a summary table of mental load performance to facilitate comparative understanding between work lines.

Table 2. NASA-TLX Score Distribution and Plant Worker Dominant Indicators

They respond	Job Type	NASA-TLX Score	Category: Beban Mental	The Most Dominant Indicator
1	Production Parts	72,6	Medium	MD, TD, EF
2	Production Operator	68,0	Medium	MD, TD, EF
3	Machine Operator	69,7	Medium	Effort
4	Shirt Making Process	24,0	Low	Temporal Demand (TD)
5	Sewing Parts	78,3	Medium	MD, TD, EF

Based on the quantitative data in Table 1, it is clear that the spectrum of workers' mental workload is in the medium category to close to the upper limit of the high category [11]. Workers in the sewing department recorded the highest score of 78.3 which indicated very heavy cognitive demands, followed by female workers in the production section with a score of 72.6 and machine operators with a score of 69.7 [1]. These findings confirm that the main triggers of psychological fatigue on the production floor are consistently dominated by the three main dimensions of NASA-TLX, namely the level of effort expended (Effort), limitation or time pressure in meeting daily targets (Temporal Demand), and high mental concentration to maintain quality and minimize product failures (Mental Demand) [5].

Discussion

Based on the close relationship between field results, the basic concept of cognitive ergonomics, and the theory of work fatigue put forward by experts in the previous literature. Quantitative data showing the large contribution of the Effort and Temporal Demand dimensions across the manufacturing companies studied indicated the presence of systemic workload [18]. According to the basic concept of cognitive ergonomics, the human brain has a limited capacity to process information input and maintain constant attention [7]. The demands of extreme processing speed to meet output targets (Temporal Demand) force the central nervous system to accelerate the allocation of cognitive resources, which directly increases the sense of urgency, emotional tension, and chronic work stress of factory employees [12].

The high Effort score felt by machine operators in plant x (score 69.7) and production (score 72.6) indicates alignment with Grandjean's theory of accumulated work fatigue, which states that cognitive fatigue accumulates linearly due to a combination of repetitive static physical tasks and constant concentration of machine supervision without adequate rest breaks [9]. When workers are forced to maintain maximum performance in industrial work environments that tend to be noisy due to machine noise and hot temperatures, the body activates the sympathetic nervous system for a prolonged period [22]. This constant physiological-psychological load conditions accelerate the onset of emotional fatigue, anxiety, and decreased self-motivation [19]. This also has direct implications for the results of the work; Reduced attention due to mental fatigue increases the rate of human error, which has a fatal risk of triggering work accidents on the floor of a manufacturing plant [26].

If associated with the results of previous research, this finding strengthens the study from Dewi and Devi (2024) on sewing operators of garment companies who confirmed that repetitive sewing work with a focus on detailed observation of stitch patterns triggers significant fatigue of the nerve centers [5]. However, there is an interesting variation in cases where the final score is recorded low (score of 24.0). Based on the results of in-depth interviews, this variance is due to the effectiveness of the implementation of a more adaptive work organizational structure, clarity of task division, and a supportive work culture between employees that minimizes non-physical psychological stressors [8]. On the other hand, in the sewing line (score 78.3), the limited number of workers in the midst of soaring orders for car seat variations forced workers to work long overtime without objective work rotation, thus triggering job mismatch which led to high levels of frustration and chronic mental fatigue of factory workers [23].

Overall, this comparative analysis proves that the mental workload of modern factory workers can no longer be separated from the design of the work system on a macro basis [6]. Company management cannot rely solely on conventional physical-based K3 interventions. It is necessary to re-engineer the work system based on cognitive ergonomics to create a real balance between the demands of the task and the psychological adaptation capacity of workers in order to prevent stagnation of national productivity and create an ergonomic learning culture [24].

Conclusion

Based on the results of the in-depth analysis, quantitative measurements using the NASA-TLX multidimensional method, and the comparative discussion that has been described in the previous section, several important conclusions can be drawn as a direct answer to the problems and objectives of this research. First, most operational workers on the manufacturing floor, particularly in the production, machine operator, and sewing divisions, experience a level of mental workload and work fatigue in the medium category, with the representation of the NASA-TLX final score dominating in the range of 61.0 to 78.3. Second, the dominant factors or main stressors that most consistently contribute to increasing the cognitive burden of factory workers in all operational lines of the company studied are the dimensions of the level of effort deployed (Effort), mental demand, and the need for time to carry out tasks (Temporal Demand). This is directly triggered by the setting of a very high and strict daily production volume target, long working hours, and the characteristics of mechanical work activities that are monotonous and repetitive for a long period of time without adequate pause in body recovery. Third, the high accumulation of mental work fatigue has been proven to have a systemic negative impact that is detrimental to both parties; For workers, this fatigue condition triggers the onset of chronic work stress, sleep disorders, emotional anxiety, depression, apathy, and a drastic decrease in the level of concentration and mental alertness while on duty. For companies, the decline in workers' cognitive capacity is directly correlated with an increase in employee absenteeism, a decrease in the quality of product output, and a soaring rate of human error which is the main trigger for work accident incidents in the manufacturing environment. Therefore, managing mental workload is an urgent need that must be integrated into the company's strategic occupational safety and health (K3) policy. As an operational recommendation for industrial management, it is recommended to immediately rearrange the layout of the workstation to be more ergonomic, implement an objective job rotation system on a regular basis to minimize burnout, restructure the fulfillment of daily targets to be in line with the capacity of human biological adaptation, regulate the distribution of night shifts more fairly to maintain the circadian rhythm of the body, and provide cognitive recovery facilities and ideal micro-breaks between operational production processes to maintain performance stability, work safety, and productivity sustainability for manufacturing companies in the face of competitive global market competition.

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