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EVALUATION OF MACHINIST'S FATIGUE AT PT. KERETA API PERSERO DAOP II BANDUNG

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ABSTRACT

Machinists have a big responsibility in controlling trains and maintaining the safety of trips. When a machinist has an irregular work schedule, monotonous and long schedules, he may experience fatigue while on duty. Fatigue can cause a decrease in performance and lead the machinist to make mistakes that can later be the cause of railway accidents. Fatigue assessments, then, become an important program that can be used by management to improve railway safety. In this study, a fatigue evaluation was conducted among 30 machinists working at the Indonesian Railway Company (PT. Kereta Api Indonesia or PT. KAI). The evaluation consists of assessing the quality of sleep with The Pittsburgh Sleep Quality Index (PSQI), the measurement of subjective sleepiness with Karolinska Sleepiness Scale (KSS), the measurement of secondary work performance with Psychomotor Vigilance Test (PVT), and heart rate measurements employing a heart rate monitor (Beurer PM-18). Results of this study showed that most of the machinists experienced sleep quality problems. Also, the sleepiness level of the machinists continued to increase at work and the reaction time was worse at the end of his shift, although levels of physical fatigue were not substantial. Suggestions were proposed to the management, including new work schedules using shift rotations in order to reduce fatigue.

Keywords: Fatigue; Machinist; Performance; Railway; Sleepiness

1. INTRODUCTION

Transportation is indispensable in supporting community life. In addition to the benefits and substantial role for public transportation, there are also problems and drawbacks arising from the use of transportation modes. One of the transportation modes that contributes to relatively high accident levels is the railway. Statistics shows that railway safety for the PT. KAI is still a major issue, as can be seen from the number of injuries and fatalities resulting from railway incidents. Based on the data from the National Transportation Safety Committee (NTSC), 661 train accidents occurred between 2005 and 2010. Of these, 66.6% were derailments, and 16.5% were related to collisions with vehicles running rail crossings. Collisions between trains were at 4.4% of the total accidents, while the remaining 12.5% is for other reasons. As a result of these accidents, 282 people died and 1,149 people were injured (Accident Reports, 2016).

NTSC also stated that 80% of train accidents were caused by human error and 45% of them involved machinists (Accident Reports, 2016). In India, the train accidents associated with poor performance of the machinist were roughly 60% (Kumar & Sinha, 2008). Study conducted by

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Kim et al. (2008) also recorded that 61% of train accidents in South Korea were linked to human error.

Desai and Haque (2006) stated that there were two things that caused traffic accidents, including drowsiness (sleepiness) and inattention (loss of alertness). Both are caused by the conditions of an exhausted driver, psychological condition, physiological conditions of the body, and monotonous work. While driving a train, the machinists generally experienced higher fatigue when on duty at night (Rajaratnam & Jones, 2004). In addition, 25% of machinists were reported to fall asleep while driving or waiting at the station (Harma et al., 2002). As a matter of fact, this study indicated that the machinists who worked on the night shift were suspected to fall asleep 6–14 times higher than those on duty in the morning shift.

Williamson et al. (2011) defines fatigue as a biological drive for recuperative rest. According to Dawson et al. (2014) fatigue is sleepiness resulting from neurobiological processes regulating sleep and circadian rhythms or the drive to sleep. It is influenced by prior sleep, prior waking and time of day. The latest definition stated fatigue as a suboptimal psychophysiological condition caused by exertion. The degree and dimensional character of the condition depends on the form, dynamics and context of exertion. The context of exertion is described by the value and meaning of performance to the individual, rest and sleep history, circadian effects, psychosocial factors spanning work and home life, individual traits, diet, health, fitness and other individual states, and environmental conditions (Buysse et al., 1989). From some of these definitions, it can be concluded that fatigue is an impact of activities undertaken by humans, and rest is a mechanism to recover from exhaustion.

There has been no fatigue evaluation of the machinists at DAOP II Bandung through the measurement of subjective sleepiness, sleep quality assessment, reaction speed and heart rate. This evaluation was very important because the work schedule of machinists was irregular and the machinist experiences a good possibility of drowsiness and fatigue during his duty. Due to those reasons, this study aimed to evaluate fatigue among machinists from PT. KAI DAOP II Bandung and expected to provide input for PT KAI against the machinists' fatigue conditions. Evaluation of the machinist's fatigue can also be used as the basis for improvements on working conditions. Two proposed work schedules were given in this study and expected to minimize the possibility of the fatigue of the machinists.

The respondents of this study were the machinists who drove the train from 5 a.m. until 11:45 a.m. between two major cities in Java Island (i.e. Bandung to Jakarta). Currently, the work schedule of the machinists seemed poor. A machinist was often scheduled a new duty at dawn, the day after his duty had finished at midnight. There was no pattern of a regular work schedule and no shift system. This caused the machinists to have difficulty adjusting to set hours of sleep every night. The distance between home and the rail station was quite far, causing the machinists to wake up very early. As a result, most machinists often felt sleepy when they had to start their duties early the next morning. When they started working in an already sleepy condition, there was the possibility of making mistakes. As a result, the risk of accidents could also be expected to be higher.

2. METHODS

Four methods were employed in this study for the purpose of assessing fatigue of 30 machinists. The first method was The Pittsburgh Sleep Quality Index (PSQI), that was used to assess the quality of sleep of the machinists over a month. The sleep quality was a measure of the ease of someone to initiate sleep and relaxation after waking from sleep (Buysse et al., 1989). It differentiates "poor" from "good" sleep by measuring seven factors: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction over the last month. The machinist himself rated each of these seven factors of sleep. Scoring of the answers is based on a 0 to 3 scale, where 3 reflects the negative extreme on the Likert Scale. A global sum of "5" or greater indicates a "poor" sleeper (Carole, 2012). Quality of sleep was used to examine the indication of the causes of fatigue in the machinists.

The second method was Karolinska Sleepiness Scale (KSS). It was used to measure the level of the machinist's sleepiness. It consists of 9 scales, ranging from extremely alert (scale 1) to very sleepy, great effort to keep awake, fighting sleep (scale 9). The sleepiness level was measured subjectively by asking the sleepiness level of machinist in the last 5 minutes. This measurement was performed every hour while the machinist ran the train.

The third method used in this study was Psychomotor Vigilance Task (PVT). PVT is a method used to measure work performance through a measurement of secondary work performance. According to Baulk et al. (2008), fatigue can be demonstrated by a decrease in work performance, including a decrease in a person's reaction speed. Using PVT, machinists were asked to respond to a stimulus by pressing a picture as soon as possible after the stimulus appeared. The emergence of random stimuli was introduced in intervals between 2000–10000 milliseconds (ms). The data recorded was the reaction time (RT) in milliseconds (ms). RT is the time measured from the stimulus to appear until the machinist presses the image. Reaction time of less than 100 ms are not valid and is considered a false start. This means that someone gave a response before the stimulus appeared. Stimuli that is responded within more than or equal to 500 ms is called minor lapse. It indicates that the machinist is unaware of the stimulus.

The fourth method was to measure heart rate using a heart rate monitor Beurer PM-18 to evaluate physical fatigue. The heart rate measurement results were converted into energy consumption. An equation created by Kamalakannan et al. (2007) was used to convert data into a heart rate of energy consumption. The heart rate was measured at the start of the work (before work), when working (working heart rate or HR), at the end of the work (after work), and at rest (resting heart rate or RHR, measured shortly after waking up in the morning). The working heart rate was measured every hour.

$$E\text{-}cost = -1967 + 8.58\,HR + 25.1HT + 4.5A - 7.47RHR + 67.8G \qquad (1)$$

where *E-cost* is the energy cost (Watt), HR is the work heart rate (bpm), HT is the height (inch), A is the age (year), RHR is the resting heart rate (bpm), and G is the gender (male=0, female=1)

3. RESULTS AND DISCUSSION

3.1. The Sleep Quality using Pittsburgh Sleep Quality Index (PSQI)

Sleep quality data were collected among machinists who started his work at dawn (4 a.m.). A machinist who started his work at dawn not only had an irregular bedtime each day, but would have trouble with sleep duration when he did not go to bed early. Machinists' sleep quality data collection were done with PSQI. The results of PSQI were the sleeping index and shown in Table 1. An individual was considered to have poor sleep quality when the sleeping index value ≥ 5. There were 22 people who had poor sleep quality (73.33%). From the analysis of PSQI score, there were 25 people who took more than 15 minutes to fall asleep. Eleven machinists took between 16 and 30 minutes to fall asleep and 14 other machinists took between 31 and 60 minutes. On the average, machinists took 31.3 minutes to fall asleep (a relatievely long period of time). The reason why it took a long time to fall asleep was not known for sure. However, it is suspected that it is caused by the irregular work schedule of the machinists that causes sleep and circadian rhythm disruption.

Table 1 Sleeping index value

Machinist	Sleeping index	Machinist	Sleeping index
1	8	16	5
2	2	17	7
3	9	18	9
4	6	19	2
5	1	20	3
6	6	21	9
7	9	22	7
8	6	23	2
9	3	24	7
10	6	25	9
11	6	26	9
12	7	27	6
13	9	28	8
14	4	29	7
15	8	30	8

Most machinists have a sleep duration of less than 7 hours. The average sleep duration of the machinists was 6.38 hours. The National Sleep Foundation (NSF) recommends a minimum of seven hours of sleep for those who are more than 18 years of age (Hirshkowitz et al., 2015). Machinists who experienced sleep deprivation will show signs of sleepiness and in the long term, this is harmful to their health. Long-term effects of a sleep deprivation are an increasing risk of heart disease and stroke (Breus, 2015). Lack of sleep can be divided into two categories: acute sleep deprivation (acute sleep loss/ASL) and chronic sleep deprivation (chronic sleep loss/CSL) (Williamson et al., 2011). ASL can be partial or total. Partial ASL occurs when a person sleeps with a short duration on the night before and total ASL occurs when he/she has not slept in the past 24 hours. CSL occurs when a person experiences sleep deprivation continuously, for example over the last week. Sleep debt will arise when he/she has suffered CSL and would interfere with the function of the body. With an irregular work schedule, it was very likely for the machinists to experience the CSL. The way to eliminate this sleep debt is by adding a portion of sleep as a form of recovery and is usually done at the end of the week when he was not working. In addition to the problem of lack of sleep, it turns out the driver also experienced sleep disturbances. Sleep disturbances experienced in the form of waking up at midnight or early in the morning to go to the bathroom. These were experienced by 24 of the 30 machinists in this study.

3.2. The Sleepiness Level using Karolinska Sleepiness Scale (KSS)

The sleepiness level of the machinists was measured every hour starting from the beginning (before work) until the end of their duty (after work). It looked at changes in the level of sleepiness every hour. The result showed that their sleepiness level continued to rise during their duty and decreased at the end. Almost 50% of the machinists had a scale of five on their levels of sleepiness at the beginning of their duty (4 a.m. to 5 a.m.). This showed the level of their sleepiness scale was already high before they even started to work. The distance between home and the train station was quite far away, causing the driver to wake up very early (before 4 a.m. everyday). As a result, the machinist often got limited sleep. On some occasions, he had to travel about one to one and a half hours using his motorcycle from home to the station. So he had to get up around 2 a.m. everyday in order to arrive at the station on time.

In doing this work, a machinist was accompanied by an assistant. The machinist would be replaced by his assistant when he did not feel fit to drive the train (for whatever reasons). However, it was found that machinist who felt sleepy while driving usually tried to maintain his conditions along the way. He kept driving despite feeling sleepy. In fact, when driving in a state of sleepiness, the machinist might incorrectly perceive the signal, which could potentially cause accidents. Another interesting finding in this study was that, the level of sleepiness during the second trip was higher than the first trip. This was probably because the machinists had experienced a monotonous driving long enough from the first trip.

3.3. Performance Measurement using Psychomotor Vigilance Task (PVT)

Performance assessment conducted in this study was the measurement of performance for the secondary job. It was measured by reaction time (RT) using PVT. The reaction time measurement was performed twice for each machinist, i.e. at the beginning and the end of his duty. The reaction time showed residual mental capacity after he did his job, and if the reaction time increased, it meant that the rest of his mental capacity declined. Mental capacity is related to the level of vigilance that is needed to drive a train. In conditions where there was a deteriorating mental capacity, the possibility for him to make mistakes would be greater. Ultimately, this could lead machinist to make wrong decisions that might eventually lead to an accident.

Reaction time measurement data consisted of mean reaction time (mean RT), maximum reaction time (RT max), minimum reaction time (min RT), and a number of minor lapses. Table 2 shows the measurement results for the four variables at the beginning and the end of work. The results showed that there was a decline in mental capacity at the end of the work shown by the increasing value of all the variables measured. This indicated a state of fatigue experienced at the end of his work schedul. Fatigue causes a decrease in the level of vigilance which may result in an error. Fatigue at the end of his work could be caused by monotony and a length of his schedule, which was about seven hours with short rest periods. This was in accordance with a study by Thiffault and Bergeron (2003) that stated monotony of the work can cause fatigue. Fatigue perceived by the machinists can be caused from his responsibility for the safety of the passengers. The responsibility for the lives of many people can be a mental burden of its own.

Table 2 Result of data processing PVT

Beginning of work (4 am - 5 am)				End of work (12 pm - 13 pm)			
Mean RT (ms)	Max RT (ms)	Min RT (ms)	Number of minor lapse	Mean RT (ms)	Max RT (ms)	Min RT (ms)	Number of minor lapse
392.48	717.50	289.90	5.17	488.45	1376.33	319.20	10.47

3.4. Physiological Evaluation using Heart Rate Measurement

In this study, the heart rate was measured every hour and was used to look at changes in heart rate of the machinist from the beginning to the end of his duty. A heart rate increase occurred from the beginning of work until 11 a.m. and declined toward the end of the work. This increase might be due to the heat of the locomotive cabin after being in Jakarta, a city with hot weather conditions. Generally, the task of the machinist is pressing the "deadman" pedal when the warning light turns on, setting the speed of the train, braking via a lever, and honking when near a rail crossing as well as when entering the station. The machinist worked in a sitting position while driving the train. Although there were no heavy physical activities, he must always be alert and concentrate while driving.

The energy cost (E-cost) calculation results also indicated that driving a train was classified as light or medium work based on the workload categories according to Sanders and McCormick (Sanders & McCormick, 1993) that can be seen in Table 3. E-cost for the machinists can be seen in Table 4. Based on the results of this e-cost, we concluded that the work of driving the train was not physiologically taxing, and physical fatigue might not be an issue here.

Table 3 E-cost category according to Sanders and McCormick

Work Severity	Heart Rate (bpm)	E-cost (kcal/min)
Light Work	<90	<2.5
Moderate Work	90–110	2.5–5.0
Heavy Work	110–130	5.0–7.5
Very Heavy Work	130–150	7.5–10
Extremely Heavy Work	150–170	>10

Table 4 E-cost for machinists and its category

Machinist	E-cost (kcal/min)	Category
1	2.11	Light Work
2	1.84	Light Work
3	2.54	Moderate Work
4	1.55	Light Work
5	1.60	Light Work
6	2.87	Moderate Work
7	4.15	Moderate Work
8	1.49	Light Work
9	1.71	Light Work
10	3.28	Moderate Work
11	3.28	Moderate Work
12	3.04	Moderate Work
13	1.39	Light Work
14	2.77	Moderate Work
15	2.04	Light Work
16	2.34	Light Work
17	2.36	Light Work
18	3.45	Moderate Work
19	3.22	Moderate Work
20	2.39	Light Work
21	2.32	Light Work
22	3.06	Moderate Work
23	4.25	Moderate Work
24	2.75	Moderate Work
25	4.14	Moderate Work
26	2.34	Light Work
27	4.05	Moderate Work
28	2.60	Moderate Work
29	2.19	Light Work
30	3.33	Moderate Work

3.5. Proposed Shift Arrangements

There are two shift arrangements proposed in this study. The first shift arrangements proposed is rotated every eight days. This first arrangement can be seen in Table 5. However, a slower rotational shift (every eight days) can make it difficult to adapt and can disrupt the circadian rhythm of the machinist. The second shift arrangements proposed is rotations every two days and after doing his duty in the night shift, the machinist will get two days off (Table 6). The second rotation is done more quickly so that the machinist can easily adapt and does not disrupt his circadian rhythms.

Table 5 The first shift arrangements (rotation every 8 days)

Schedule Number	Shift	Route Number	Route	Time
1	Morning	1	Jng-Jakk-Bdg	04:00-12:01
		2	Bdg-Gbr-Bdg	04:00-12:15
		3	Kac-Bjr	10:00-14:18
		4	Bjr-Kac	08:15-13:43
		5	Bdg-Bjr	07:30-11:15
		6	Bjr-Bdg	04:02-08:56
		7	Day off	
		8	Morning reserve	06:57-11:08
2	Afternoon	9	Afternoon reserve	14:00-22:00
		10	Jng-Jakk-Kac	11:00-19:00
		11	Jng-Jakk-Kac	14:00-22:00
		12	Afternoon reserve	17:30-24:00
		13	Bdg-Cn	14:10-19:15
		14	Day off	
		15	Cn-Bdg	17:30-01:15
		16	Kac-Jakk-Kac	11:30-19:33
3	Night	17	Bdg-Bjr	22:00-06:00
		18	Bjr-Bdg	18:30-24:40
		19	Kac-Bjr	18:30-24:00
		20	Bjr-Kac	01:40-06:34
		21	Night reserve	18:30-24:00
		22	Day off	
		23	Bdg-Cn	00:17-05:18
		24	Cn-Bdg	18:30-24:00
4	Morning	25	Bdg-Gbr-Bdg	05:35-13:50
		26	Bdg-Bjr-Kac	06:00-00:28
		27	Morning reserve	04:30-10:15
		28	Bdg-Gbr-Bdg	07:45-16:00
		29	Morning reserve	06:00-14:00
		30	Day off	
		31	Morning tracks switching	06:00-14:00
		32	Bdg-Gbr-Bdg	11:00-00:44
5	Afternoon	33	Bdg-Bjr	18:00-23:04
		34	Bjr-Bdg	14:00-22:00
		35	Bdg-Gbr-Bdg	15:15-23:17
		36	Bdg-Gbr-Bdg	13:30-21:35
		37	Bdg-Bjr	14:25-19:14
		38	Day off	
		39	Bjr-Kac	10:57-15:45
		40	Jng-Gbr-Bdg	14:45-22:44
6	Night	41	Kac-Bjr	22:30-04:59
		42	Bjr-Kac	22:09-03:14
		43	Bdg-Bjr	18:30-23:45
		44	Bjr-Bdg	19:35-01:15
		45	Kac-Jakk-Jng	22:30-04:11
		46	Day off	
		47	Night tracks switching	19:00-03:00
		48	Bdg-Jakk-Jng	18:50-00:00

Table 6 The second shift arrangements (rotation every 2 days)

Schedule No	Shift	Route No	Route	Time
1	Morning	1	Jng-Jakk-Bdg	04:00-12:01
		2	Bdg-Gbr-Bdg	04:00-12:15
2	Afternoon	3	Afternoon reserve	14:00-22:00
		4	Jng-Jakk-Kac	11:00-19:00
3	Night	5	Bdg-Bjr	22:00-06:00
		6	Bjr-Bdg	18:30-24:40
4		7	Days off	
		8		
5	Morning	9	Kac-Bjr	10:00-14:18
		10	Bjr-Kac	08:15-13:43
6	Afternoon	11	Jng-Jakk-Kac	14:00-22:00
		12	Afternoon reserve	17:30-24:00
7	Night	13	Kac-Bjr	18:30-24:00
		14	Bjr-Kac	01:40-06:34
8		15	Days off	
		16		
9	Morning	17	Bdg-Bjr	07:30-11:15
		18	Bjr-Bdg	04:02-08:56
10	Afternoon	19	Bd-Cn	14:10-19:15
		20	Cn-Bd	17:30-01:15
11	Night	21	Night reserve	18:30-24:00
		22	Bdg-Jakk-Jng	18:50-00:00
12		23	Days off	
		24		
13	Morning	25	Bdg-Gbr-Bdg	11:00-00:44
		26	Bdg-Bjr-Kac	06:00-00:28
14	Afternoon	27	Bdg-Bjr	18:00-23:04
		28	Bjr-Bdg	14:00-22:00
15	Night	29	Kac-Bjr	22:30-04:59
		30	Bjr-Kac	22:09-03:14
16		31	Days off	
		32		
17	Morning	33	Morning reserve	04:30-10:15
		34	Bdg-Gbr-Bdg	07:45-16:00
18	Afternoon	35	Bdg-Gbr-Bdg	15:15-23:30
		36	Bdg-Gbr-Bdg	13:30-21:45
19	Night	37	Bdg-Bjr	18:30-23:45
		38	Bjr-Bdg	19:35-01:15
20		39	Days off	
		40		
21	Morning	41	Morning reserve	06:00-14:00
		42	Morning tracks switching	06:00-14:00
22	Afternoon	43	Bdg-Bjr	14:25-19:14
		44	Bjr-Kac	10:57-15:45
23	Night	45	Kac-Jakk-Jng	22:30-04:11
		46	Night tracks switching	19:00-03:00
24		47	Days off	
		48		
25	Morning	49	Morning reserve	06:57-11:08
		50	Bdg-Gbr-Bdg	05:35-13:50
26	Afternoon	51	Kac-Jakk-Kac	11:30-19:33
		52	Jng-Gbr-Bdg	14:45-22:44
27	Night	53	Bdg-Cn	00:17-05:18
		54	Cn-Bdg	18:30-24:00
28		55	Days off	
		56		

Abbreviation: Bdg = Bandung, Cn = Cirebon, Jakk = Jakarta Kota (Downtown Jakarta), Bjr = Banjar, Kac = Kiaracondong, Gbr = Gambir, Jng = Jatinangor. *Note*: Time information based on the Western Indonesian Time

4. CONCLUSION

From this study, we conclude that the machinists experienced high mental fatigue. It was characterized by extreme sleepiness experienced by most machinists during their work schedule. This could likely be due to poor sleep quality and sleep deprivation. If their condition continues, it could result in increased risk of train safety. To avoid that risk, an action for mitigating fatigue must be done. It can be done by improving the machinist's work schedule. This research proposes to apply the shift system and rearrange the order of the schedules by the machinist. Shift rotation should be done so that no machinist will always get the same shift two days in a row. It aims to maintain the normal circadian rhythm of machinist.

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