Reducing workplace accidents in a cement company by assessment of physical and mental workload: a case study

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Abstract. As one of the leading cement companies in Indonesia, PT Semen Padang is known for its extensive distribution network. As the largest cement factory, the employees at this company engage in work that requires a high level of physical and mental effort. Although the tasks performed by the employees may be similar, the experience of psychological workload can vary greatly among them. The TPM (Total Productive Maintenance) and AFR (Alternative Fuel and Raw Material) departments in the company have several routine activities carried out daily. The numerous job demands that require physical exertion within limited time constraints can lead to a high workload level for employees in TPM and AFR. This workload is not limited to physical aspects but also includes psychological impacts that can disrupt employees's concentration and performance. In this study, questionnaires were given to 7 employees from TPM and 7 employees from AFR. Based on the research conducted on physical workload using the CVL method, AFR employees experienced more physical workload compared to TPM employees. In terms of mental workload, using the NASA-TLX method, both TPM and AFR employees had 2 employees each with very high mental workload.

1 Introduction

In the era of globalization and intense company competition, a company must pay attention to and consider employee productivity, as operational efficiency is key to a company's success. Therefore, companies must give special attention to employee workload and productivity as a foundation for sustainable development and growth. One type of company that must consider this is a manufacturing company with a large human resource base. Cement Company, a leading manufacturer in the cement production sector, must pay attention to employee performance as it is a large company that requires both physical and mental strength, especially for employees who work both in the office and in the field. These employees must manage their energy to ensure smooth operations. As Cement Company is recognized as the largest producer of cement and clinker in Indonesia and Asia, the performance of employees working in both office and field settings must be carefully monitored to avoid workload imbalances and job discrepancies. One of the units that requires such attention is the TPM (Total Productive Maintenance) Unit, which is responsible for maintenance and innovation, and AFR (Alternative Fuel and Raw Material), which focuses on using more sustainable and environmentally friendly alternative fuels and raw materials.

Based on the above statement, several studies have demonstrated that workload can affect worker performance. According to data from the International Labour Organization, in 2013, there were 200 million workers who experienced work-related accidents due to fatigue. The study explained that out of 58,115 samples, 32.8% experienced work accidents due to fatigue [1]. Another study proved that in a hospital, 394 pharmacists every month from 2012 to 2018 in two major service centers in Taiwan, as concluded by Shao et al., reducing workload correctly can assist pharmacist performance.

Based on the above studies, the same consideration should be given to employees in the TPM and AFR units of Cement Company to ensure smooth operations. The TPM unit requires a cohesive team performance to ensure the maintenance and upkeep of equipment run safely and smoothly, aiming to increase the company's productivity and quality. Similarly, the AFR unit plays a crucial role in producing raw materials for coal substitution at the Indarung plant, requiring employees with good performance in their jobs. The numerous job demands require sufficient energy to complete tasks; therefore, actions are needed to prevent employees from becoming stressed, easily tired, frustrated, and experiencing other physical or mental issues. Therefore, to understand the physical and mental workload experienced by employees of Total Productive Maintenance and Alternative Fuel and Raw Material at Cement Company, the author conducted research and observations on a case study titled "Analysis of Physical and Mental Workload of TPM (Total Productive Maintenance) and AFR (Alternative Fuel and Raw Material) Employees at Cement Company Using the CVL (Cardiovascular Load) Method.

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2 Method

2.1 Types of research

This research employs a mixed-methods approach, incorporating both quantitative and qualitative research types. Mixed-methods research is a process that uses data in the form of numbers and results from observations or interviews as tools to analyze the research being conducted. The objective of this study is to assess and understand the level of physical and mental workload experienced by TPM (Total Productive Maintenance) and AFR (Alternative Ruel and Raw Material) at PT Semen Padang.

2.2 Data collection

The data collected by the researcher consists of two types: primary data, which comes from direct observations, and secondary data, which is company data. The data analysis methods used include Pareto analysis, fishbone diagram analysis, and improvement proposal analysis.

3 Results and discussion

3.1 CVL processing and analysis

Data processing carried out in the CVL method is based on the data that has been taken. The data that has been taken will be processed until % CVL is obtained. Before obtaining % CVL, the researcher must first determine the pulse rate when working and resting, age and maximum working pulse rate of the respondents being studied. Pulse measurement is done by feeling the pulse of the radial artery on the wrist and measuring using a stopwatch with the 10-beat method. The provisions in taking the questionnaire are that employees A-G are TPM employees while employees H-N are AFR employees. The following are the results of the calculation of DNK (Working Pulse Rate) and DNI (Resting Pulse Rate), age, and DNK Maxs in Table 1.

Table 1. Calculation results of DNK, DNI, and DNK max employees

No	Respondents	Gender	Resting Heart Rate/min	Working Heart Rate/min	Maxs Working Pulse	Age
1	Employee A	Male	65.22	94.94	172	48th
2	Employee B	Male	59.06	72.73	171	49th
3	Employee C	Male	87.21	125.00	171	49th
4	Employee D	Male	74.17	93.75	171	49th
5	Employee E	Female	68.65	91.19	165	35th
6	Employee F	Male	57.97	81.08	174	46th
7	Employee G	Male	46.62	85.96	167	53th
8	Employee H	Male	59.70	101.69	179	41th
9	Employee I	Male	82.42	112.78	171	49th
10	Employee J	Female	49.92	60.00	151	39th
11	Employee K	Male	90.36	93.90	182	38th
12	Employee L	Male	59.46	119.52	192	28th
13	Employee M	Female	103.45	106.01	170	30th
14	Employee N	Male	78.02	96.77	197	23th

Based on Table 1, we can give an example of Employee C with a calculated DNI of 87.21 beats/minute and a calculated DNK of 72.73 beats/minute with an age of 49 years and getting a maximum pulse rate of 171. The following is an example of calculating the resting, working, and maximum pulse rates of Employee C.

$$\text{Resting Pulse Rate (pulses/minute)} = \frac{10 \text{ pulse}}{\frac{\text{calculation}}{\text{time}}} \times 60 \quad (1)$$

$$\text{Resting Pulse Rate} = \frac{10 \text{ pulse}}{6.88} \times 60 = 87.21 \textit{ beats/minutes}$$

$$\text{Working Heart Rate (pulses/minute)} = \frac{10 \text{ pulse}}{\frac{\text{calculation}}{\text{time}}} \times 60 \quad (2)$$

$$\text{Working Heart Rate} = \frac{10 \text{ pulse}}{4.80} \times 60 = 125 \text{ beats/minute}$$

Next, after obtaining the employee's working and resting heart rate, the employee's maximum heart rate is determined using the formula 220 for men and 200 for women minus the employee's age, the following will be exemplified for Employee C [2].

$$\text{Maximum Heart Rate} = \text{std male } 220 - \text{Age} \quad (3)$$

Maximum Heart Rate= 220-49 years = 171 beats/minute

Next, after obtaining DNK, DNI, and DNK Max, determine the employee's %CVL. The assessment of the workload level classification cannot be directly determined from the percentage of cardiovascular load (%CVL). The %CVL value is calculated based on the workload classification level based on the increase in the work pulse rate that has been determined as follows [3].

So it can be concluded that the level of fatigue or disturbance felt by employees is based on the %CVL

obtained according to the classification/criteria that have been set in Table 1. Furthermore, the %CVL of each employee is determined by using the calculation example for Employee C based on the following formula.

$$\%\text{CVL } (\textit{Cardiovasculer Load}) = \frac{\text{DNK-DNI}}{\text{DNK Maxs-DNI}} \times 100 \quad (4)$$

$$\%\text{CVL } (\textit{Cardiovasculer Load}) = \frac{125.00\text{-}87.21}{171\text{-}87.21} \times 100$$

$$\%\text{CVL } (\textit{Cardiovasculer Load}) = 45.10\%$$

The calculation of the pulse rate that has been obtained in the data processing will describe the %CVL which will show whether the employee is experiencing fatigue at work or not, with the provision that the employee needs further action for the work he is experiencing or not. The following is a description of the %CVL of TPM (Total Productive Maintenance) and AFR (Alternative Ruel and Raw Material) Employees of PT Semen Padang (Fig. 1).

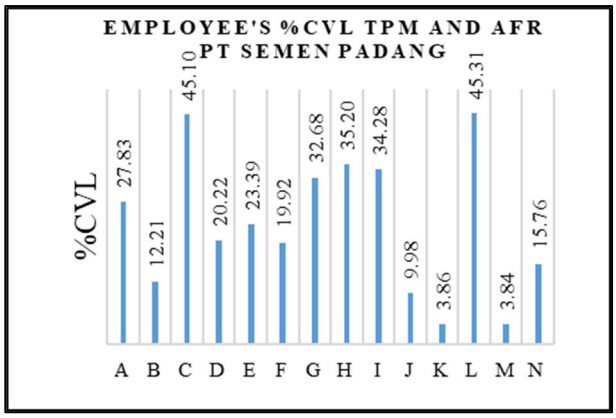

Fig. 1. %CVL of TPM and AFR employees of PT Semen Padang (source: PT Semen Padang)

Based on Fig. 1, we can conclude that in this study when all data has been collected, then we can determine the %CVL of the operators who work. The results of the % of employees who are classified as safe or do not experience fatigue at work are Employee A, Employee B, Employee D, Employee E, Employee F, Employee J, Employee K, Employee M, Employee N. The 9 employees did not experience fatigue at work due to the %CVL produced by less than 30%. While for Employee C, %CVL reached 45.10%, Employee G reached 32.68%, Employee H reached 35.20%, Employee I reached 34.28%, and the last Employee L with the highest percentage reached 45.31%. The value or % indicates that the operator needs improvement and must be followed up, for a more specific % can be seen in the data processing in Table 1.

Based on the research conducted by the researcher, there are 5 employees or operators who need further improvement for smooth work, consisting of Employees C and G who come from TPM, and Employees H, I, and L come from AFR. Seen from the high physiological load reaching 45.31%, this certainly occurs due to the age and very limited working time of the operator, which causes physical conditions to decline. The difference in the results of the physical workload of employees is due to age, physical factors, and uneven division of labor. So, it is necessary to add employees so that the gap and physical condition of employees do not decrease. This has also been revealed by Silvia, where there are 3 workers in the range of 30% - 60% and 3 other workers in the range of 60% - 80%, Silvia said that age factors and uneven work are factors that cause operator fatigue to occur [3].

The workload felt by the operators can be known to have a value that is not small. Therefore, improvements need to be made to reduce the workload. Before the work improvements are made, an analysis of the causes of the operator's workload is carried out using the Fishbone Diagram. The following (Fig. 2) are the results of the analysis.

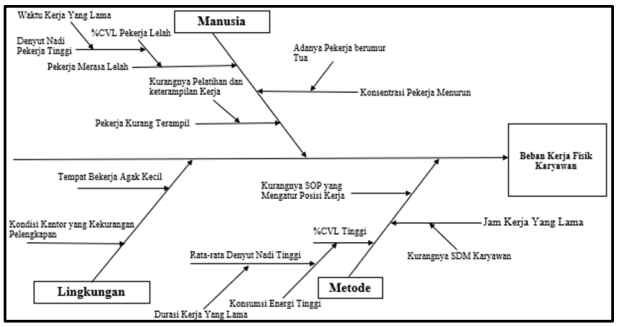

Fig. 2. Fishbone diagram of physical workload

Figure 2 above shows the results of the analysis of the causes of high operator workloads seen from several factors, namely humans, environment, machines, and methods. The first factor is the human factor which has 3 causes, namely long working hours which make workers' pulse rates high and workers' CVL% high which causes workers to feel tired, lack of job training which results in workers being less skilled, and there are older workers which causes concentration to decrease. The second factor is the method which has 3 causes, namely there is no SOP that regulates work positions, too long work duration makes the average pulse rate high and high energy consumption which results in high CVL%. From all the causes, the results of the calculation of Employee C's CVL% are 45.10% and Employee L's CVL% 45.31% which really need additional rest time.

3.2 NASA-TLX processing and analysis

Next is to do mental processing based on the NASA-TLX method. The data taken is obtained based on a questionnaire distributed to employees. This questionnaire consists of 2 parts, namely the weighting and rating sections for each indicator. The weighting attached to the questionnaire is in pairs of 15 pairs. The ratings presented are given a range between 0 and 100 which are guided by 6 indicators, including Mental Demand (MD), Physical Demand (PD), Temporal Demand (TD), Own Performance (OP), Frustration (FR), Effort (EF).

The calculation is done to obtain the WLL (Weighted Workload) value. Based on the WWL value obtained, we will get a conclusion of the mental workload experienced by TPM and AFR employees of PT Semen Padang. First, we must add up the weighting of 14 respondents, then the results obtained will be summarized for each indicator. The data obtained from the results of the indicator comparison can be seen in Table 2.

Table 2. Comparison of TPM and AFR employee indicators

INDICATOR	RESPONDENT													
	EMPLOYEE TPM							EMPLOYEE AFR						
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
MD (Mental Demand)	4	1	3	1	3	1	1	2	1	2	5	3	4	2
PD (Physical Demand)	0	3	4	2	5	2	3	4	3	2	2	4	1	2
TD (Temporal Demand)	4	2	3	4	2	3	4	2	1	3	3	1	3	1
OP (Own Performance)	3	3	2	3	3	1	4	3	2	5	3	3	4	3
EF (Effort)	3	3	3	5	2	5	3	3	3	3	2	4	3	4
FR (Frustration)	1	3	0	0	0	3	0	1	5	0	0	0	0	3
TOTAL	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**

Based on Table 2, we can see that the indicator that is slightly chosen by each TPM and AFR employee of PT Semen Padang is FR (Frustration). While the other indicators are almost completely filled. After making a comparison, employees will fill in the rating of the 6 indicators with a value range from 0 to 100. Employees will fill in according to the conditions when they work or the actual situation. The results of the calculation can be seen in Table 3 as follows.

Table 3. Results of TPM and AFR employee ratings

INDICATOR	RESPONDENT													
	EMPLOYEE TPM							EMPLOYEE AFR						
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
MD (Mental Demand)	70	80	85	15	45	40	90	40	45	75	80	70	70	60
PD (Physical Demand)	40	80	20	15	45	40	90	40	55	55	80	30	80	50
TD (Temporal Demand)	70	70	75	15	40	70	70	35	55	80	75	70	80	60
OP (Own Performance)	100	85	85	15	60	80	100	70	75	90	90	70	100	80
EF (Effort)	60	90	85	15	65	60	70	70	35	75	80	50	80	80
FR (Frustration)	40	85	75	15	40	70	80	30	40	70	80	40	40	70
TOTAL	**380**	**490**	**425**	**90**	**295**	**360**	**500**	**285**	**305**	**445**	**485**	**330**	**450**	**400**

Table 3 shows that the value or in general the total sum of the indicators obtained, namely Employee G, was obtained for the employee amounting to 500. While the one who got the lowest value was Employee D, which was 90. While for TPM employees with the highest rating is Employee G with a rating of 500, while for AFR it was obtained by Employee K with a rating of 485. For the highest rating value in general, it is 100 and the lowest rating is 15. After getting the value, the next step is to calculate the Weight Work Load (WWL). This value is obtained by multiplying the rating that has been obtained by the comparison weight on each indicator. Then add up each indicator value. The following are the results of multiplying the indicator comparison data and the rating value in Table 4.

Table 4. Multiplication of indicators and employee WWL

INDICATOR	RESPONDENT													
	EMPLOYEE TPM							EMPLOYEE AFR						
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Mental Demand	280	80	255	15	135	40	90	80	45	150	400	210	280	120
Physical Demand	0	240	80	30	225	80	270	160	165	110	160	120	80	100
Temporal Demand	280	140	225	60	80	210	280	70	55	240	225	70	240	60
Own Performance	300	255	170	45	180	80	400	210	150	450	270	210	400	240
Effort	180	270	255	75	130	300	210	210	105	225	160	200	240	320
Frustration	40	255	0	0	0	210	0	30	200	0	0	0	0	210
TOTAL	**1080**	**1240**	**985**	**225**	**750**	**920**	**1250**	**760**	**720**	**1175**	**1215**	**810**	**1240**	**1050**

Based on Table 4, the results obtained with the highest value are Employee G with a value of 1250 who is a TPM employee, while for AFR employees it is Employee K which is 1215, and the smallest value obtained for TPM employees is Employee D with a value of 225, while the smallest value for AFR employees is 720 for Employee I. These results are obtained by adding up the results of the multiplication of the six indicators. The multiplication of indicators and rating values for Employee C is as follows.

Nilai WWL = ∑Rating x Weight (5)
Mental Demand (MD) = 3 x 85 = 255
Physical Demand (PD) = 4 x 20 = 80
Temporal Demand (TD) = 3 x 75 = 225
Own Performance (OP) = 2 x 85 = 170
Effort (EF) = 3 x 85 = 255
Frustration (FR) = 0 x 75 = 0

The value obtained will be continued by calculating the average WWL. This value is obtained by dividing the WWL by the total weight. The following are the results obtained.

Table 5. Average WWL

INDICATOR	RESPONDENT													
	EMPLOYEE TPM							EMPLOYEE AFR						
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
MD (Mental Demand)	18.7	5.3	17.0	1.0	9.0	2.7	6.0	5.3	3.0	10.0	26.7	14.0	18.7	8.0
PD (Physical Demand)	0.0	16.0	5.3	2.0	15.0	5.3	18.0	10.7	11.0	7.3	10.7	8.0	5.3	6.7
TD (Temporal Demand)	18.7	9.3	15.0	4.0	5.3	14.0	18.7	4.7	3.7	16.0	15.0	4.7	16.0	4.0
OP (Own Performance)	20.0	17.0	11.3	3.0	12.0	5.3	26.7	14.0	10.0	30.0	18.0	14.0	26.7	16.0
EF (Effort)	12.0	18.0	17.0	5.0	8.7	20.0	14.0	14.0	7.0	15.0	10.7	13.3	16.0	21.3
FR (Frustation)	2.7	17.0	0.0	0.0	0.0	14.0	0.0	2.0	13.3	0.0	0.0	0.0	0.0	14.0
TOTAL	72	82.7	65.7	15.0	50.0	61.3	83.3	50.7	48.0	78.3	81.0	54.0	82.7	70.0

Table 5 explains that the highest WWL value or average WWL value was obtained by Employee G with a value of 83.3 for TPM employees, and Employee M obtained a WWL of 82.7 for AFR Employees. The lowest WWL value for TPM employees was found in Employee D, only 15.00, while for AFR employees it was found in Employee H, which was 50.7. The following is an example of calculating the average WWL value for Employee E.

$$\text{Average WWL} = \frac{\text{Nilai WWL}}{\sum \text{Botot}} = \frac{750}{15} = 50 \quad (6)$$

After getting the WWL value, we will interpret the score obtained by each employee using the score interpretation table. This is as explained by Hart and Staveland [4] in their book explaining the theory and basics of NASA-TLX, along with the interpretation of mental workload by NASA-TLX.

Table 6. Workload categories

Workload Class	Value
Low	$0 \leq x \leq 9$
Medium	$10 \leq x \leq 29$
Slightly High	$30 \leq x \leq 49$
High	$50 \leq x \leq 79$
Very High	$80 \leq x \leq 100$

Table 6 shows the scores and range of assessments in WWL for NASA-TLX consisting of 5 categories, namely low, medium, rather high, high, and very high. For the range of values, we can see in the table. So from the WWL results obtained, it is stated that the category scores for TPM and AFR Employees of PT Semen Padang are as follows.

Table 7. Mental workload assessment categories

	No	Respondent	Nilai Beban Kerja	Golongan Beban Kerja
EMPLOYEE TPM	1	Employee A	72.00	(K.A) High
	2	Employee B	82.67	(K.B) Very High
	3	Employee C	65.67	(K.C) High
	4	Employee D	15.00	(K.D) Medium
	5	Employee E	50.00	(K.E) High
	6	Employee F	61.33	(K.F) High
	7	Employee G	83.33	(K.G) Very High
EMPLOYEE AFR	8	Employee H	50.67	(K.H) High
	9	Employee I	48.00	(K.I) Slightly High
	10	Employee J	78.33	(K.J) High
	11	Employee K	81.00	(K.K) Very High
	12	Employee L	54.00	(K.L) High
	13	Employee M	82.67	(K.M) Very High
	14	Employee N	70.00	(K.N) High

Based on Table 7, we can see that for employees who get a very high workload, there are 4 people, namely Employee B, G who are TPM employees and Employee K, and M who are AFR employees. For employees who get a high mental workload, there are 8 people, namely Employees A, C, E, F, they are employees from the TPM

unit and Employees H, J, L, and N who are AFR employees. For the rather high one, it is obtained by Employee I who is an AFR employee, while for TPM employees with a rather high workload group, there are none, and the moderate category is only Employee D and that is a TPM employee and for AFR with this group there is none. While the category that gets a low mental workload does not exist.

Based on the information attached in Table 7, we have obtained the mental workload values of 14 TPM and AFR employees of PT Semen Padang. Hart and Staveland [5] in their book entitled Development of NASA-TLX (Task Load Index Results of Empirical and Theoretical Research. In Human Mental Workload), the values obtained in the mental workload category that really need to be considered are workloads with a value range of 80-100. However, in addition to employees with very high performance, also pay attention to employees whose performance is almost in the very high (high) category, and so on. While in this study there were several employees whose recapitulation of mental workload results reached almost 80 and even exceeded 80. To make it clearer, Fig. 3 shows a description of the mental workload classification of TPM and AFR employees of PT Semen Padang.

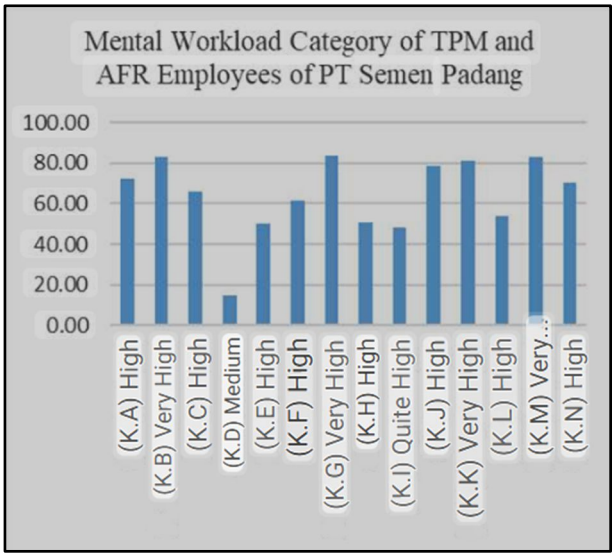

Fig. 3. Mental workload category of TPM and AFR employees of PT Semen Padang (source: PT Semen Padang)

Next, AFR Employees, for AFR with a very high category, there are more than TPM, namely Employees K, and M, then I with a fairly high category. Employee K is one of the AFR employees who is tasked with checking waste and office performance, as well as Employee M who is an employee who is more often in the field or in field checks. Then Employee I, with a fairly high category, the constraints are almost similar to Employee G, due to their increasingly advanced age and being given authority as a leadership staff and must be good at dividing between field and office performance, Employee I is also authorized to check the waste that is processed. The rest are employees with a high mental burden category, but high performance also requires further handling so that a company's performance runs smoothly, for employees with this high category have the same constraints where they have to divide between work in the field and work in the office.

A different thing was shown by employee D who is a TPM employee in the Innovation field, the employee is in the moderate mental workload category, this happened because based on the research that has been done, the job is a suitable job for him, so the employee feels that the mental workload he feels is only a little. In order for the indicators that influence the employee's work to be more clearly visible, here is the percentage of each indicator which can be seen in Table 8.

Table 8. % Overall indicators

INDICATOR	Total Score	%
MD (*Mental Demand*)	2180	16
PD (*Physical Demand*)	1820	14
TD (*Temporal Demand*)	2235	17
OP (*Own Performance)*	3360	25
EF (*Effort*)	2880	21
FR (*Frustation*)	945	7
TOTAL	13420	100

Table 8 we can see that the indicator with the largest percentage is performance with a percentage of 25%, slightly different from Effort at 21%, then 17% for Temporal Demand, 16% for Mental Demand, 14 for Physical Demand, and mental workload with the smallest percentage, namely Frustration with a percentage of 7%. Furthermore, to make it clearer, here is a comparative description of the percentage of indicators that affect the mental workload of TPM and AFR employees of PT Semen Padang. The following is a Fishbone Diagram of the mental workload that has been obtained from the analysis of the case above which aims to find the problems that occur in the case.

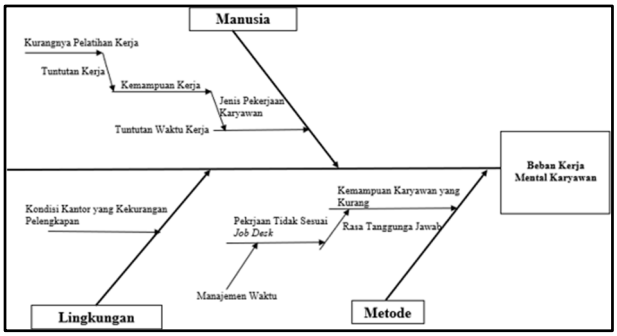

Fig. 4. Mental workload fishbone

Based on Fig. 4, the results of the analysis of the causes of high operator workload are seen from several factors, namely humans, environment, machines, and methods. The first factor is the human factor, which has 3 causes, namely long working hours that make employee workloads high, including methods, humans, and the environment. The first factor, namely the method, shows that the ability, sense of responsibility and work that are

less in accordance with employees will damage time management. Furthermore, the human factor, with many work demands and reduced training will make the mental workload of employees high. Third, namely the environment where in the office the equipment to carry out office activities is still reduced will decrease employee performance and increase workload. So that the improvement that can be done is to provide training so that employees can work optimally.

4 Conclusion

Based on the data processing and analysis that has been done, we can conclude that there are 5 employees or operators who need further improvement for work to run smoothly in physical workload, consisting of Employees C and G from TPM, and Employees H, I, L from AFR. Furthermore, the mental workload using the NASA-TLX method of TPM and AFR employees of PT Semen Padang tends to be high, consisting of 4 TPM employees with a high category, 4 AFR employees with a high category, the rest with a very high category by 2 TPM employees and 2 AFR employees, 1 AFR employee with a rather high category and 1 TPM employee with a moderate category, which is based on the most influential mental workload indicator, namely performance. So it is stated that, AFR and TPM employees with physical workload categories based on % Cardiovascular Load are supervisors and AFR field employees, namely Employee L. Employees with the highest mental workload are the TPM innovation leadership staff, namely Employee B. Based on this conclusion, improvements that can be proposed are by requiring effective time division and adding employees to weigh employees who have exceeded the limit in the job. Then sufficient training is needed so that employee potential development can be developed in their work.

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