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NASA-TLX Assessment of Mental Workload in Manufacturing Industry

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ABSTRACT

Mental workload assessment is essential for the optimal interaction of human system in the manufacturing industry. Manufacturing industry engaged in the construction, maintenance, and fabrication service. Performance of the worker will be lower if the higher workload. In the manufacturing industry are two type of workers that mainly involved in the fabrication process such as operator and welder. In This process was found several defects in the finished good which caused the company to suffer losses. Fatigue due to overtime work for seven days and a high mental workload. The aim of this study was to measure the mental workload in the manufacturing industry. In This study was performed on 10 worker in the operator and welder. Mental workload were assessed using NASA Task Load Index (NASA-TLX) and Fault Tree Analysis (FTA) tools. One operator workers and one of welders belonged to the heavy workload category. Finally, NASA-TLX was significantly higher for operator and welder. High mental workload in the manufacturing industry indicated the defection on mental workload. It is recommended to fixes are evaluating and updating rule work, system work, and existing SOP.

INTRODUCTION

Manufacturing industry is one of the many industries in Indonesia. The manufacturing and construction industries have a large number of injuries in Indonesia (Astuti, et.al, 2022). Higher physical and mental demands such as fatigue, repetitive movements, and awkward body postures are one of the causes of musculoskeletal disorders (MSDs). There are three categories of potential problems that require clinical attention for the occurrence of MSDs and mental burden, namely mild cases with care providing advice and guiding employees to adjust workload or activities. The second is giving medicine to employees. The third is by giving time to rest. These disturbances and conditions will delay the production of a company (Mohammadian, et al, 2022; Braarud, 2021; Kerr, P, 2021).

In this study, observations were made in the work area or workshop of some manufacturing industry in Cilegon Indonesia. The company engaged in construction, engineering, and maintenance services but has now offered a more comprehensive range of services in engineering and structural steel

fabrication, and civil construction services. The industry is developing a platform capable of offering multiple suites supported by local-based management, administration, and offsite resources to ensure the timely completion of the most demanding contracts. Various activities were carried out in this area, such as making poles for construction, providing fire extinguishers and various machine tools, welding various pipes, loading goods, and others

Several problems were found such as low work time efficiency, uncomfortable working conditions, a limited number of workers, inaccuracy when measuring products for fabrication, and others. This impacts the low efficiency of time-related to the delivery of goods, procurement of rework for fabricated products, and the frequent holding of overtime hours, which is very risky for workers and can cause losses for the company. It was found that these problems were related to human error caused by the existing workload.

In addition, based on historical data, when the number of projects received is too large, the number of existing defective products also increases. For example, in December 2021, the number of projects received was three, and two units of defective products were found. However, from January-February 2022, the number of accepted projects increased to 5-6. it makes the number of defective products increase to 5-6 units. Many say that the work is quite heavy in these two months because the number of projects received is higher than in the previous months. Some of them also said that the workload they received was large enough to cause stress because they had to be able to manage time to meet the demands of each project.

Therefore, researchers are interested in measuring how much mental workload is experienced by workers, especially in the workshop area, then analyze what factors affect the perception of the value of workload and provide recommendations for improvements to the work system, work rules, and Standard Operating Procedures (SOP), which exists. Companies need to measure mental workload to determine their workers' ability to minimize the existing mental workload. To achieve this, we need a way to calculate the mental workload of the worker. Several well-known methods are commonly used to measure mental workload, one of which is the National Aeronautics and Space Administration Workload Index (TLX) method or what we often know as NASA-TLX. The method was developed in 1981 by Sandra G. Hart of NASA's Ames Research Center and Lowell E. Stavland of San Jose State University. This method is a questionnaire developed to answer the need for a subjective workload measurement that is simpler but sensitive to workload measurement. There are six dimensions of mental workload in this method, namely Mental Demand (MD), Physical Demand (PD), Temporal Demand (TD), Performance (PO), Effort (EF), and Frustration (FR).

RESEARCH METHOD

NASA TLX

Nasa-TLX is a method of subjectively to measuring mental workload (Galy, Paxion, & Berthelon, 2018). This method method was first proposed in 1981 by Sandra G. Hart and Lowell E. Staveland, representatives from NASA Ames Research Center and San Jose State University. The target will answer a questionnaire created in response to the need for a more accessible and more sensitive subjective workload measurement. So, it can be concluded that NASA-TLX is a method of analyzing mental workload that uses a questionnaire as a medium to ask several issues regarding the things that most affected work. NASA-TLX is equipped with six mental stress indicators like mental demand, physical demand, temporal demand, performance, effort and frustration level. The following explains the six indicators (Putri, 2017).

Table 1. NASA-TLX Indicators

Dimension	Scale
Mental Demand (MD) Is there a minimum level of mental activity and perception required for this job? (e.g., decide, search, count, see, remember). Depending on the circumstances, the work is light or heavy, simple or complex, loose or tight.	Low - High
Physical Demand (PD) How much physical activity is needed for this job (e.g., pushing, pulling, twisting, maneuvering, running)? Is the job easy or difficult, slow or fast, calm or urgent?	Low - High
Temporal Demand (TD) How does it feel to work under time pressure? Does the job feel slow and comfortable, or fast and tiring?	Low - High
Performance (PO) How successful is the work in achieving the goals? How satisfied is the performance in achieving the goals?	Low - High
Effort (EF) How much effort in mentally and physically to reach the best level of performance?	Low - High
Frustration level (FR) How frustrated, stressed, and disturbed about safety, appropriateness, comfort, and satisfaction are felt at work?	Low - High

The first step is to calculate the value of each aspect by multiplying the rating value by the indicator weight.

$$Aspect\ Value\ =\ Rating\ x\ Indicator\ Weight$$

After calculating the value of each aspect, calculate the weighted workload (WWL) value by adding up all the aspect values.

$$WWL\ = \Sigma\ Aspect\ Value$$

Then, calculate the NASA-TLX score by dividing the resulting WWL value by the total weight of the data set.

$$Score\ =\ WWL/15$$

After obtaining the NASA-TLX score, the score will be classified where if the score is <50, it is considered mild. If the score is 50-80, it is considered moderate. Lastly, if scores >80, it is considered severe.

Fault Tree Analysis (FTA)

Fault Tree Analysis (FTA) is a top-down problem analysis method used to detect and evaluate events and event combinations that cause system failures or unexpected component appearances (Ardiansyah & Wahyuni, 2018). FTA uses logical symbols to indicate failures in the system and logical relationships between failures. The deductive analysis is carried out by identifying the disturbance (undesirable event) and then relating the error (undesired event) to all possible events that can cause impairment (Khare, Nema, & Baredar, 2019). So, we can conclude that FTA is a type of deductive analysis in which the graphs are created to identify and analyze the possible damage that occurs now and in the future. The analysis will reveal all events and their causes, from the earliest to the most frequent. In this case, deductive analysis is used in the FTA to determine the causal relationship of an event in the system. There are five steps to performing a Fault Tree Analysis (FTA) analysis. (Nur & Ariwibowo, 2018):

a. Define the problem and limitation from reviewed system
b. Graphical model depiction of Fault Tree

c. Determine the minimum cut set of analysis Fault Tree
d. Doing analysis qualitative from Fault Tree
e. Doing analysis quantitative from Fault Tree

RESULTS AND DISCUSSION

The following is table 2, which contains the WWL calculation of *operator* workers and *welder workers*. No 1-4 show results in evaluation from *operator* workers while no 5-10 shows the result evaluation of workers showing *welder.*

Table 2. Results of WWL

No	Worker	Aspect	Rating	Weight	Rating* Weight	WWL	SCORE
1	Darmini	MD	50	3	150	1005	67.00
		PD	65	1	65		
		TD	70	4	280		
		PO	75	4	300		
		EF	70	2	140		
		FL	70	1	70		
2	Junaidi	MD	80	2	160	1226	81.73
		PD	90	3	270		
		TD	76	1	76		
		PO	80	4	320		
		EF	85	4	340		
		FL	60	1	60		
3	Sawiri	MD	70	1	70	1116	74.40
		PD	80	3	240		
		TD	57	2	114		
		PO	78	4	312		
		EF	80	3	240		
		FL	70	2	140		
4	Asrul Muhito	MD	75	4	300	1035	69.00
		PD	50	2	100		
		TD	70	3	210		
		PO	75	3	225		
		EF	50	1	50		
		FL	75	2	150		
5	Zet Elwan Majid	MD	50	3	150	1045	69.67
		PD	75	1	75		
		TD	70	4	280		
		PO	85	2	170		
		EF	80	4	320		
		FL	50	1	50		
6	Danik Kriswanto	MD	70	3	210	1120	74.67
		PD	80	3	240		
		TD	80	1	80		
		PO	75	4	300		
		EF	80	2	160		
		FL	65	2	130		
7	Arif Eka Pratama	MD	65	2	130	1211	80.73
		PD	80	3	240		
		TD	76	1	76		
		PO	85	5	425		
		EF	85	4	340		
		FL	64	0	0		
8	Nur Achmad Syarifudin	MD	70	3	210	1155	77.00

No	Worker	Aspect	Rating	Weight	Rating* Weight	WWL	SCORE
		PD	75	3	225		
		TD	70	1	70		
		PO	75	3	225		
		EF	85	5	425		
		FL	25	0	0		
9	M. Habib Ainun Sodri	MD	70	2	140	1155	77.00
		PD	75	4	300		
		TD	85	3	255		
		PO	70	1	70		
		EF	70	1	70		
		FL	80	4	320		
10	Setyo Adi	MD	75	3	225	1010	67.33
		PD	50	3	150		
		TD	60	1	60		
		PO	75	2	150		
		EF	75	5	375		
		FL	50	1	50		

To ensure that NASA TLX scores generated deserve and get used in research, extreme data will be discarded and not entered in the calculation next (Restuputri, Febriansyah, & Masudin, 2022). With k (level confidence) around 95% or k = 2, obtained the Upper Control Limit and Lower Limit Control value.

$$\text{Upper Limit Control } (UCL) = \bar{X} + 2\sigma$$

UCL = 73.953 + 2(5.019)

UCL = 83.992

$$\text{Lower Limit Control } (LCL) = \bar{X} - 2\sigma$$

LCL = 73.953 – 2(5.019)

LCL = 63.915

Figure 1 shows the map graph control for value NASA TLX scores. From the graph, we can see if there is score Nasa-TLX score that exceeds the control limit or not. If no NASA TLX score exceeds the Upper Control Limit (UCL) or Lower Control Limit (LCL), the data is declared uniform and tests the data uniformity.

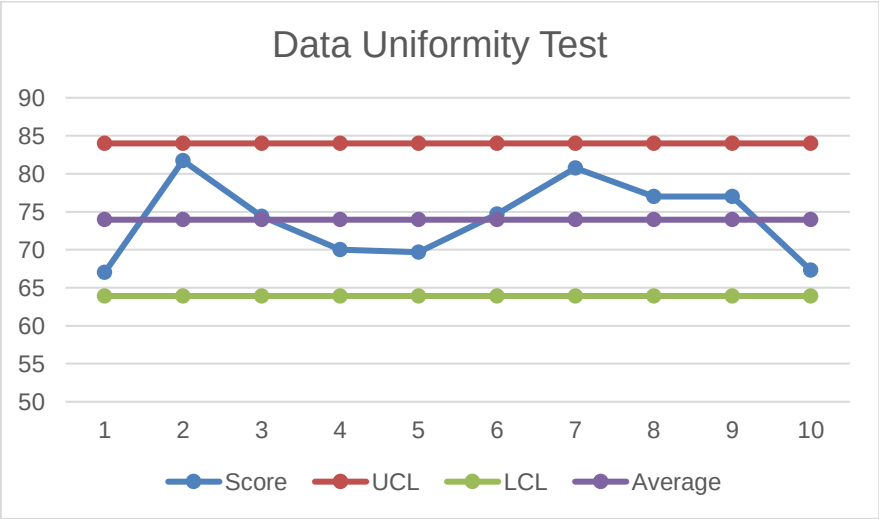

Figure 1. Graph of Data Uniformity Test

The data adequacy test is intended to ensure that the data obtained is feasible and can be used in research. Following degrees of trust and accuracy are certain (Restuputri, Febriansyah, & Masudin,

2022) To set how many amounts of proper observations were made, moreover formerly set how many levels of trust *(confidence level)* and degree accuracy *(degree of accuracy)* will be used in design measurement. The researcher set score level trust by 95% so that value of k = 2 and degree accuracy by 5% (s). if the score is smaller than the value of N, then the study's data could already be sufficient and pass the data adequacy test. Following is the calculation for knowing the score on research:

$$N' = \left(\frac{\frac{k}{s}\sqrt{N\sum x^2 - (\sum x)^2}}{\sum x} \right)^2$$

$$N' = \left(\frac{\frac{2}{0.05}\sqrt{(10 \text{ x } 54942.9) - (739.53)^2)}}{739.53} \right)^2$$

N' = 7.37

From the calculation, we could see that N' < N. This indicates that the data obtained from results observation is enough or passed from data adequacy test.

Table 3 shows the classification type workload on the illustrative NASA-TLX score perception of the workload experienced by ten workers (operators and *welders)* in the workshop area belonging to PT XYZ. Green signifies category low, orange indicates category medium, and red signifies category heavy.

Table 3. Classification of Workload of Workers

No	Worker	Score	Classification
1	Darmini	67.00	Medium
2	Junaidi	81.73	Heavy
3	Sawiris	74.40	Medium
4	Asrul Muito	70.00	Medium
5	Zet Elwan Majid	69.67	Medium
6	Danik Kriswanto	74.67	Medium
7	Arif Eka Pratama	80.73	Heavy
8	Nur Achmad Syarifudin	77.00	Medium
9	M. Habib Ainun Sodri	77.00	Medium
10	Setyo Adi	67.33	Medium

Based on the NASA-TLX score data in table 3, it can be seen that from 4 operators, there is one worker classified as a type of heavy workload, and from 6 *welders,* there is one worker classified as a type of heavy workload. The average NASA-TLX score obtained from 10 workers shows that the average workload faced by workers in the workshop area is moderate.

After the calculations, researchers were curious to see if the average ratings given by operators and welders were based on the six NASA-TLX factors (operating load, physical load, temporal load, frustration level, performance, and effort).

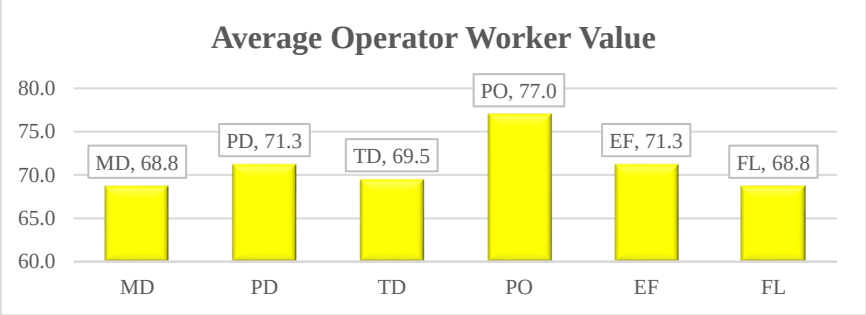

Figure 2. Diagram of Operator Rating Average

Figure 2 shows a comparison rating value owned by operator workers. Based on the diagram, we could see the three most dominating aspects with a rating value reaching more than 70. these Aspects are physical needs with a value of 71.3 then, performance with a value of 77, and level effort with a value of 71.3

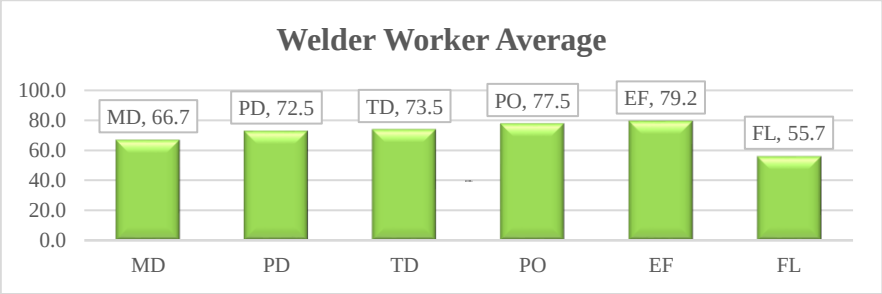

Figure 3. *Welder* Rating Average

Figure 3 shows a comparison rating value owned by *welder* workers. The diagram shows four aspects dominate the most, with rating value reaching more than 70. Aspect these are physical needs with a value of 72.5, then temporal requirement with a value of 73.5, performance with a value of 79.2, and level effort with a value of 79.2.

From the two analyzes, it is concluded that there are four most dominating factors, namely aspects of physical needs, aspects of temporal needs, aspects of performance, and aspects of business level. Furthermore, the four aspects will be analyzed to find out the root causes that make the value of the NASA TLX Score so that improvements can be made in terms of the work system, work rules, and applicable SOPs.

Measure Figure 4 shows the cause analysis of the magnitude of the WWL value obtained in calculating NASA-TLX operator and *welder workers*. Four factors have a high rating value: physical load, temporal load, performance, and level of effort.

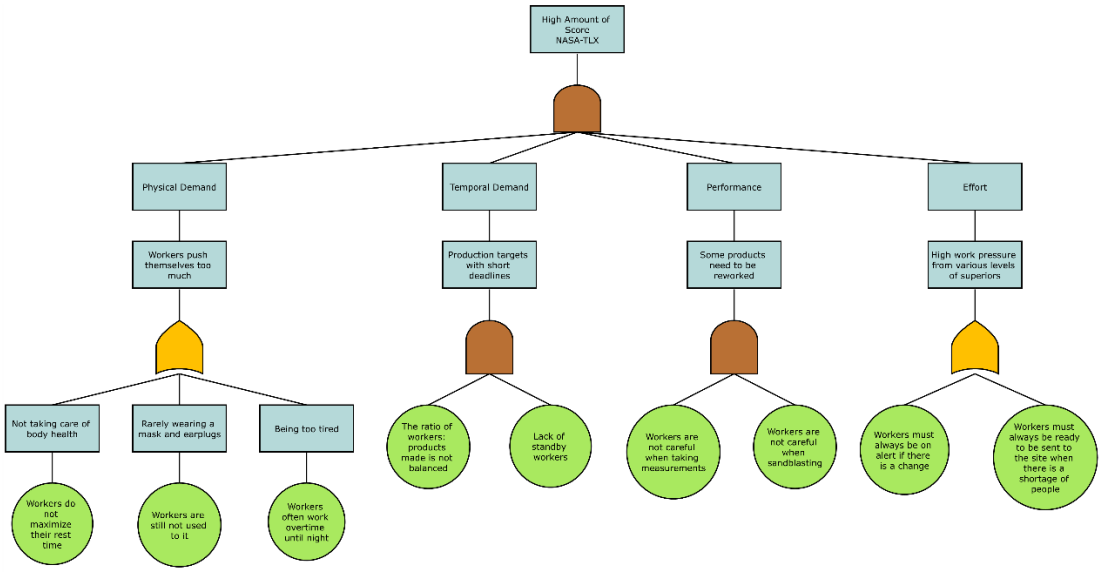

Figure 4. Faut Tree Diagram

Too pushy workers can cause a high rating value on the physical demand aspect. This can occur due to 3 things. First, workers do not take care of their body health because workers do not maximize their rest time and prefer to complete other jobs. Second, workers rarely wear masks because they are not used to them, so they often feel disturbed by dust from the surrounding environment and odors that arise from a series of fabrication processes. Furthermore, workers feel too tired and tired due to frequent overtime due to unfinished work demands.

According to Henry (2020), companies need to ensure that the work provided must align with their competencies and capabilities to create a balanced workload. In this case, the company needs to review the burden physically borne by workers in completing their work. Job rotation can also be done to reduce problems with physical loads by alternating heavy work with light work so that workers can rest for a while. By doing this, it is hoped that problems in the physical load aspect can be resolved.

The high value of the rating on the temporal demand aspect is caused by the production target and the short work deadline. This can happen due to 2 things: first, the ratio of the number of workers to the products made by each worker is still not balanced due to the limited number of existing workers. Secondly, the number of permanent or *standby workers* at the workshop is lacking. Workers are often drawn to the *site* as additional workers, so the production target is not following the initial plan (Sugimoto et.al, 2022; Sanjog, 2019; Van Bogaert et.al, 2010).

According to Rachmuddin (2021), the problem of the temporal load aspect can be overcome by increasing the number of workers. Recruiting more workers can make the ratio between workers and the products they produce become more prominent so that the workload experienced by each worker will decrease. The addition of the number of workers is expected to help in reducing the workload in terms of temporal load.

The high rating value on the performance aspect is caused by the presence of products that need to be re-fabricated / *reworked*. This can occur due to 2 things. First, workers are not careful when measuring raw materials because workers feel tired due to a lack of proper rest time management. Second, workers are not careful during the *sandblasting process*, causing corrosion factors that arise during the *finishing process.*

According to Pradhana & Suliantoro (2018), overcoming the problem of the magnitude of the value of the performance aspect, it can be done by re-management of rest periods. Giving proper rest breaks can improve the performance of a worker. Some so many workers cannot maximize their rest time because their break time is cut off by worship time. Therefore, companies need to readjust their working hours and rest periods to reduce workers' workload and risk perception. In addition, the company also needs to conduct training to encourage workers to be more accustomed to working in quite congested situations so that problems related to the performance aspect they experience can be resolved.

The high rating value on the effort aspect is caused by work pressure for high responsibilities from various superiors. This can occur due to 2 factors. First, workers must always be available when there is a change from their superiors because, in work, especially in construction, orders and requests often change due to differences of opinion from superiors. Second, workers must always be ready to be sent to the *site* as additional workers to cover or *cover* the shortage of workers on other projects so that the effort made for workers in the workshop area will increase (Astuti et.al, 2022; Oyewole, 2010; Sokhibi et.al, 2022; lund et.al, 2021).

According to Pradana (2022 and Mach,2022), project management can be carried out to overcome the high the rating value from the effort aspect. This is done by re-management of the number of projects received against the availability of the existing number of workers. In addition, this project management must also pay attention to the time remaining and the type of request required for each project so that there is no longer a shortage of workers, which results in sudden labor withdrawals. In addition, by re-management, the number of projects and the pressure received by workers can decrease. Workers can maximize their performance against other projects with a high rating value, namely physical burden, temporal load, performance, and level of effort.

Recommendations of the manufacturing industry

System Work (Work Settings)

Here are some aspects related to the work system that can be improved:

- Improve the layout of the workplace to minimize required movements
- Using shelves wheels for professional convenience load or disassemble goods
- Make a handle particular to all goods in packaging or boxes, and others that will lift nor carry,

or determine the part that can be used as a handle.
- While working on objects/goods, carrying, lifting, and so on, avoid movement, bend down, or rotate the waist.
- To avoid fatigue and injury body, those who do the work lift burden heavy, preferably interspersed with light jobs.
- Consult with workers on how to improve working time setting.
- Fix storage arrangement from every work tool.
- Work tools to be maintained and checked regularly.
- Subtract factor vibrations that can affect workers to increase safety, health, and work efficiency.
- Protect workers from weather hot or too cold in the room.
- Ensure tools protector self-acceptable to all workers and tools protector self in-state clean and well maintained.
- Maintain a fixed work area arranged and not some items are not wanted so that could increase comfort and efficiency of workers
- Clarify track evacuation if there is a state emergency
- Train workers to take responsibility answer and allow them to make improvements in the profession they

Rule Work in Organization

Following are recommendations of rule work for PT XYZ workshop area workers:

a. Destination
   1. Explain rights and obligations and ensure legal certainty for the company and employees.
   2. Set working conditions for workers to realize harmonious, safe, steady, and dynamic working relationships.
   3. Increase good relationship and cooperation between the company and workers

b. Wages

Wage strategy company aims to provide Attractive wages to encourage workers to work as expected. System wages are organized and structured in an attractive/competitive manner, with scale wages (*salary range)* that can be described as comparison worker wages in reasonable limit. Principle Remuneration where every worker who does their job will be paid with an equal amount (*equal job equal pay)* must also become true with reasonable.

c. Review Wages
   1. review wages are made at least very in a year. Increase amount and time wages _ depending on the situation Remuneration industry tobacco at that time and the company's capabilities.
   2. Award performance (*merit increase)* will enter in wages. The wage Range will be reviewed according to the situation and conditions.

d. Guarantee During Sick
   1. Deep worker care pain is not a result of work accident and not can do the job up to 6 (six) months consecutively stated with letter description doctor appointed by the company, will accept wages for 6 (six) months.
   2. Supposedly until 6 (six) months, the worker is still permanent in maintenance and has not been able to perform their duties. They can be declared incapable of doing work and get interpreted as not fulfilling position requirements. And the Head of the Company can decide about their working relationship.

e. Working time

Regular working hours will be determined at each place of work following the necessary local operation. The factory's working hours cover 8 hours a day or a maximum of 56 hours per week. The working hours do not include mealtimes, prayer time, and rest time.

f. Workshop Area Working Hours

Monday - Saturday : 07.30 - 16.30 WIB

g. Overtime

1. Overtime work is carried out by workers who exceed the usual working time on weekdays or professions that work in hours/ days rest or day holiday official. Overtime work is done on orders by the worker's supervisor, who is authorized and approved by the worker.
2. Overtime work is not a must, except in urgent matters as follows:
   a) If profession no things resolved soon, that will result in a loss significant against the Company, State, or society.
   b) An in-state emergency, for example, fire, explosion, flood, or another calamity.
3. Wage payment overtime will be combined with weekly wage payments

h. Overtime Rates

If the working time on the day regular set 8 hours a day and six days within one week, the following method calculates wages overtime:

a) If overtime work is done after regular working hours:
   1) 1.5 times wages hourly for overtime hours first.
   2) Two times hourly wages for overtime hours afterward.
b) When working overtime on the day weekly break and or day holiday official:
   1) For the first hour until the eighth hour of 1.5 times wages hourly.
   2) The ninth hour onwards is two times the wages hourly.

i. Safety

a) *Safety Requirements*
   1. Mandatory workers use PPE standards such as helmets, safety shoes, glass safety, and uniform.
   2. Mandatory workers use additional PPE such as glass safety, gloves welding hand, protector face, welding mask, and stopper ear.
   3. When working at work temperature high and hot, mandatory workers prepare tool safety such as net safety, lifeline, protection fire, and tool extinguisher.
b) *Safety Sign Board*
   1. Mandatory workers prepare board sign safety when work to remind everyone in the workshop area as needed.
c) *First Aid Need*
   1. Mandatory worker check is the first aid kit has complete contents
   2. Mandatory workers each other provide information about the position of the box help first
   3. Every worker must give first help to the other if an incident occurs
d) *Disposal & Rubbish Boxes*
   1. Mandatory workers prepare and make box disposal trash and place it as needed.
   2. Mandatory workers give a sign to all box trash according to type rubbish
   3. Workers must throw away all trash regularly _ from the workshop area
e) *Safety performance board*
   1. someone who has chosen to become a *leader* must prepare and make a design *safety performance board* for education and ingredients evaluation.

Standard Operating Procedures (SOPs)

The following are SOP recommendations for the PT Cipta Muslia Semesta workshop area:

a) *Welder*

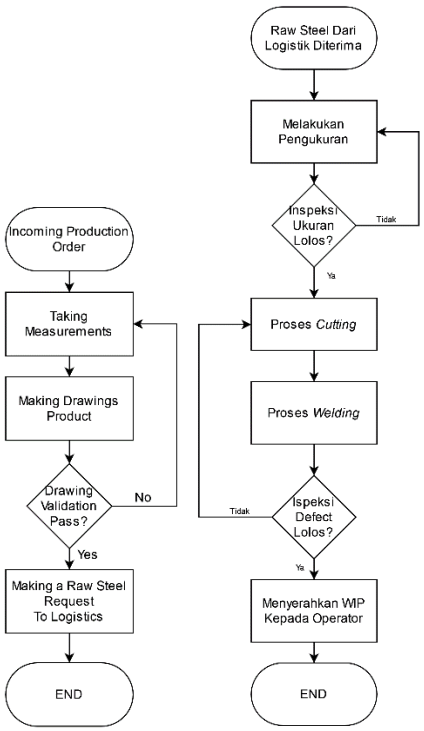

Figure 5. SOP Welder

b) *Operator*

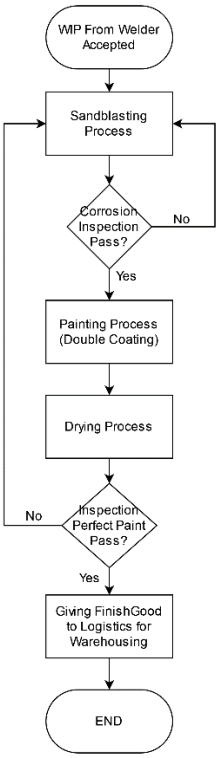

Figure 6. SOP Operator

CONCLUSION

Conclusions that can be taken study burden mental work using the NASA-TLX method in the workshop area at PT XYZ. The average value WWL score earned from results data collection will perception burden mental work experienced by operators and welders in the workshop area is 73.85. 1 in 4 operators includes burdening work weight in the category, and the rest in the category burden work medium. Of the six welders observed, one person has a burden work weight, and the rest belong to the category medium. Four factors have been founded that cause big NASA TLX scores on workers operator or welder: physical demand, temporal demand, performance, and effort. The Fault Tree Analysis (FTA) found nine root causes related to big score NASA TLX scores. There are many workers not maximizing time rest, workers still not yet used to wear a mask, too much overtime, ratio worker with the product made not balance, lack amount standby worker, a worker not careful enough when do measuring, a worker not careful enough during the sandblasting process, workers must ready standby to change sudden, workers must always ready sent to the site when a shortage of people occurred. Possible fixes are evaluating and updating rule work, system work, and existing SOPs.

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