Redesigning the work system of rubber industries based on total ergonomics and ergo-micmac integration

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Abstract: The factory capacity achievement and the bottleneck reduction of production process at wet-blanket workstations are influenced by the balance of life quality rates and worker’s productivity, along with the worker’s ability and limitations, tasks, organization and work environment. The life quality of workers is indicated by: the reduction of workload, and fatigue. Meanwhile, work productivity is measured by increasing production results per work shift. The optimization of the quality of life and productivity of workers is achieved by redesigning the system and workstations based on ergonomics integrating Total Ergonomics with Ergo-MicMac (Micro Ergonomics and Macro Ergonomics), which includes redesigning wet-blanket folding worktable, regulating the system pattern of working in pairs, giving official break time, giving extra nutritious intakes such as sweet tea and snack Pempek, giving personal protective equipments, and redesigning physical working environments. This study was an experimental study, with treatment by subject design involving 30 workers sampled at a workstation condition before and after Ergonomics based redesign. The findings and conclusions of the study were derived from the reduction of the workload by 16.06%, fatigue by 18.84% and the increase of production results per work shift by 20.29%.

1. Introduction
Redesigning work system at rubber industries is becoming a requirement in order to optimize the factories’ productivity by synchronizing the industrial development technology innovation roadmap of rubber-raw materials in South Sumatera. This redesigning process is occurred by considering the aspects of Micro Ergonomics and Macro Ergonomics (Ergo-MicMac) integrated with Total Ergonomics impacting on ENASE (effectiveness, convenience, safety, health, and efficiency).

The output of work system production of wet blanket workstation at one of the rubber industries in South Sumatera, MK 2 Factory, has not been able to fulfill the input requirements of a good crumb rubber workstation, for wet-blanket workstation is yet dominated by a manual work system. Some work facilities of wet-blanket workstation are breaker machines, hammer mill, 5 creeper machines for wet-blanket making, ten wet-blanket folding tables, a pipeline hose called Salangan, and a manually maintained trolley. Then the wet blankets having been weighed are spread out in a room to dry. The installed production capacity of the crumb rubber factory is 150,000 tons per year. In 2014, the production is just 85.97% of the installed capacity[1] [2]. Therefore, the production in wet blanket workstation should be accelerated for the balance between the production acceleration of the creeper machine and the necessity of the crumb rubber workstation,

The production process is generally: the rubber-processed materials from the stocks which are processed in the breaker machine, in the cleaning machine, and in fine hammer mill machine, and lasted
in the creeper machine to become wet-blanket chips. The output of those three creeper machines is wet-blanket chips with 10-13 mm of thick and about 50 cm of width, coming out continually from the machines. Later, the wet-blankets are processed manually by the people working (workers) in 6 different folding tables with one people for one table. They are in charge of folding and cutting the wet blankets into 4-6 m of length and put them in Salangan. The wet blankets weight 10-15 kg of each. After the blankets amount to 10-15 chips, they are brought with the trolley to weigh and hang them on the drying shed chains to dry.

In the workstation, the production process bottleneck is still found due to the unbalance of the acceleration of those three creeper machines to fold and cut the wet blankets by ten people in the tables, the factory capacity which has not fulfilled yet and is dominated by manual workers. As a result, ergonomics based wet-blanket workstation redesign is required, along with the track balance between creeper machines and the wet-blanket folding process. Redesign is implemented by redesigning the wet-blanket folding table, the work organization, and the physical work environment. The manual process of folding the wet blankets which does not offset the output acceleration of the creeper machines is supposed to be the main factor of bottleneck occurrence on the wet blankets being sent into the drying room. On the folding work process, human factor plays an important role in the wet blanket production process, which is dominated by manual workers. The dominance of manual workers is one factor that has the potential occurrence of fatigue[5], [6]. The level of the heavy workload and severe fatigue can cause early fatigue which results in the slow work, and then ultimately in a low productivity or failure of achieving the target productivity.

The workers do manual work such as managing the work pieces like wet blanket chips as the results of the creeper machine by hand to grab, pull, fold, cut, lift, and put the wet blanket. Backs bent and hands folding and cutting the wet blanket are monotonous and repetitive with non-ergonomically working gesture and position. The work position which is repetitive and requires greater energy in the process of cutting pieces of the wet blankets will have an impact on fatigue more quickly[10]. The complaints experienced by the workers are as a result of the lack attention to the life quality of the workers and can merely derive the worker productivity low.

The results of the preliminary study with eight variables depending on productivity and worker life quality showed: the workload score 135,85 ± 7,22, the fatigue score 105,25 ± 12,05, the production result per work shift 15.350,67 ± 1288,36 kg per work shift, and the work [4]. Those results indicated that the life quality of the workers decreased below 15% compared to the normal state, so it should be improved. Similarly, the worker productivity needs to be improved, so it can reduce the phenomenon of bottlenecks and can achieve installed capacity of the factory, i.e. 150,000 tons / year.

To address the above issues, it was being urgent to redesign wet blanket workstations based on ergonomics and to take into consideration all aspects of the integration approaches that include the concept of total ergonomics involving AT (appropriate technology) utilization and SHIP (systemic, holistic, interdisciplinary, participatory) done consistently and continuously by integrating Ergo-MicMac. Repairing or redesigning the work system is conducted on aspects: task, work organization and the physical work environment in the wet blanket workstations, in order to create working conditions which are effective, convenient, safe, healthy, and efficient, with the use of functional human body optimally for the effective work productivity with taking into account the life quality of workers. The low level of worker life quality will directly affect the level of worker productivity.

Based on the foregoing, it is necessary to do research on redesigning wet blanket workstations with total ergonomics-based interventions (through the application of AP and SHIP approach), to improve the life quality and productivity of workers by reducing: (1) the workload, (2) fatigue, and by increasing: (3) the results of the product / shift work. The total ergonomics based on interventions in the rubber industry / crumb rubber are expected to make the results achieved more humane, competitive and sustainable[8].

2. Research Method
The research method used is experimental research design with the design of the same subject (treatment by subject design) with implementation in series and washing out period, as well as the adaptation for 2 days. The sample size was calculated based on the Colton formula[7], [9], with the number of male
workers aged 25-50 years old in the wet blanket workstation and were selected by simple random sampling. The redesign of ergonomics-based wet blanket workstations was done by: designing a folding table (MLB2-R) with the table surface roll mechanism, which was given the cutting blades wet blanket where its height was adjustable and ergonomics; allocating an official break time, with 30-minute break every 30-minute work time; setting the pattern of pair work system and job rotation / week; giving additional nutrients which were a glass of sweet tea (120 cc) and 2 pieces of Pempek (250 grams) at the official break at 09.00 a.m. and a glass of sweet tea (120 cc) at the official break at 14:00 p.m., a long break for rest, prayer, and lunch at 11:30 - 12:30 p.m.[9]; putting on personal protective equipment (PPE) such as wear pack, ear muff, gloves, and boots; making 1 piece of natural ventilation in the wall sized of 1.5 x 2 m, and 3 pieces of fans in every corner; painting the walls ivory color; installing 3 transparent roofs with 1 x 3 m and fixing the placement of three unit lamps with gallows and energy saving lamps; spraying Deorub 3 times a day; adding janitors in the area of wet blanket workstations.

The survey of the subject’s condition was conducted to determine the weight, height, age, high blood pressure, and elbow standing worker (anthropometry). The environmental conditions were recorded every hour starting at 7:00 a.m. to 16:00 p.m. on 4 directions (West, North, East, and South) with a distance of ½ m, 1 m, 1.5 m, 2 m, and 2.5 m. The environmental conditions measured were dry temperature, wet temperature, humidity, wind speed, noise level, and lighting intensity. The results of the physical condition measurement were averaged to obtain the physical environment conditions before the wet blanket workstation redesign (P0) and after the redesign (P1).

The data retrieval of the worker’s life quality included the workload data through pulse measurement 2 times, early before work (pretest) and just after work (posttest), both at P0 and P1. The measurement of resting pulse rate (pretest) was done in 15-second method[13]. To determine the maximum workload, the measurement of working pulse rate was also done every 30 minutes. This analysis was reinforced with% CVL (cardiovascular load). To get the ECPT (extra cardiac pulse due to temperature) and ECPM (extra cardiac pulse due to metabolism), it was also required to measure the recovery pulse with tens pulse method, which was done by measuring the pulse every minute for 30 seconds to five minutes after they stopped working. The data retrieval of work productivity was obtained by recording the results of product / shift work, and also the calculation of the ratio between the wet blanket product result average per shift work which could be produced with a pulse employment multiplied by hours of shift work, and measured after work activities (posttest) at P0 and P1.

3. Result and Discussion
The study results in Micro Ergonomics aspects are presented in Figures 2 and 3 on designing the work system for the workers at the wet blanket workstation. Meanwhile, Macro Ergonomics is explained more on the aspects of benefits for the work system of organizational scale.

3.1 Workers’ Characteristics
The conditions and characteristics of the workers at the wet blanket workstation are presented in Table 1.

| No. | Description                        | Average | Standard Deviation |
|-----|------------------------------------|---------|--------------------|
| 1.  | Age (year old)                     | 37.45   | 5.75               |
| 2.  | Body Weight (kg)                   | 54.66   | 8.95               |
| 3.  | Height (cm)                        | 159.97  | 7.17               |
| 4.  | Elbow Height / Altitude of Standing Position (cm) | 98.25   | 4.25               |
| 5.  | Working Experience (year)          | 15.89   | 7.01               |
| 6.  | First Period of resting pulse rate(beats/minute) | 80.12   | 5.78               |
| 7.  | Body Mass Index(kg/m²)             | 21.50   | 3.90               |

A person's physical capacity is directly proportional to a certain age. The average age of workers has the physical capacity and muscle strength that is no longer optimum for doing work activities, especially workers who are above 40 years old (>40). Nonetheless, the workers in general are still in the category
of healthy and can work normally. The workers’ weight and height determine the body mass index (BMI), which is useful to know the energy balance that enters the body through nutrition or food intake equal to the energy expended. This situation would derive the normal weight. The workers’ BMI average was 21.50 ± 3.90 kg/m², which means that the nutritional status of the workers was in the normal category and was good enough to work optimally. The average of the systolic blood pressure was 114.71 ± 10.53 mmHg, and the average of the diastolic blood pressure was 77.06 ± 4.70 mmHg. They indicated the normal condition, for the systolic blood pressure was <130 mm Hg and diastolic was <85 mmHg. The worker resting pulse rate was on average 80.12 ± 5.78 beats per minute, indicating the workers in good health and able to perform their duties.

The average of the upright position was 98.25 ± 4.25 cm. This was used to calculate the height of the surface MLB2-R, which is at the fifth percentile calculated using the $T = \bar{X} - 1.645SB$ formula and obtained height 90.35 cm. Therefore the height of the rear table surface was 90.35. The average of the workers’ work experience was 15.89 ± 7.01 years. This number showed long working experience that was believed to assist the workers gain the skills and abilities to adapt to the environment.

### 3.2 Redesigning Tasks and Work Equipment at Wet-Blanket Workstation

The task conditions performed by the workers in the wet-blanket workstation at P0, or the workers in bending / unnatural work position and cutting the wet blanket manually by hands as the working facility of the old wet blanket folding tables used had no cutting blades for blanket wet and not ergonomics, were without any given official break, without given intake of additional nutrients, without wearing work clothing and footwear everyday course. Besides, the conditions showed that the physical environment was so hot, a bit dark, cramped. In addition, the walls and floors were dirty and smelly, and sometimes the flow of water drainage was obstructed. The unnatural working attitudes and unergonomics work facilities definitely impacted on the decrease of worker life quality which is indicated by the increase of the workload, and fatigue. The decrease of the life quality of the workers would likely impact the decline in the workers’ productivity which could be measured through the low product results per shift.

Meanwhile, P1 attempted to give interventions towards total ergonomics and ergo-micmacin order to improve the life quality and productivity of workers. The interventions included; redesigning the working tools (redesigning prior wet-blanket folding tables into redesigned wet-blanket folding table with the roll mechanism table surface and a wet blanket cutting blade which were adjustable and ergonomics), setting the paired-working system pattern, giving the official break, giving additional nutritional intake, and using PPE. The wet-blanket workstation redesign on P1 was proven to improve the quality of life and productivity of the workers. The selection of MLB2-R was based on objective reasons (workload and anthropometry) and subjective reasons (fatigue). The design of MLB2-R was considered to be able to meet the workers’ desire, simply by increasing the surface of the roll mechanism and the wet blanket blade manually driven based on the faster and neater cutting process, and the more production results per shift. The other benefits as the reason of the changes and modifications were workload, and mild fatigue having implications in the worker productivity increased.

### 3.3 Redesigning Work Organization at Wet-Blanket Workstation

The workers at the wet-blanket workstation at P0 worked in 1 work shift per day (8 hours) without alternating shifts. There were 10 workers working at 10 units of prior wet-blanket folding table. The product achievement per work shifts was not enough to accomplish the target of 150 tons per shift per team, so the workers felt dissatisfaction for not getting an extra pay.

The six workers for 10 units of prior wet-blanket folding table still raised the bottleneck-shaped when balancing the wet blanket output from the engine creeper. The bottleneck-shaped was occurring because the cycle time of the production process per chip was not optimal. It still took a long time to use prior wet-blanket folding tables, especially during the wet blanket cut by hand manually and worker fatigue factor. The official break time was only given one time at 12:00 to 13:00 p.m. It merely derives the workers to extra fatigue. The workers rarely had a break out of the official break time because it would reduce working hours and make violation against the company rules. As a result, to avoid more fatigue,
the workers had been trying to find time for a break. The rotation between work shifts done per month gave an impact on the long-term boredom, for they had to wait for a new work atmosphere too long. The redesign of the work organization at P1 was made by total ergonomics and ergo-micmac interventions, so the issues at P0 work organization could be improved. The total ergonomics and ergo-micmac based interventions performed were; to provide a well-regulated official break to avoid fatigue. The workers were set up to work in pairs. Two workers were employed interchangeably. When the first worker was working, the second worker took an official break. The regulation of the officially break was patterned of 30 minutes to work and 30 minutes to formal break. Regulating the work patterns shown to be able to reduce the workload, fatigue, and to improve product results per shift giving impact on the worker satisfaction for being able to achieve the target of at least 150 tons per shift per team, so workers got an extra pay beyond their basic salaries.

Another intervention was to provide additional nutritional intakes by providing sweet tea (120 cc) and 2 pieces of Pempek (250 gr) on an official break. In addition to providing the nutritional intakes, the workers were allowed to drink water provided in the rest room during their official break. The work organization gave psychological and physiological impacts on improving the quality of workers’ lives and increasing the productivity to achieve the target and to reduce the bottleneck-shaped production.

3.4 Redesigning Physical Work Environment at Wet-Blanket Workstation

Redesigning the physical work environment gave an impact on the significantly-different environmental conditions as shown in Table 2.

| Table 2. Different Environmental Conditions at Wet-Blanket Workstation |
|---------------------------------------------------------------|
| **No** | **Variables Measured** | **1st Period** | **2nd Period** |
| | | **Average** | **Standard Deviation** | **Average** | **Standard Deviation** |
| 1. | Dry Temperature (°C) | 36.28 | 2.90 | 34.38 | 3.04 |
| 2. | Wet Temperature (°C) | 33.82 | 2.78 | 31.27 | 1.88 |
| 3. | Humidity / RH (%) | 76.65 | 4.89 | 66.70 | 4.92 |
| 4. | Wind Velocity (m/sec) | 1.50 | 1.00 | 1.06 | 0.61 |
| 5. | Lighting (lux.) | 179.90 | 9.83 | 200.09 | 6.59 |

The temperature average in the wet-blanket workstation was outside of the comfort zone, where the temperature of the comfort zone for Indonesian ranged between 22-28 °C. Otherwise, Grandjean established the high temperature tolerance limits in the physical work environment of 35-40 °C[4]. The temperature at P0 was higher because the physical working conditions in the wet-blanket workstation interventions had not been done with the fan installations in every corner and the addition of natural ventilation on the walls, so the different test results showed that the difference was significant (p <0.05) between the dry temperature and the wet temperature at P0 and P1.

The average humidity per RH at P0 was 76.65 ± 4.89%, and at P1 was 66.70 ± 4.92%, or which was categorized above the comfortable criteria of Indonesian, which is 70-80%. The tolerance limit for the humidity level in the working environment should range between 65-95% and 40-60%, and then the moist air at P1 was relatively considered standard.

The average of the wind speed or movement differed significantly (p <0.05), because at P1 it was equipped with the 1.5 x 2 m natural ventilations on the wall and the installation of 3 fans in every corner of the workstation. The average of the noise levels had significantly different meanings p = 0.000 (p <0.05), because the workers wore ear muffs which could reduce the noise of ± 30 dBA.

The different test average of the illumination intensity at P0 to P1 had the significant difference (p <0.05), it was found at P1 the increase of lighting intensity of 200.09 ± 6.59 lux (up 10.90%) due to the redesign intervention at P1 by adding 3 pieces of transparent roof put on the right above the work area, modifying lampposts, adding artificial ventilation holes in the wall, and painting a wall ivory color which was expected to give a reflectance of 60-65%.
The bad smell becoming the most problem of the rubber industry came from rubber processed materials, which could not be eliminated but could be reduced by improving the quality of raw materials in the freezing process, by considering the process in the raw material warehouse and the production process in the workstation. The reduction of odor in rubber processed materials was done by the usage of Deurob smoke liquid sprayed on the raw material warehouse, the workstation, and all areas causing the odor. Spraying Deurob liquid was performed 3 times per shift.

3.5 Quality of Life and Worker Productivity

a. Workloads

Table 3 describes the workers workload measured by pulse rate, ECPT, ECPM, and % CVL.

| Variable | 1st Period | | 2nd Period | |
|----------|------------|----------|------------|----------|
|          | Mean       | Standard Deviation | Mean       | Standard Deviation |
| RPR      | 82.82      | 5.92      | 81.71      | 4.99      |
| WRP      | 144.43     | 4.53      | 121.24     | 4.82      |
| % CVL    | 62.95      | 6.67      | 40.73      | 8.69      |
| ECPT     | 45.25      | 12.72     | 38.50      | 8.99      |
| ECPM     | 269.86     | 21.53     | 249.82     | 20.6      |

Note: RPR = Resting Pulse Rate; WPR = Work Pulse Rate; ECPT = Extra Cardiac Pulse due to Temperature; ECPM = Extra cardiac Pulse due to Metabolism; and % CVL = % Cardiovascular Load

The worker’s in the viewpoint of work and rest periods based on WBGT and % CVL is presented in Fig1.

![Figure 1. Work and Resting Time Graph Based on WBGT and % CVL](image)

At P0, before the redesign of the wet-blanket workstation by giving the total ergonomics intervention on tasks, work organization, and physical working environment of the workers in the category 75% work and 25% break, it indicated the heavy workload category of the WRP at 144.43 dpm, the WBGT at 34.17°C, and the % CVL at 67.92%. Whereas, at P1, after the ergonomics-based intervention, the graph line shifted to the left down into the category of 50% work and 50% break, which indicated the WRP 121.24 dpm, the WBGT 31.45 °C, and the CVL at 37.73%. The result was consistent with the work organization redesign applying the method of work in pair every 30 minutes for work and then 30 minutes for break (Figure 1).

The measurement result showed that the ECPM was greater than the ECPT. It proved that the work shift regulation gave a bigger influence on the metabolic disorder than on temperature. However,
simultaneously redesigning the physical working environment had been shown to reduce the WBGT, which also gave a further impact on declining the workload seen from the % CVL decrease [14]. The workload is generally decreased by 18.85%. The workload changed from the hard work category at P0 into the moderate work category at P1.

b. Work Fatigue

Different test average of fatigue before activity, or at P0, was 70.78 ± 3.17, and it was down by 0.21% to 70.63 ± 2.68 at P1, showed by p value 0.942 (p >0.05), which meant that fatigues before the intervention did not differ significantly between at P0 and P1. Meanwhile, the fatigue-score after work at P0 was 110.06 ± 7.82, and that fell by 19.85% to 89.33 ± 3.72 at P1. The fatigue after work at P0 and P1 differed significantly (p <0.05), which indicates a decrease in fatigue levels after the ergonomics intervention at P1.

The score value of fatigue with 3 aspects (activity, motivation, and physical) before work was greater than 0.05 (p> 0.05). It showed that the data of fatigue before work were significantly different from the fatigue category of work activity aspect and of motivational aspects, for the p-value was lower than 0.05 (p <0.05). Meanwhile, the fatigue category of physical aspect was not significantly different from the p value (p >0.05). It showed that the workers did not change on the physical fatigue after work activity. The decrease of the fatigue score was caused by redesigning the wet-blanket workstation based on ergonomics applied at P1, done by: the use of redesigned wet-blanket folding tables that had been adapted to anthropometry, ergonomics, and an adjustable height according to the worker's body dimensions; the regulation of the official breaks, the provision of additional nutrient intakes, the use of PPE; and the improvement of environmental conditions by administering fans, spraying Deurob, and painting a wall ivory color making it more effective, convenient, safe, healthy, and efficient which could improve the quality of life and productivity of the workers.

At P0, the average deviation of motion (motion time study) conducted by workers as early indicators of fatigue were 2.11 ± 0.32 times per shift [10], and at P1 the average deviation was 1.08 ± 0.20 times per shift. It has a different meaning / significant p = 0.003. The ineffective movement of the workers was decreased by 88.77%. It indicated that redesigning the wet-blanket workstation based ergonomics (P1) could reduce the motion irregularities committed by the workers while folding the wet blanket.

Redesigning the wet-blanket workstation based on ergonomics (P1) also resulted in the weight loss reduction of the workers after work at 18.83%. The body weight after working at P0 decreased 1.55 kg to 1.06 kg at P1.

c. Product Results per Shift

The product results per shift was the amount of wet blanket production successfully carried out and placed in the Salangan (like a canal or pipe) to dry during one work shift. One Salangan contained of 10-15 pieces of wet blankets weighing 100-225 kg per Salangan.

Different average of the product results per shift at P0 and at P1 was 25,689.51 kg per shift and 35,919.78 kg per shift with p value 0.000 (p <0.05), indicating the ergonomics intervention at P1 could significantly improve the production per shift, which increased 27.29%. Whereas, the productivity index measured was partial productivity index, i.e. the mean output ratio of wet blanket total production per work shift by workers and the input average of workers’ pulse per shift. The difference of the average worker productivity index at P0 and at P1 was 59.62 ± 4.83 and 81.93 ± 3.79, with p = 0.000 (p <0.05), indicating that the redesigned ergonomics intervention at P1 was able to significantly improve worker productivity index, which was 29.23%.

Here is presented the Total Ergonomics and Ergo-MicMic integration between the works system before and after the implementation of the redesign[11], [12].
4. Conclusions and Suggestions

4.1. Conclusions

Redesigning a wet-blanket workstation based on Total Ergonomic and Ergo-MicMac integration could improve the quality of life and productivity of the workers at MK 2 Factory, indicated by:

1. Reducing the workload by 18.85%.
2. Reducing the fatigue by 19.85%.
3. Improving the product results per shift work by 27.29%.

4.2 Suggestions

1. The redesign of the total ergonomics and ergo-micmacintegration based wet-blanket workstation by designing wet-blanketfolding tables, regulating official breaks, setting a work in pair system, applying a job rotation per week, giving additional nutrient intakes, using PPE, installing natural ventilations, installing fans, and spraying Deurob was proven to improve the quality of workers’ life by lowering workload, and fatigue.

2. The redesign of the total ergonomics and ergo-micmacintegration based wet-blanket workstation by designing wet-blanketfolding tables with SHIP and AP approach should be prioritized to be implemented, for the redesigned wet-blanketfolding tables were very simple, easily made, and cheap, yet it could increase the number of product results per work shift.

3. Further study was suggested on the redesign at workstations or parts of crumb rubber production process II, at an attitude and a working position, and at the reduction of odor based on ergonomics, so it can promote effectiveness, convenience, safety, health, and efficiency, improve the quality of life and productivity of the workers in all parts of the production process.
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