SME Worker Affective (SWA) index based on environmental ergonomics

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Abstract. Small-Medium sized (SME) is a focal type of Indonesian industry which contributes to national emerging economies. Indonesian government has developed employee social security system (BPJS Ketenagakerjaan) to support worker quality of life. However, there were limited research which could assist BPJS Ketenagakerjaan in evaluating worker quality of life. Worker quality of life could be categorized as the highest worker needs or affective states. SME Worker Affective (SWA) index is being concerned as a basic tool to make balance between worker performance and quality of life in workstation of SMEs. The research objectives are: 1) To optimize the environmental ergonomics in SMEs; 2) To quantify SME Worker Affective (SWA) index based on optimized environmental ergonomics. The research advantage is to support Indonesian government in monitoring SMEs good practices to its worker quality of life. Simulated annealing optimized the heart rate and environmental ergonomics parameters. SWA index was determined based on comparison between optimized heart rate and environmental ergonomics parameters. SWA index were quantified for 380 data of worker. The evaluation indicated 51.3% worker in affective and 48.7% in non-affective condition. Research results indicated that stakeholders of SMEs should put more attention on environmental ergonomics and worker affective.

1. Introduction
Small-Medium sized (SME) is a focal type of Indonesian industry which contributes to national emerging economies. The characteristics of Indonesian SMEs were \cite{1}: 1) Application of appropriate technology; 2) Labour intensive-based production; 3) Significant economic contribution; 4) Not yet total ergonomics-oriented. Indonesian government has developed employee social security system (BPJS Ketenagakerjaan) to support worker quality of life \cite{2}. However, there were limited research which could assist BPJS Ketenagakerjaan in evaluating worker quality of life. Worker quality of life could be categorized as the highest worker needs, or known as affective states. Affective or implementation of Kansei has relationship with ergonomic as psychological and emotional response from worker satisfaction \cite{3}. Heart rate was proven as reliable non-verbal parameter to represent...
affective states [4]. Environmental ergonomics influenced significantly worker affective states [5][6]. Environmental ergonomics is the effects of indoor environment on the health, convenience and productivity of human work [7]. SME Worker Affective (SWA) index is being concerned as a basic tool to assess quality of life in workstation of SMEs.

There were some research which developed ergonomic assessment based on environmental ergonomics. Gläser et al. [8] have developed the ergonomic assessment based on simulation of digital human model and data sensor. Fallahi et al. [9] have developed ergonomic assessment for tractor based on algometer. Ahmadi et al.[10] have developed indicator of ergonomic assessment based on standard of international labour organization and international ergonomic association for the application in assembly-packaging industry. However, none of them is applicable for assessment of SWA index.

The research objectives are: 1) To optimize the environmental ergonomics in SMEs; 2) To quantify SME Worker Affective (SWA) index based on optimized environmental ergonomics. The research advantage is to support Indonesian government in monitoring SMEs good practices to its worker quality of life. In industrial practice, SWA index could be used as an indicator to assess the ergonomic feasibility of a production system.

2. Materials and Method

2.1. Database
The Six (6) SMEs of different food products were used for the database, i.e., crackers, nuggets, fish chips, bakpia (a traditional pastry), tempeh and herbal instant beverages. Three hundred and eighty (380) data sets were analysed. The environmental ergonomics data consisted of heart rate after working, temperature before and after working, Relative Humidity (RH) before and after working, light intensity after working. The work measurement before and after working was suggested by Ushada et al. [5].

2.2. Research Methodology
Research methodology was defined in Fig. 1. Environmental ergonomics data consisted of affective states (Heart rate after working) and workplace environment (Workplace temperature and relative humidity before and after working and light intensity after working). The environmental ergonomics were modeled using simulated annealing algorithm. The temperature before working was set as target for the optimization. The temperature was measured before working since it was the closest one to the convenient temperature in the morning time. The temperature ranged from 24.8 to 33.1°C. The other parameters were optimized based on target of temperature before working. The index of each parameters were determined based on the comparison between measured and optimized values. SWA index was determined based on standardization of each parameter index.

2.3. Simulated Annealing
The algorithm for simulated annealing were developed using MATLAB R2015a (8.5.0.19763) and consists of following steps:

1. Set the cooling scheme (Value of annealing parameter):
   a. Initial temperature ($T_0$) and final temperature ($T_f$)
   b. Factor of decreasing temperature ($F$)
   c. Amount of iteration in each temperature value ($N$)
2. Select the initial solution $X$ by random or using specific heuristic method.
3. Determine the value of objective function: $E = f(X)$.
4. Set the value of temperature parameter: $T = T_0$.
5. Generating the new solution $X_{\text{new}}$
6. Determine the value of objective function: $E_{\text{new}} = f(X_{\text{new}})$.
7. Determine $X = X_{\text{new}}$ and $E = E_{\text{new}}$ based on probability (Metropolis criterion) in equation 1:
   $$\min\left(1, \exp\left(\frac{E-E_{\text{new}}}{T}\right)\right)$$

2
8. Repeat the step 5 to 7 for the $N$
9. Reduce the temperature parameter by setting: $T = T \times F$
10. Stop the algorithm if termination criterion is satisfied. If it is not, back to step 5.

![Research methodology diagram]

Figure 1. Research methodology.

2.4. SME Worker Affective
Index of heart rate is determined based on equation 2:

$$I_{HR} = \frac{HR_0}{HR_1} \times 100$$  \hspace{1cm} (2)

$I_{HR}$ = Index of heart rate  
$HR_0$ = Measured heart rate (Pulse/minutes)  
$HR_1$ = Optimized heart rate based on simulated annealing (Pulse/minutes)

Index of workplace temperature before working is determined based on equation 3:

$$I_{TB} = \frac{T_{B_0}}{T_{B_1}} \times 100$$  \hspace{1cm} (3)

$I_{TB}$ = Index of temperature before working  
$T_{B_0}$ = Measured temperature before working ($^0C$)  
$T_{B_1}$ = Target of temperature before working ($^0C$)

Index of workplace temperature after working is determined based on equation 4:

$$I_{TA} = \frac{T_{A_0}}{T_{A_1}} \times 100$$  \hspace{1cm} (4)

$I_{TA}$ = Index of temperature after working  
$T_{A_0}$ = Measured temperature after working ($^0C$)
\( TA_1 \) = Optimized temperature after working based on simulated annealing (\(^{\circ}\)C)

Index of workplace RH before working is determined based on equation 5:

\[
I_{RHB} = \frac{RH_{B0}}{RH_{B1}} \times 100
\]

(5)

\( I_{RHB} \) = Index of RH before working
\( RH_{B0} \) = Measured RH before working (%)
\( RH_{B1} \) = Optimized RH before working based on simulated annealing (%)

Index of workplace RH after working is determined based on equation 6:

\[
I_{RHA} = \frac{RH_{A0}}{RH_{A1}} \times 100
\]

(6)

\( I_{RHA} \) = Index of RH after working
\( RH_{A0} \) = Measured RH after working (%)
\( RH_{A1} \) = Optimized RH after working based on simulated annealing (%)

Index of light intensity after working is determined based on equation 7:

\[
I_{LI} = \frac{LI_{0}}{LI_{1}} \times 100
\]

(7)

\( I_{LI} \) = Index of light intensity after working
\( LI_{0} \) = Measured light intensity after working (Lux)
\( LI_{1} \) = Optimized light intensity after working based on simulated annealing (Lux)

SWA index are determined based on equation 8:

\[
SWA = (I_{HR} \times 0.4) + (I_{TB} \times 0.4) + (I_{TA} \times 0.05) + (I_{RHB} \times 0.05) + (I_{RHA} \times 0.05) + (I_{LI} \times 0.05)
\]

(8)

Workers were regarded as affective if SWA Index \( \leq 112 \). The value of 112 was determined using the average value from population of 380 data. The weights of SWA index was determined based on the importance of each index. The highest weight was determined on \( I_{HR} \) due to representative of non-verbal affective parameters. The highest weight was determined on \( I_{TB} \) due to target value of simulated annealing optimization.

3. Results and Discussion

3.1. Risk Classification

The risk score was determined based on classification of affective and environmental parameter. The heart rate was classified by AIHA in Kolus et al. [11] (Table 1). This kind of classification was reviewed by Kolus et al. [12]. The temperature was classified based on Regulation of Ministry of Energy and Mineral Resources (RMEMR) No.13 Year of 2012 [13]. RH range was classified based on Regulation of Ministry of Health No.1077 Year of 2011 [14]. Light intensity was classified based on Regulation of Ministry of Health No.1405 Year of 2002 [15].

| No | Parameters | Classification | Range | Score |
|----|------------|----------------|-------|-------|
| 1  | Heart rate (Pulse per minute) | Sitting | 60-75 | 0 |
|    |            | Very light | 65-75 | 0 |
|    |            | Light | 75-100 | 1 |
|    |            | Moderate | 100-125 | 2 |
|    |            | Heavy | 125-150 | 3 |
|    |            | Very heavy | 150-175 | 4 |
|    |            | Extremely heavy | >175 | 5 |
| 2  | Workplace Temperature (\(^{\circ}\)C) | Recommendable | \( \leq 30 \) | 0 |
|    |            | Not recommendable | >30 | 1 |
| 3  | Workplace RH (%) | Recommendable | 40 - 60 | 0 |
|    |            | Not recommendable | >60 | 1 |
3.2. Simulated Annealing
Simulated annealing was conducted on 17 trials and various targets of before working temperatures as shown in Table 2.

3.3. Optimized Environmental Ergonomics
Optimized parameters were generated using simulated annealing and risk classification as following (Table 3):

| Trials | Simulated Annealing (°C) | Measured (°C) | Absolute Error | Risk Score |
|--------|---------------------------|---------------|----------------|------------|
| 1      | 26,94                     | 27,50         | 0,56           | 5          |
| 2      | 29,27                     | 29,30         | 0,03           | 4          |
| 3      | 30,12                     | 31,10         | 0,98           | 5          |
| 4      | 26,74                     | 27,50         | 0,76           | 4          |
| 5      | 29,02                     | 29,30         | 0,28           | 5          |
| 6      | 30,19                     | 31,10         | 0,91           | 4          |
| 7      | 29,06                     | 29,10         | 0,04           | 5          |
| 8      | 28,67                     | 30,20         | 1,53           | 5          |
| 9      | 28,71                     | 29,00         | 0,29           | 5          |
| 10     | 28,59                     | 29,00         | 0,41           | 4          |
| 11     | 27,64                     | 28,20         | 0,56           | 5          |
| 12     | 28,63                     | 28,80         | 0,17           | 1          |
| 13     | 28,52                     | 29,60         | 1,08           | 5          |
| 14     | 28,80                     | 29,10         | 0,30           | 1          |
| 15     | 29,51                     | 30,20         | 0,69           | 6          |
| 16     | 29,36                     | 29,40         | 0,04           | 2          |
| 17     | 28,27                     | 29,00         | 0,73           | 1          |

Table 3. Optimized environmental ergonomics

| No | Parameter                              | Metric       | Values     |
|----|----------------------------------------|--------------|------------|
| 1  | Heart rate                             | Pulse/minutes| 69,58      |
| 2  | Workplace temperature after working    | °C           | 28,46      |
| 3  | Workplace RH before working            | %            | 59,80      |
| 4  | Workplace RH after working             | %            | 40,64      |
| 5  | Light intensity after working          | Lux          | 64357,93   |
| 6  | Target of temperature before working   | °C           | 28,80      |
| 7  | Simulated temperature before working   | °C           | 28,63      |

3.4. Quantification SWA Index
Based on the optimized parameters in Table 3, the index of environmental ergonomics were determined using equations (2), (3), (4), (5), (6) and (7). Subsequently, SWA index was quantified for 380 worker data using equation (8). The evaluation indicated 51.3% workers were in affective condition while 48.7% others were in non-affective condition. The research results indicated that stakeholders of SMEs should put more attention on environmental ergonomics and worker affective. SWA index could be used to assess feasibility of workplace environment to generate worker quality of
life. Further research is suggested for the development of national affective assessment system based on integration of SWA index and employees social security system.

4. Conclusion
Simulated annealing optimized the heart rate and environmental ergonomics parameters based on temperature before working. SWA index was determined based on comparison between optimized heart rate and environmental ergonomics parameters. SWA index were quantified for 380 workers. The evaluation indicated 51.3% workers were in affective state while the rest of 48.7% workers were in non-affective condition. The research results indicated that stakeholders of SMEs should put more attention on environmental ergonomics and worker affective. SWA index could be used to assess feasibility of workplace environment to generate worker quality of life.

5. References
[1] Ushada M, Suyantohadi A, Khuriyati N and Okayama 2017 Identification of environmental ergonomics control system for Indonesian SMEs Proc. of IEEE-ICCAR 2017 Nagoya Japan.
[2] Anonym 2017 Badan Penyelenggara Jaminan Sosial Ketenagakerjaan/BPJS Ketenagakerjaan (National employees social security system) http://www.bpjsketenagakerjaan.go.id/, accessed on June 7, 2017
[3] Kwong C K, Huimin J and Luo X G 2016 AI-based methodology of integrating affective design, engineering, and marketing for defining design specifications of new products. Eng. Appl. Artificial Intelligence 47 pp 49-60
[4] Ushada M, Okayama T, Khuriyati N and Suyantohadi A 2015 Kansei’s physiological measurement in small-medium sized enterprises using profile of mood states and heart rate. Springer Lecture Notes in Electrical Engineering series (LNEE).
[5] Ushada M, Okayama T and Murase H 2015 Development of kansei engineering-based watchdog model to assess worker capacity in Indonesian small-medium food industry Eng. in Agric., Environ. Food 8 pp 241-250
[6] Ushada M, Okayama T, Suyantohadi A, Khuriyati N and Murase H 2017b Kansei Engineering-based artificial neural network model to evaluate worker performance in small-medium scale food production system. Int. J. Indust. Sys. Eng., In Press.
[7] Parsons K C 2000 Environmental ergonomics: a review of principles, methods and models. App. Ergon. 31 pp 581-594
[8] Gläser D, Fritzschle L, Bauer S and Sylaja V J 2016 Ergonomic assessment for DHM simulations facilitated by sensor data. Procedia CIRP 41 pp 702-705
[9] Fallahi H, Abbaspour-Fard M H, Azhari A, Khojastehpour M and Nikkhah A 2016 Ergonomic assessment of drivers in MF285 and MF399 tractors during clutching using algometer. Inform. Process. in Agric. 3 pp 54-60
[10] Ahmadi M, Zakerian S A and Salmanzadeh H 2017 Prioritizing the ILO/IEA ergonomic checkpoints' measures; a study in an assembly and packaging industry. Int. J. Indust. Ergon. 59 pp 54-63
[11] American Industrial Hygiene Association (AIHA) Ergonomic guide to assessment of metabolic and cardiac costs of physical work (1971) in Kolus A, Imbeau, D, Dubé, V, Dubateau, D. Classifying work rate from heart rate measurements using an adaptive neuro-fuzzy inference system App. Ergon. 54 pp.158-168
[12] Kolus A, Imbeau D, Dubé P-A and Dubateau D 2016 Classifying work rate from heart rate measurements using an adaptive neuro-fuzzy inference system App. Ergon., vol. 54 (2016), pp.158-168
[13] Anonym 2012 Regulation of Ministry of Energy and Mineral Resources of Republic Indonesia No.13: Electricity Saving (In Bahasa Indonesia: Peraturan Menteri Energi dan Sumber
Daya Mineral Nomor 13 tentang Penghematan Pemakaian Listrik), Ministry of Energy and Mineral Resources of Republic Indonesia

[14] Anonym 2011 Regulation of Ministry of Health Republic Indonesia No. 1077: Healty Indoor Air at Home (In Bahasa Indonesia: Pedoman Penyehatan Udara dalam Rumah). Ministry of Health Republic Indonesia.

[15] Anonym 2002 Regulation of Ministry of Health Republic Indonesia No. 1405: Requirement of occupational health for office and industry (In Bahasa Indonesia: Persyaratan kesehatan lingkungan kerja perkantoran dan industri). Ministry of Health Republic Indonesia.

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