Ergonomic-Value Stream Mapping to Evaluate Ergonomic Manufacturing Performance: A Case Study in Plywood Industry

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**Abstract.**  In the present day, ergonomic manufacturing is crucial for the support of production processes that prioritize ergonomic risks. Nevertheless, there is still a lack of research on the use of the Manufacturing Ergonomics Score (MES) in ergonomic manufacturing assessment to enhance ergonomic performance. Consequently, the objective of this research is to suggest a novel framework for the assessment of manufacturing ergonomics, which will be founded on ergonomic risk indicators and lean concepts. This investigation integrates a variety of ergonomic indicators, such as noise level, safety risk, mental workload, physical workload, and body posture. It is suggested that the ergonomic indicators be assigned weights using the Analytical Hierarchy Process (AHP) method. The efficiency of each ergonomic indicator is assessed prior to its integration into the Ergonomic Value Stream Mapping (Ergo-VSM) and Traffic Light System (TLS). The proposed framework effectively addressed the challenges encountered by the plywood industry when it was applied to a case study. The results indicate that the company's performance requires additional attention and improvement measures, as the manufacturing ergonomics score in the industry has reached 66.17%. Additionally, this investigation comprises implications and suggestions for future advancements.

**Keywords:** Ergonomic manufacturing, Lean Manufacturing, Ergo-VSM, AHP, Ergonomic Assessment

# INTRODUCTION

In today's industrial environment, manufacturers have prioritized the enhancement of productivity and efficiency [[1](#_ENREF_1)]. However, this level of excellence is impossible to achieve without taking ergonomics into account [[2](#_ENREF_2)]. Ergonomics is crucial for the safety and well-being of workers and the improvement of performance [[3](#_ENREF_3)]. Manufacturers can enhance their overall performance and efficiency by undertaking comprehensive ergonomic assessments, which can identify and reduce the risk of work-related injuries and illnesses [[4](#_ENREF_4), [5](#_ENREF_5)]. Moreover, ergonomic evaluations can assist manufacturers in the optimization of production processes, the reduction of costs, and the enhancement of their competitiveness in the global market [[6](#_ENREF_6)]. In the context of the manufacturing industry's continuous growth, ergonomic assessments are critically important [[7](#_ENREF_7)]. Consequently, in order to ensure a safe, healthy, and productive work environment that is advantageous to both the organization and its employees, manufacturers must prioritize ergonomic evaluations.

Previous studies have assessed ergonomic performance in manufacturing environments; however, these evaluations are often restricted to specified work areas [[8](#_ENREF_8), [9](#_ENREF_9)]. There is still a challenge in conducting a thorough assessment of ergonomic conditions throughout the complete production line [[7](#_ENREF_7)]. To address this issue, it is essential to map ergonomic performance indicators at each stage of production to ensure the well-being and productivity of workers are optimized. While Value Stream Mapping (VSM) is a well-known method for mapping production processes, it does not adequately account for ergonomic factors [[10](#_ENREF_10)]. In response, Ergo-VSM has been created to integrate ergonomic considerations into VSM [[11](#_ENREF_11)]. Ergo-VSM is an essential tool for assessing ergonomic risks, enhancing efficiency, and minimizing waste in processes [[12](#_ENREF_12), [13](#_ENREF_13)].

While Ergo-VSM has been utilized to assess ergonomic performance, it does not provide a detailed visual representation or specific metrics for evaluating the performance of manufacturing processes [[8](#_ENREF_8)]. To overcome these limitations, a new framework named Ergonomic Performance Assessment (EPA) has been proposed, combining Ergo-VSM and the weighting of ergonomic indicators. The EPA offers a comprehensive ergonomic assessment approach within the manufacturing sector by integrating Ergo-VSM with ergonomic indicator weighting. This framework includes the identification and mapping of ergonomic indicators via Ergo-VSM, evaluating the significance of these indicators using the AHP method, and calculating the Manufacturing Ergonomic Score Index. The research aims to develop and apply the EPA to improve ergonomic performance in manufacturing, which will ultimately contribute to industry advancement and foster a safer, healthier workplace that emphasizes employee well-being.

# METHODS

# Proposed framework

This section presents the Ergonomic Performance Assessment (EPA) framework designed to assess the Manufacturing Ergonomic Score. The framework comprises five key phases, illustrated in **FIGURE 1**. First, relevant indicators are selected. The second phase involves establishing the efficiency formulas for these indicators. In the third phase, the indicators are weighted using the Analytical Hierarchy Process (AHP). Thefourth phase involves Ergo-VSM mapping based on the efficiency ratings of each indicator. The final phase is the evaluation of the Manufacturing Ergonomic Score.

**FIGURE 1**. The proposed framework for Ergonomic Performance Assessment (EPA)

The first step in the MEA framework is choosing pertinent indicators. This process entails a thorough analysis of the value stream, focusing on ergonomic risk evaluation. To effectively assess these indicators, we organized Focus Group Discussions (FGD) with specialists in the field and carried out a comprehensive review of the literature on ergonomic assessment. The development of Ergo-VSM takes into account factors such as Time, Physical Load, Mental Load, Posture, Safety Risk, and Noise Level.

During this second phase, it is suggested to evaluate the efficiency of each pertinent ergonomic indicator to determine the efficiency at every step of the production process. The performance of the company can be gauged by using the efficiency indicator scores [[14](#_ENREF_14)]. The indicators and assessment criteria for evaluating sustainability performance are outlined in **TABLE 1**

**TABLE 1.** The indicator and the equations used to calculate indicator scores

|  |  |  |  |
| --- | --- | --- | --- |
| No | Indicators | Equation | Sources |
| 1 | Time (Minute) |  | [Hartini, et al. [14]](#_ENREF_14) |
| 2 | Mental Load Index |  | [Hart and Staveland [15]](#_ENREF_15) |
| 3 | Physical Load Index |  | [Hollmann, et al. [16]](#_ENREF_16) |
| 4 | Safety Risk Assessment |  | [RISK [17]](#_ENREF_17) |
| 5 | Posture Assessment |  | [Hignett and McAtamney [18]](#_ENREF_18) |
| 6 | Noise Level |  | [Faulkner and Badurdeen [19]](#_ENREF_19) |

Following the computation of efficiency scores for each indicator, the third step in this framework involves assigning weights to the indicators used to determine the Manufacturing Ergonomic Score (MES). This study suggests using the Analytical Hierarchy Process (AHP) method to allocate weights to the pertinent indicators [[20](#_ENREF_20)]. Weights are assigned to the chosen indicators to determine the significance of each in the performance assessment [[21](#_ENREF_21)]. Pairwise comparisons of ergonomic indicators were carried out using FGD. In these comparisons, a scale ranging from one (indicating equal importance) to nine (indicating greater importance) was applied for the evaluation. indicates the comparison between indicators and . The outcomes of the pairwise comparisons are depicted using the matrix P as demonstrated in Equation (1). To normalize the pairwise comparison matrix, each element of the decision matrix should be divided by the sum of its column, as stated in Equation (2). The eigenvalues and eigenvectors, detailed in Equations (3) through (6), are derived from the calculations described in Equation (2). To determine the consistency index (CI) and consistency ratio (CR), Equations (7) and (8) are applied. The pairwise comparison matrix is deemed consistent according to the AHP method if the CR value is below 10%.

During the fourth phase, we use Ergo-VSM to map the indicators. When incorporating the relevant indicators, which have had their efficiency evaluated, into the modified Ergo-VSM framework, we employ the Traffic Light System (TLS) principle. According to TLS, efficiency is classified as follows: performance below 60% (red) necessitates immediate improvement, performance ranging from 60% to 90% (yellow) needs effectiveness enhancement, and performance over 90% (green) surpasses the target [[22](#_ENREF_22)].

The last step in the proposed framework involves determining the Manufacturing Ergonomic Score (MES). This score is derived by multiplying the efficiency ratings with the assigned weights for each indicator. The formula for calculating the MES is presented in Equation (9).

(1)

(2)

(3)

(4)

(5)

(6)

(7)

(8)

(9)

# DATA AND CASE STUDY

This proposed framework is implemented in a case study conducted in a plywood industry located in Jombang, Indonesia. In this scenario, the choice of indicators is a critical aspect connected to the company's conditions. The production process of plywood involves 13 stages, including log cutting, rotary, clipper, dryer, composer, setting, glue, press, sizer, putty, sander, grading, and packaging. A Focus Group Discussion (FGD) facilitated by three experts evaluated the weight of the indicators through pairwise comparisons of each ergonomic aspect and indicator. The pairwise comparison results for each indicator are shown in **TABLE 2**

**TABLE 2.** Evaluation of each indicator on the social side using pairwise comparisons

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Indicators** | **Pair-wise Comparisons** | | | | | |
| Time | Physical Load | Mental Load | Safety Risk Assessment | Posture Assessment | Noise Level |
| Time | 1 | ½ | 3 | 1 | 2 | 2 |
| Physical Load |  | 1 | 3 | 2 | 3 | ½ |
| Mental Load |  |  | 1 | 1 | ½ | 1 |
| Safety Risk Assessment |  |  |  | 1 | 1 | 1 |
| Posture Assessment |  |  |  |  | 1 | ½ |
| Noise Level |  |  |  |  |  | 1 |

# RESULTS AND DISCUSSION

The determination of indicator weights in this study is guided by the relevance of each indicator. Decision-makers' preferences, employing the AHP method, establish these weights, as illustrated in **TABLE 3**. The results reveal that the mental load indicator carries the highest weight of 0.253. This suggests that mental load substantially affects ergonomic manufacturing performance, given its long-term impact on company performance. High mental load among workers significantly influences productivity, with excessive labor demands being a major source of workplace stress [[23](#_ENREF_23), [24](#_ENREF_24)]. Posture assessment also carries a significant weight of 0.207. This highlights the critical role of workers' body positions and movements in enhancing ergonomic manufacturing efficiency. Poor ergonomic posture can result in physical problems like back, neck, and joint pain, which can ultimately impact both employee performance and overall company productivity [[25](#_ENREF_25)]. Even though safety risk assessment ranks third with a weight of 0.170, it still plays a crucial role in assessing ergonomic performance. Significant safety hazards can result in severe injuries to employees, hinder productivity, and pose life-threatening dangers [[26](#_ENREF_26)].

**TABLE 3.** Weight assessment for each indicator

|  |  |
| --- | --- |
| **Indicators** | **Weight Indicators** |
| Time | 0.117 |
| Physical Load | 0.107 |
| Mental Load | 0.253 |
| Safety Risk Assessment | 0.170 |
| Posture Assessment | 0.207 |
| Noise Level | 0.147 |

The production process mapping using Ergo-VSM reveals that Mental Load and Safety Risk Assessment have low efficiency values of 58.46% and 59.94%, respectively, as indicated in **FIGURE 2**.

These results pinpoint critical areas in the company's ergonomic performance needing further attention and substantial improvement. Consequently, the company should focus on enhancing efficiency in these areas by implementing stress and mental load reduction programs and boosting workers' awareness and skills in identifying and mitigating workplace accident risks [[27](#_ENREF_27)]. Moreover, the company also needs to conduct further analysis to identify the factors affecting efficiency in both indicators, as well as develop effective strategies to improve the company's ergonomic performance. Thus, the company can increase productivity and efficiency, as well as reduce the risk of accidents and health issues among workers [[28](#_ENREF_28)].



**FIGURE 2.** Mapping results for Ergo-VSM

The Manufacturing Ergonomic Score Index (MES) serves to assess the ergonomic performance of manufacturing processes. Findings reveal that factors like Time, Physical Load, Posture Evaluation, and Noise Levels significantly influence MES, with contributions ranging from 75% to 66.46%, as seen in **TABLE 4**. On the other hand, Mental Load and Safety Risk show lower efficiencies, at 58.46% and 59.94%, respectively. The overall MES stands at 66.17%, suggesting that while some ergonomic factors are well managed, others need improvement. To boost employee well-being and productivity, the company should prioritize addressing the low-efficiency indicators: Mental Load and Safety Risk Assessment. To tackle these issues, measures such as implementing stress and mental load reduction programs, and enhancing worker awareness and skills in recognizing and reducing workplace accident risks, are recommended. Additionally, the company can improve worker skills through targeted training and education and optimize workplace and equipment design to lessen mental load and safety risks. This approach will not only enhance worker well-being and productivity but also improve the overall ergonomic performance of the manufacturing process.

**TABLE 4.** Manufacturing Ergonomic Score Assessment results

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Indicators** | **Indicator’s efficiency (%)** | **Weight Indicators (%)** | **Dimension Index (%)** | **MES (%)** |
| Time | 74.40 | 0.117 | 8.705 | 66.17 |
| Physical Load | 75 | 0.107 | 8.025 |
| Mental Load | 58.46 | 0.253 | 14.79 |
| Safety Risk Assessment | 59.94 | 0.170 | 10.189 |
| Posture Assessment | 70.98 | 0.207 | 14.69 |
| Noise Level | 66.46 | 0.147 | 9.769 |

# CONCLUSIONS

This study successfully created a new framework for Ergonomic Performance Assessment (EPA) tailored for manufacturing processes. The framework was implemented to evaluate ergonomic performance across various production lines, yielding significant improvements. Additionally, the research incorporated lean manufacturing and ergonomic principles to enhance ergonomic performance in animal feed production. The results highlight that using EPA is an effective method for boosting ergonomic manufacturing performance. However, the study's scope was limited to the production lines of a particular company and did not explore a wider range of ergonomic risk indicators. Despite these limitations, the findings have broad applicability and can be extended to other manufacturing sectors, offering valuable insights and practical guidance for improving ergonomic performance in manufacturing.

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