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Research Article

An Integrated Framework for Ergonomic Performance Assessment in Food Manufacturing: A Case Study Using Ergo-VSM, AHP, and TLS

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ABSTRACT

In food processing industries, particularly nut-based production that relies heavily on manual labor, ergonomic challenges related to repetitive motion, prolonged static postures, and thermal stress are increasingly prominent due to rising production demands. These issues are often concentrated at specific workstations and tend to be overlooked in conventional performance evaluations. To address this gap, this study proposes an integrated Ergonomic Performance Assessment (EPA) framework designed to evaluate ergonomic performance comprehensively across the entire production line. The framework integrates Ergonomic Value Stream Mapping (Ergo-VSM) for process visualization, the Analytical Hierarchy Process (AHP) for assigning weights to ergonomic criteria, and the Traffic Light System (TLS) for intuitive performance classification. A case study was conducted in a peanut processing facility, involving 8 workstations. Data were gathered through direct observations, detailed task analyses, and expert input from three expert via Focus Group Discussions (FGDs). Ergonomic indicators were derived from literature and expert consensus, weighted using AHP based on pairwise comparisons, and assessed using structured observational metrics. The results were visualized within the Ergo-VSM framework using TLS. Ergonomic performance was quantified through the Manufacturing Ergonomic Score (MES), which reached 69.15%. Based on a three-tier classification system low (<60%), moderate (60–90%), and high (>90%) this score falls within the moderate category, indicating several areas require improvement. Musculoskeletal disorder risks and high working temperatures were identified as the most critical concerns, particularly at thermally intensive and physically demanding workstations. The EPA framework enabled the visualization of ergonomic variation between workstations, allowing for systematic identification of priority areas for improvement. This research contributes to ergonomic evaluation literature by offering a structured, data-driven approach and provides practical insights for enhancing worker well-being and operational productivity.

Keywords: ergonomic performance assessment, manufacturing ergonomic score, Ergo-VSM, AHP, lean manufacturing

INTRODUCTION

The manufacturing sector plays a vital role in technological advancement and meeting market demands. However, production systems often face hidden challenges that affect efficiency and sustainability—one of which is ergonomics-related issues [1]. The implementation of ergonomic principles is essential to maintaining a balance between productivity and worker well-being [2, 3]. Unmanaged physical and mental workloads may elevate the incidence of injury, fatigue, and stress, thereby reducing overall industrial performance [4, 5]. These issues are prominent in the processed nut food industry, which relies heavily on manual tasks such as material handling, boiling, drying, and sorting [6]. Preliminary observations at the partner facility involved in this case study revealed that over 70% of production activities were performed manually without the use of lifting aids. Environmental measurements also indicated thermal exposure ranging from 36°C to 38°C during the boiling and roasting stages. These findings align with initial field observations, where most workers on the snack food production line reported muscle discomfort and prolonged static postures. Moreover, during the sorting and packaging phases, workers face high cognitive demands to ensure accuracy and product quality consistency, requiring sustained concentration and attention [7]. The combination of physical and cognitive strain raises the risk of musculoskeletal disorders and stress, underscoring the need for strategic ergonomic management to maintain competitiveness [8, 9]. Therefore, a systematic approach is needed to identify high-risk points in the production flow and support continuous improvement.

Despite growing recognition of ergonomics in industrial contexts, many studies on ergonomic assessment and process mapping in manufacturing remain limited in scope and lack methodological integration. For instance, studies by Arce, et al. [10] and Edwards and Winkel [11] employed Value Stream Mapping (VSM) to visualize production processes but did not incorporate ergonomic assessment, thereby failing to uncover hidden risks within work areas. Other study, such as those by Sakthi Nagaraj, et al. [12] and Edwards, et al. [13], included ergonomic evaluation but lacked indicator weighting and score normalization, leading to potential bias and limited comparability across workstations. Most also focused only on physical workload and musculoskeletal disorders, ignoring cognitive demands and environmental factors like heat. These limitations make them inadequate for capturing the full complexity of ergonomic issues in labor-intensive food processing industries. Only a few studies, such as Domínguez-Alfaro, et al. [14], have attempted to integrate visualization tools like the Traffic Light System (TLS); however, these efforts still fall short due to the absence of efficiency scoring or systematic indicator weighting. Additionally, standard tools like REBA and RULA typically analyze static postures in isolation and ignore task interdependencies and links to production metrics [15]. Thus, a more comprehensive approach is needed one that spans all production stages, addresses multiple ergonomic risk dimensions, and supports decision-making through structured performance visualization.

To address the limitations of prior ergonomic assessments, mapping ergonomic performance across all production stages has become essential to ensure both worker well-being and productivity. This approach enables companies to identify high-risk areas and take corrective actions accordingly [16, 17]. The strength of this approach lies in its ability to offer a comprehensive understanding of ergonomic impacts at each point along the work process [18]. One of the most widely recognized tools for process mapping is Value Stream Mapping (VSM), which has been extensively used in strategic planning and change management within the manufacturing sector [19-21]. While VSM is highly effective in visualizing and communicating process flows [22-25], the need to incorporate ergonomic considerations into this framework is becoming increasingly urgent. To fill this gap, the Ergo-Value Stream Mapping (Ergo-VSM) method was introduced, incorporating ergonomic aspects into the traditional VSM framework [18]. Ergo-VSM has shown effectiveness in identifying ergonomic risks, reducing mental workload, and eliminating non-value-added tasks within production lines [16, 26].

Despite the advantages offered by Ergo-VSM, its methodological application remains constrained by several critical limitations. Specifically, Ergo-VSM has predominantly relied on qualitative mapping based on direct observation and simple checklists, without incorporating structured weighting or numerical quantification of ergonomic scores [18]. Furthermore, this approach does not account for work time variability, excludes psychosocial risks such as

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social pressure and occupational stress, and is highly dependent on assessor subjectivity [10]. These limitations indicate that Ergo-VSM has yet to be fully aligned with the principles of systems ergonomics, human factors engineering, or participatory design frameworks [16]. To address these shortcomings, the present study proposes an integrated approach that combines VSM with analytical methods such as the Analytic Hierarchy Process (AHP) for indicator weighting, linear normalization for efficiency scoring, and visualization through the Traffic Light System (TLS). This integration enhances the objectivity of ergonomic evaluations and advances the mapping approach toward a more systematic and context-sensitive quantitative assessment framework.

These gaps in the existing literature underscore the need for an ergonomic evaluation approach that moves beyond qualitative checklists, incorporates structured indicator weighting, and provides a more systematic and quantitative performance visualization. In response, this study develops an Ergonomic Performance Assessment (EPA) framework that integrates Ergo-Value Stream Mapping (Ergo-VSM) for process visualization, the Analytic Hierarchy Process (AHP) for structured ergonomic indicator weighting, and the Traffic Light System (TLS) for intuitive performance classification. These three methods are not only complementary in functionality but are also aligned in terms of logical structure, data scale, and practical applicability on the production floor. AHP is selected due to its flexibility in capturing expert judgment through rational weighting [27], offering a more context-sensitive approach compared to alternatives such as the Best Worst Method (BWM) or entropy-based weighting, which are less suited for ergonomic issues. TLS, meanwhile, is chosen for its communicative effectiveness in conveying risk prioritization to decision-makers at the operational level [28]. The resulting Manufacturing Ergonomic Score (MES) is calculated as a composite index that captures physical, cognitive, and environmental workload dimensions, enabling a holistic evaluation of ergonomic performance across production workstations.

Although the Ergo-VSM approach has been applied across various manufacturing sectors such as electronics [10, 29] and textiles [12], most existing studies have utilized it primarily for qualitative mapping without systematically assessing the efficiency of ergonomic indicators [30]. However, effective ergonomic evaluation in manufacturing contexts requires relevant and quantifiable indicators to support strategic decision-making. The TLS-based visualization developed in this study addresses this gap by offering rapid and informative risk prioritization mapping. Accordingly, the proposed EPA framework contributes to the advancement of data-driven and process-based ergonomic evaluation methods that are more objective, practical, and contextually relevant particularly for labor-intensive food manufacturing environments.

This study aims to enhance ergonomic evaluation in manufacturing, with a focus on the processed nut food industry, which faces serious ergonomic challenges due to repetitive and labor-intensive tasks. It introduces a unified framework that integrates Ergonomic Value Stream Mapping (Ergo-VSM), the Analytical Hierarchy Process (AHP), and the Traffic Light System (TLS), along with the Manufacturing Ergonomic Score (MES) as a quantitative performance indicator. To date, few studies have combined these three approaches into a unified framework tailored to labor-intensive food processing industries. By developing a structured, data-driven evaluation system, this framework aims to assist companies in objectively prioritizing ergonomic improvements, enhancing worker well-being, and strengthening operational productivity. This approach may also be adapted to other manufacturing sectors with similar ergonomic challenges, although its generalizability depends on the specific characteristics of each industry. Nonetheless, while this study focuses on the processed nut food industry, the proposed framework provides a useful reference for broader ergonomic assessment in manufacturing.

METHODS

This section presents the conceptual framework for assessing ergonomic performance in manufacturing industries, as illustrated in Figure 1. The process begins with problem identification and the collection of ergonomic indicators

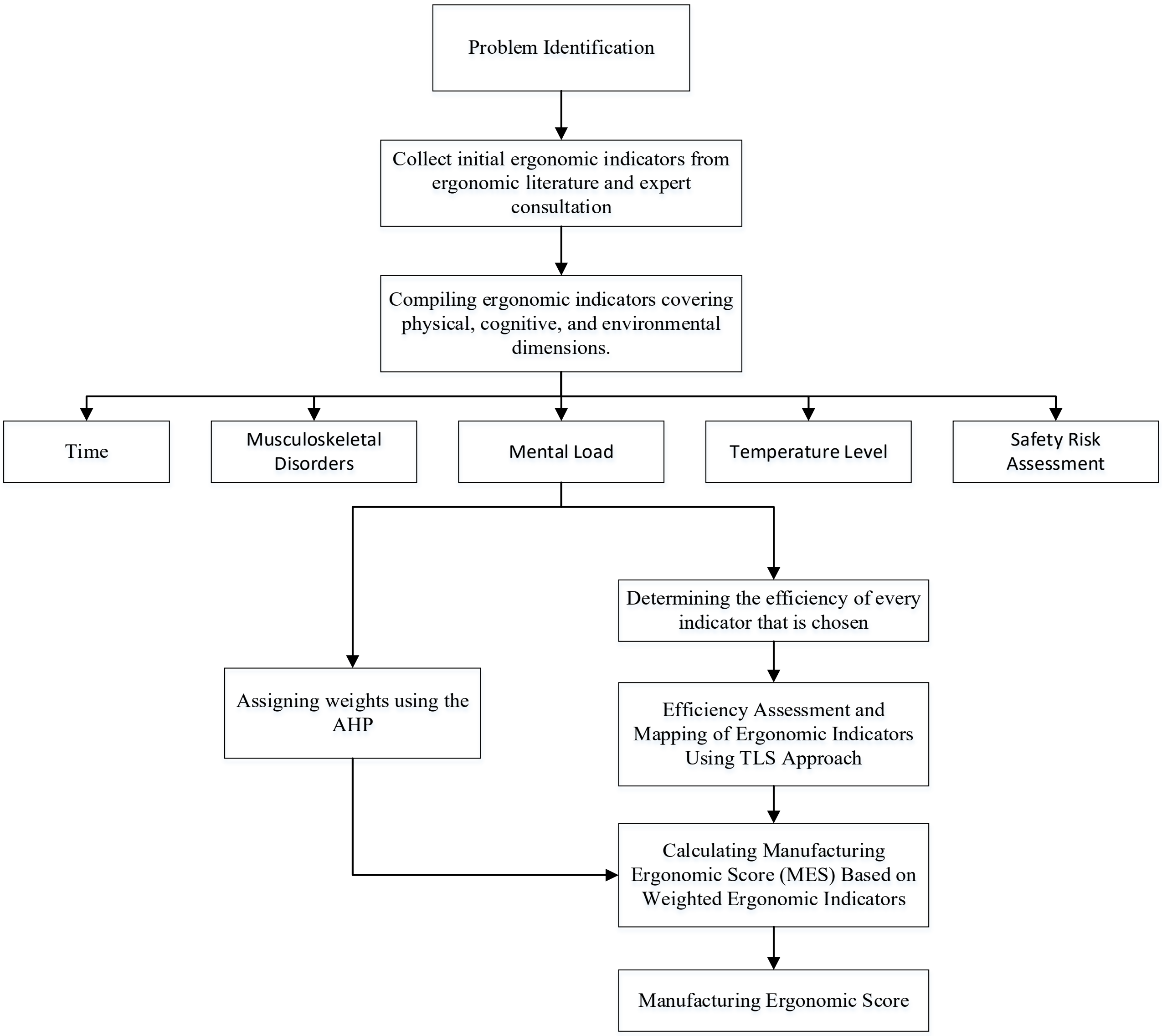

Figure 1. Conceptual Framework for Ergonomic Performance Assessment in Manufacturing

from the literature and expert consultations, covering five dimensions: time, musculoskeletal disorders, mental load, environmental temperature, and safety risks. The selected indicators are weighted using the Analytic Hierarchy Process (AHP), and their efficiency is subsequently evaluated and mapped using the Traffic Light System (TLS) approach. The final outcome, referred to as the Manufacturing Ergonomic Score (MES), is derived from the integration of the indicator weights and efficiency values, providing a comprehensive overview of ergonomic conditions across the production line.

Identification and Selection of Relevant Ergonomic Indicators

The proposed EPA framework starts with selecting ergonomic indicators. This process begins with a detailed analysis of the value stream, focusing on identifying the most important ergonomic factors. To ensure accurate representation, a Focus Group Discussion (FGD) was held with ergonomics experts, supported by a thorough literature review on ergonomic assessment [31]. Table 1 shows the identified indicators from the literature. The five main indicators used in the development of Ergo-VSM—Time, Musculoskeletal Disorders, Mental Load, Temperature Level, and Safety Risk Assessment—were chosen based on how often they appear in previous studies,

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Table 1. Indicators of Ergonomic Assessment

Ergonomic Indicator	Reference
Time	Hartini, et al. [30]; Faulkner and Badurdeen [25]
Musculoskeletal Disorders	Domínguez-Alfaro, et al. [14]
Mental Load	Hart and Staveland [32]
Temperature Level	Faulkner and Badurdeen [25]
Safety Risk Assessment	Arumugaprabu, et al. [33]

their relevance to manual work in the food processing industry, and their ability to reflect physical, cognitive, and environmental aspects of ergonomics. To reduce subjectivity during the FGD, structured evaluation guidelines were provided, and discussions were facilitated to ensure each participant contributed equally. Final decisions on indicator selection were made through open consensus. With these considerations, the EPA framework provides a clear picture of ergonomic conditions in manufacturing workplaces.

Ergonomic indicators such as Time, Musculoskeletal Disorders, Mental Load, Temperature Level, and Safety Risk Assessment play pivotal roles in the ergonomic assessment process. Time is critical because it reflects task duration and process efficiency, which indirectly signal exposure to prolonged static postures or repetitive ergonomic stress. According to Hartini, et al. [30], time measurement can help identify potential bottlenecks and workload imbalances that may lead to both physical and mental fatigue. Meanwhile, Musculoskeletal Disorders directly capture the physical strain experienced by workers during manual operations. Domínguez-Alfaro, et al. [14] assert that evaluating musculoskeletal complaints enables companies to monitor symptoms arising from repetitive ergonomics and lifting activities, thereby facilitating the design of targeted ergonomic interventions to prevent injury.

Mental load reflects cognitive demands such as concentration, decision-making, and sustained attention. Hart and Staveland [32] stated that assessing mental workload helps organizations manage occupational stress and supports cognitive resilience. Although this indicator is subjective, it is converted into numerical form using standardized instruments such as the NASA-TLX, which has been empirically validated. This approach enables individual perceptions to be transformed into systematically measurable scores. However, the interpretation of results must still consider task context and worker characteristics. Temperature level is a critical indicator, as hot working environments can affect both comfort and safety. Faulkner and Badurdeen [25] found that high temperatures are associated with fatigue and reduced focus. Meanwhile, Safety Risk Assessment is used to identify potential hazards at each workstation. Arumugaprabu, et al. [33], emphasized that safety risk assessments support accident prevention strategies and help create a safe working environment. By integrating these physical and cognitive indicators, the ergonomic assessment approach provides a comprehensive understanding that can be used to improve occupational health and productivity.

Formulation of Efficiency Metrics for Each Ergonomic Indicator

The efficiency of each ergonomic indicator is evaluated to measure performance at different stages of the production process. The efficiency formulas were developed based on a literature review to ensure a structured and objective analysis. Table 2 presents the specific formulas used for each indicator. Efficiency scores are calculated using a linear normalization method, with the general formula: efficiency = 1 – (actual value / maximum value). This method is applied to both quantitative data and subjective indicators, such as mental load and safety risk, to ensure consistent numerical representation. Although it assumes a linear relationship between workload and ergonomic efficiency, the context and limitations of each indicator are still considered. The efficiency scores are then used to classify

Table 2. Ergonomic Indicator Formulas

No.	Indicators	The related-Metrics	Equation	Sources
1.	Time (Minute)	TE = Time Efficiency VAT = Time in Value-Added Activities TT = Total Time NVAT = = Time in Non-Value-Added Activities i = index of production process (i ϵ n)	$TE = \frac{VAT}{TT}$ $VAT = \sum_{i=1}^{n}(VATi)$ $NVAT = \sum_{i=1}^{n}(NVATi)$ $TT = VAT + NVAT$	[30]
2.	Musculoskeletal Disorders	MSD_s= Musculoskeletal Disorder Rate NR = Number of employees reporting MSDs in the area N = Total employees reporting MSDs	$MSD_s = \left(\frac{NR}{N_{total}}\right)x100$	[14]
3.	Mental Load Index	Nasa Task Load Index (NASA TLX) MLIE= Mental load index efisiensi	$MLIE = 1 - (\frac{\text{Score NASA TLX}}{\text{Max score NASA TLX}})$	[32]
4.	Temperature Level	TL = Temperature Level Efficiency in the Area ZE = Zones exceeding permitted temperature in the area Z_{total} = Total zones assessed	$TL = \left(\frac{ZE}{Z_{total}}\right)x100$	[14]
5.	Safety Risk Assessment	HIRA	$HIRA = 1 - (\frac{\text{Score HIRA}}{25})$	[35]

performance using the Traffic Light System (TLS), which will be explained in the next section. This approach improves the accuracy of ergonomic evaluation and supports strategic improvements in the manufacturing process [34].

Indicator Weighting with AHP

Weighting the indicators to calculate the Manufacturing Ergonomic Score (MES) is conducted using the Analytical Hierarchy Process (AHP). AHP is used to assign weights to each indicator based on their importance level [36]. This step is essential to understand the relative contribution of each indicator to overall ergonomic performance in manufacturing [37]. The indicators identified in the earlier Focus Group Discussion (FGD) were then weighted to prioritize those with the greatest influence on ergonomic risk. The FGD involved three experts from different backgrounds: an ergonomics lecturer, a production line manager, and a senior worker from a snack food industry. The worker had over three years of experience on the main production line and was familiar with both physical and mental workloads in daily operations. The discussion took place in two rounds to reach agreement on the selected indicators. Disagreements were resolved through open discussions supported by recent literature, and consensus was achieved before conducting the pairwise comparison using AHP. This method ensures the evaluation process is objective, systematic, and based on a clear hierarchy [38].

Pairwise comparisons between ergonomic indicators were conducted through structured discussions in Focus Group Discussions (FGDs), using the 9-point scale developed by Saaty [39]. In this scale, a value of 1 indicates equal importance between two indicators, while values from 2 to 9 represent increasing levels of preference, ranging from weak to extreme importance. Each comparison result is expressed as a p_{ij} value, representing the relative importance

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of indicator i compared to indicator j. All p_{ij} values are organized into a pairwise comparison matrix P, as presented in Equation (1).

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{21} & \cdots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{bmatrix} \tag{1}$$

To obtain the normalized matrix, each element in a column of the pairwise comparison matrix P is divided by the sum of all elements in that column. The resulting normalized matrix is expressed in Equation (2).

$$P = \begin{bmatrix} \frac{p_{11}}{\sum_{i=1}^{n} p_{11}} & \frac{p_{12}}{\sum_{i=1}^{n} p_{12}} & \cdots & \frac{p_{1n}}{\sum_{i=1}^{n} p_{1n}} \\ \frac{p_{21}}{\sum_{i=1}^{n} p_{21}} & \frac{p_{22}}{\sum_{i=1}^{n} p_{22}} & \cdots & \frac{p_{2n}}{\sum_{i=1}^{n} p_{2n}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{p_{n1}}{\sum_{i=1}^{n} p_{n1}} & \frac{p_{n2}}{\sum_{i=1}^{n} p_{n2}} & \cdots & \frac{p_{nn}}{\sum_{i=1}^{n} p_{nn}} \end{bmatrix} \tag{2}$$

The local weight for each indicator is calculated by taking the average value of each row in the normalized matrix, as stated in Equation (3). The resulting local weights are then arranged to form the weight vector W, as presented in Equation (4).

$$W_i = \frac{\sum_{i=1}^{n} p'_{ij}}{n} \tag{3}$$

$$W = \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{bmatrix} \tag{4}$$

Next, to evaluate the consistency of the weights, the weight vector W is multiplied by the pairwise comparison matrix P to produce a new vector W' as expressed in Equation (5). Subsequently, the maximum eigenvalue (λ_{max}) is calculated by taking the average ratio between the elements of W' and W as formulated in Equation (6).

$$W' = PW = \begin{bmatrix} W'_1 \\ W'_2 \\ \vdots \\ W'_n \end{bmatrix} \tag{5}$$

$$\lambda_{max} = \frac{1}{n}\left(\frac{W'_1}{W_1} + \frac{W'_2}{W_2} + \cdots + \frac{W'_n}{W_n}\right) \tag{6}$$

Consistency evaluation is a critical aspect of the AHP method. The consistency index (CI) and consistency ratio (CR) are computed using Equations (7) and (8), respectively. If the consistency ratio is less than 10%, the pairwise comparison matrix is deemed acceptable. The indicator weights derived from AHP serve as essential metrics for evaluating manufacturing ergonomics performance.

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{7}$$

$$CR = \frac{CI}{Random\ Index\ (RI)} \tag{8}$$

Mapping of Ergo-VSM and TLS based on the Efficiency Assessment of Indicators Ergonomic

Ergonomic indicators were mapped using Ergonomic Value Stream Mapping (Ergo-VSM) to visualize the value stream related to ergonomic aspects in the production process [10]. This method helps companies identify high-risk areas, find improvement opportunities, and assess the impact of changes on the production system in a structured way. Mapping was carried out at the workstation level, where each node represents a key activity along the production line, from Raw Material Receiving to Warehouse Storage. Data for the indicators Time, Musculoskeletal Disorders, Mental Load, Temperature Level, and Safety Risk Assessment were collected through direct observation, time measurements, environmental monitoring, and perception-based questionnaires such as NASA-TLX and HIRA. Each indicator was calculated individually for every workstation and then converted into efficiency values using a linear normalization method.

The evaluated indicators were mapped into the Ergo-VSM using the Traffic Light System (TLS), which helps simplify the identification of ergonomic performance levels [37]: TLS uses three color categories: red for low performance, yellow for moderate, and green for optimal. Efficiency scores are grouped into red (below 60%), indicating the need for immediate improvement; yellow (60–90%), showing moderate performance that should be improved; and green (above 90%), representing performance that exceeds the target. These thresholds were adapted from the TLS method used by Hartini, et al. [30] and refined through expert discussions in this study to match the conditions of food manufacturing environments. This visual approach helps clarify how ergonomic indicators relate to each production stage and allows organizations to focus improvement efforts on areas with higher risk.

Manufacturing Ergonomic Score (MES) Assessment

The final stage of the framework involves calculating the Manufacturing Ergonomic Score (MES), which is obtained by multiplying the efficiency of each indicator by its corresponding weight, as presented in Equation (9). The MES provides a comprehensive overview of the overall manufacturing ergonomics performance, thereby assisting companies in identifying strategic improvement opportunities and setting long-term sustainability targets.

$$\mathrm{MES} = \sum\nolimits_{\mathrm{i}}^{\mathrm{n}} W_i \cdot \mathrm{E}_i \tag{9}$$

where MES denotes the Manufacturing Ergonomic Score, $\mathrm{W_i}$ represents the efficiency of the i-th, ergonomic indicator, $\mathrm{E_i}$ is the weight assigned to the i-th indicator, and n refers to the total number of indicators evaluated in the ergonomics assessment.

Case Implementation

The proposed framework was applied to a case study in a peanut-based food industry consisting of eight main stages: raw material reception, boiling, drying, gravity separation, sorting, roasting, packaging, and warehouse storage. Each stage was assessed using five ergonomic indicators: Time, MSDs, Mental Load, Temperature, and Safety Risk. The ergonomic indicator weights were determined using pairwise comparisons during a Focus Group Discussion (FGD) with three domain experts, following the Saaty scale (1–9). Table 3 presents the completed reciprocal matrix, reflecting expert judgments on the relative importance of each indicator in this specific production context. While

Table 3. Pairwise Comparison of Each Indicators

Indicators	Pair-wise Comparisons				
	Time	Musculoskeletal Disorders	Mental Load	Temperature Level	Safety Risk Assessment
Time	1	1/3	1/3	1	1/2
Musculoskeletal Disorders	3	1	3	1	3
Mental Load	3	1/3	1	1	1
Temperature Level	1	1	1	1	2
Safety Risk Assessment	2	1/3	1	1/2	1

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Table 4. Weight Assessment for Each Indicator

Indicators	Weight Indicators
Time	0.11
Musculoskeletal Disorders	0.35
Mental Load	0.18
Temperature Level	0.21
Safety Risk Assessment	0.14

Time was considered important, MSDs were rated higher due to frequent physical strain observed at multiple workstations. The consistency ratio (CR) of the matrix is discussed in the results section.

Ergonomic data were collected through direct observation, standardized instruments, and structured surveys across all workstations. Time was measured using a stopwatch, temperature with an infrared thermometer, mental workload with NASA-TLX, and safety risks via a HIRA checklist assessed by two trained evaluators. To ensure reliability, measurements were conducted over three working days under typical production conditions, with consistent personnel for each assessment type.

RESULT AND DISCUSSION

Indicator Weight Assessment Results

This section presents the results of weighting ergonomic indicators based on the decision-makers' preferences using the Analytical Hierarchy Process (AHP) method. Table 4 shows the weighting results, indicating that the calculations were performed consistently, as evidenced by a consistency ratio of 0.09, which is below the 10% threshold established in the AHP framework. This value confirms that the pairwise comparisons between indicators were conducted logically and systematically, ensuring that the resulting weights can be reliably utilized as a basis for subsequent evaluations.

The analysis results indicate that the Musculoskeletal Disorders indicator received the highest weight (0.35) based on expert evaluation, underscoring the need to prioritize the mitigation of musculoskeletal injury risks in the examined work environment. In peanut-based food production, workers are heavily engaged in manual tasks such as transporting raw materials, boiling, drying, and sorting all of which impose repetitive strain on the back, shoulders, and arms. These risks are compounded by working conditions involving static postures and repetitive movements, which substantially elevate the likelihood of musculoskeletal disorders over time [40, 41]. Accordingly, mitigating this risk should be a central component of ergonomic improvement efforts to support both worker well-being and operational sustainability.

The Temperature Level indicator ranked second with a weight of 0.21, emphasizing the critical role of temperature regulation in maintaining worker comfort and productivity. In peanut processing, several stages such as boiling and roasting generate considerable heat, which, if not adequately controlled, may lead to heat stress among workers [42]. Prior studies have demonstrated that prolonged exposure to elevated temperatures can impair concentration and increase the risk of fatigue-related accidents [43]. Thus, enhancements in ventilation systems and the provision of thermal protective measures should be considered integral to strategies aimed at improving occupational health conditions.

The Mental Load indicator received a weight of 0.18, suggesting that cognitive demands are considered relevant and should be addressed within the work context of the peanut processing industry. During the sorting and packaging stages, workers are required to maintain high levels of concentration and accuracy over extended periods, thereby increasing the risk of stress and mental fatigue. Unmanaged mental workload can impair concentration, elevate the likelihood of errors, and negatively impact productivity [44]. Therefore, task rotation management and the provision of adequate rest periods are recommended as supportive strategies to maintain workers' mental well-being.

The Safety Risk Assessment indicator obtained a weight of 0.14, indicating that occupational safety must remain an integral part of a comprehensive ergonomic approach in peanut processing environments. Hazards such as slipping in wet areas, burns from heating equipment, and injuries caused by separating machines must be proactively identified and mitigated. The implementation of a safety system grounded in rigorous risk assessment can significantly reduce accident potential and support production continuity [45]. Meanwhile, the Time indicator received the lowest weight (0.11), making it the least contributing factor in this analysis, though it remains relevant in the context of operational efficiency. Effective time management during boiling, drying, and packaging stages can help prevent product quality degradation and reduce workers' exposure to ergonomic risks. Hence, optimizing work time should be considered an essential component in efforts to enhance both productivity and occupational health.

Ergonomic Value Stream Mapping

This section presents the production flow mapping using Ergonomic Value Stream Mapping (Ergo-VSM) as illustrated in Figure 2. The map outlines the sequence of production activities from Raw Material Receiving to Warehouse Storage, where each node or workstation represents a core production process. Each station is mapped based on five ergonomic indicators: Time, Musculoskeletal Disorders, Mental Load, Temperature Level, and Safety Risk Assessment. The efficiency value for each indicator is calculated individually at each workstation and then categorized using the Traffic Light System (TLS) approach: green for efficiency levels above 90%, yellow for 60–90%, and red for below 60%. The unit of analysis employed in this mapping is at the station level, representing the key tasks across the production line.

The mapping results showed that two main indicators with low performance were Mental Load and Safety Risk Assessment. For the Mental Load indicator, five workstations were in the red category: Raw Material Receiving (49%), Boiling (55%), Sorting (40%), Baking (55%), and Packaging (52%). For Safety Risk Assessment, two stations were also marked red: Raw Material Receiving (45%) and Boiling (52%). In addition, the Boiling station had low

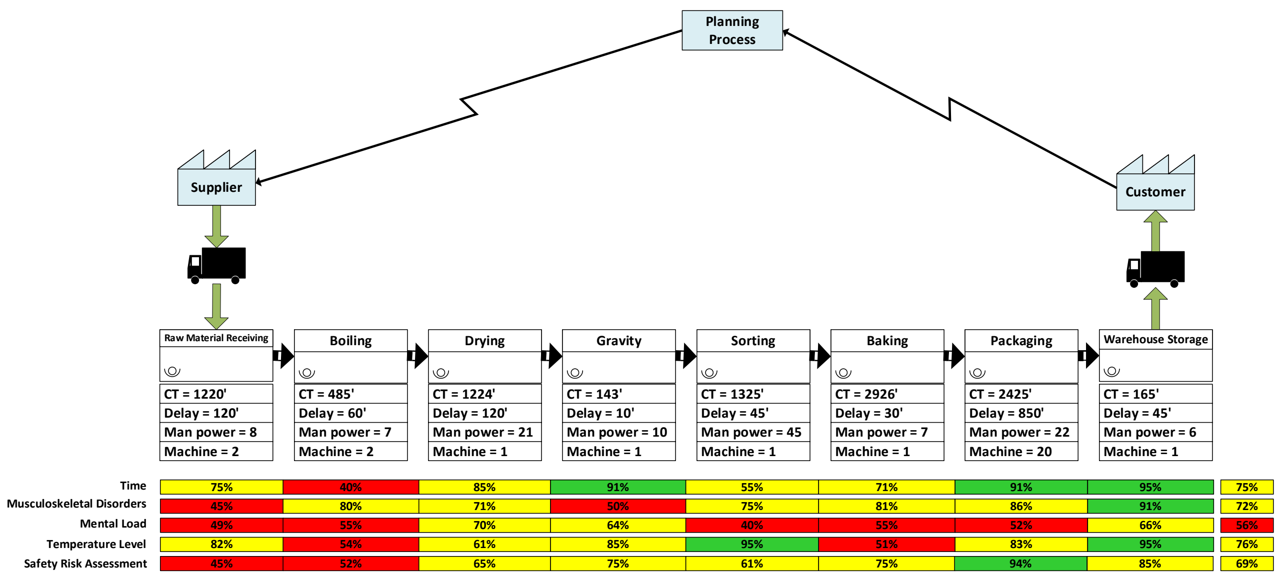

Figure 2. Ergo-VSM Mapping

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efficiency scores in Time (40%) and Temperature Level (54%), making it a critical area in the production line. The boiling process involves high heat, intense physical effort, and long working hours, which together cause significant physical and mental fatigue. As explained in the methodology, efficiency values for qualitative indicators like Mental Load and Safety Risk Assessment were calculated through linear normalization of subjective data gathered from structured surveys and checklists. This method allows perceived risks to be converted into measurable data, enabling fair comparison across indicators and clear visualization through Ergo-VSM.

These findings reflect the inherent characteristics of peanut-based processed food production, which is predominantly manual, repetitive, and carried out in high-temperature environments. Based on the indicator weights shown in Table 4, Musculoskeletal Disorders (MSDs), which received the highest weight (0.35), also showed poor performance at two key stations: Raw Material Receiving and Boiling. This supports the need to prioritize ergonomic improvements in these areas. Meanwhile, Mental Load, with a moderate weight (0.18), was the lowest-performing indicator overall, with five workstations falling into the red zone. This suggests that, although experts did not rate it as the most critical, field data show it places a high cognitive burden on workers. Similarly, Safety Risk Assessment, which had the lowest weight (0.14), also showed poor performance in several workstations. This highlights a gap between expert perceptions and actual working conditions. These differences emphasize the need to combine expert-based weighting methods (like AHP) with real-time performance data (from TLS) to set ergonomic priorities more accurately. Therefore, workstations such as Boiling, Sorting, Baking, and Packaging should be the main focus of ergonomic improvements. Recommended actions include redesigning workstations, rotating tasks to balance physical and mental demands, improving ventilation and cooling in hot areas, and conducting regular safety training. With this data-driven approach, companies can focus their efforts more effectively, helping to improve both productivity and sustainability.

Ergonomic Manufacturing Performance Score

This section presents the manufacturing ergonomics performance score as indicated by the MES index. The assessment results show that the total MES score reached 69.15%, indicating that the overall ergonomics performance falls within the moderate category. This value suggests that while most ergonomic aspects have been implemented, there remains significant room for improvement, particularly in work areas with low efficiency levels. Figure 3 illustrates the distribution of MES scores across five main indicators: Musculoskeletal Disorders (MSDs),

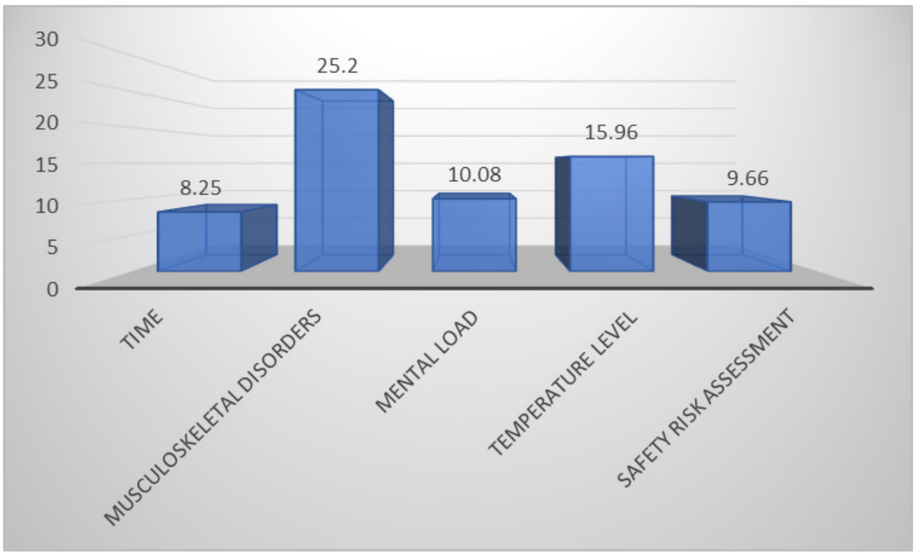

Figure 3. Index Performance for Each Ergonomic Indicator

Temperature Level, Mental Load, Safety Risk Assessment, and Time. Among the five indicators, the largest contribution to the MES score was attributed to Musculoskeletal Disorders (MSDs), accounting for 25.2%. This figure indicates that musculoskeletal issues represent the most dominant ergonomic risk factor in the workplace environment. It reflects low efficiency levels at several workstations such as raw material receiving and gravity separation where workers are exposed to significant physical loads due to repetitive tasks involving lifting, pushing, and prolonged static postures.

Subsequently, the Temperature Level indicator ranked second with a score of 15.96, showing that workplace temperature especially during boiling and baking has not yet reached ideal conditions. Prolonged exposure to heat without proper ventilation or cooling systems can lower worker comfort and increase the risk of fatigue and errors [46, 47]. The Mental Load indicator scored 10.08, indicating that cognitive pressure is still a concern, particularly during sorting and packaging. These tasks require sustained focus and accuracy, which can cause mental fatigue if not supported by task rotation or adequate rest [44]. The remaining two indicators with the lowest scores were Safety Risk Assessment (9.66) and Time (8.25). The low score for the safety indicator highlights ongoing risks of workplace accidents, especially at stations with hot equipment and slippery surfaces, such as the boiling and raw material receiving areas. The low Time score suggests that work time efficiency is still suboptimal. This issue may result from uneven process durations, particularly in boiling, drying, and packaging stages, where unsynchronized task times cause delays and idle periods, increasing the overall workload.

Overall, the MES results show that physical aspects (MSDs and temperature), cognitive aspects (mental load), and work system aspects (time and safety) still need improvement through a comprehensive ergonomic approach. Improvement efforts should target workstations with low efficiency scores by applying strategies such as layout redesign, better workload distribution, improved ventilation, and safety training and time management programs [48, 49]. With proper interventions, ergonomic performance across the production line can be improved significantly, supporting both the sustainability and productivity of the peanut processing industry.

Research Implications

This section outlines the research implications for ergonomics-based manufacturing performance assessment, both from academic and managerial perspectives. The study makes a theoretical contribution by enriching the literature on ergonomic performance evaluation methods within the food manufacturing sector, particularly in the processed nut industry. In addition, the research has practical implications for operational managers and decision-makers, especially in efforts to evaluate and enhance ergonomic practices within production environments. A more detailed explanation of the theoretical and managerial implications derived from the research findings is presented in the following sections.

Academic Implications

Based on the theoretical implications, the findings of this study contribute significantly to the understanding of how to comprehensively evaluate ergonomics-based manufacturing performance. By incorporating five key indicators musculoskeletal disorders, ambient temperature, mental workload, safety risks, and time efficiency this approach integrates both physical and cognitive dimensions within a unified assessment framework. The study employs the Analytical Hierarchy Process (AHP) as a weighting method to determine the relative priorities among these indicators and applies ergonomic efficiency evaluation at the workstation level. While both AHP and efficiency-based evaluation methods have been widely adopted across various fields, their integrated application in the context of ergonomic assessment within the food manufacturing sector remains relatively underexplored in the existing literature. Moreover, the use of a visualization system based on the Traffic Light System (TLS) for ergonomic

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performance mapping enhances the ability to quickly identify critical areas for improvement. Although the results of this study are context-specific, the proposed approach presents a promising alternative for further investigation in similar industries that share manual and repetitive work process characteristics.

Managerial Implications

From a managerial perspective, the implications of this study offer valuable contributions for managers and decision-makers seeking to enhance ergonomic performance in the processed nut food industry. The findings indicate that the indicators of Musculoskeletal Disorders (MSDs), Mental Load, and Safety Risk Assessment still exhibit low performance levels. These deficiencies are particularly evident at workstations such as raw material receiving, boiling, sorting, and packaging. Therefore, to improve ergonomic performance, especially regarding MSDs and Mental Load, it is recommended that the processed nut food industry develop and implement Standard Operating Procedures (SOPs) focused on reducing workers' physical and mental loads [50]. Additional measures should also be undertaken, including providing comfortable rest areas for workers, adjusting work schedules to allow for mental recovery periods, and improving workplace design to minimize physical fatigue [51, 52].

The company must also establish realistic work targets, avoiding excessive pressure that could exacerbate workers' physical and mental burdens. Uncontrolled work stress may negatively affect employee well-being and long-term operational sustainability [53]. To address issues related to physical load, it is recommended that the company adopt ergonomic work design principles in accordance with guidelines from NIOSH and OSHA. For instance, the use of mechanical lift-assist devices in the raw material receiving area is suggested to reduce the frequency of manual lifting exceeding 23 kg, in line with the NIOSH Lifting Equation threshold [54]. Additionally, in the sorting process, it is advisable to optimize workstations by introducing adjustable-height tables and rearranging tools to conform to the ideal work zone defined in ISO 11228, thereby minimizing repetitive reach postures and static loads [55]. By implementing these standards-based ergonomic recommendations, the company is expected to achieve significant improvements in manufacturing ergonomic performance, ultimately supporting productivity, worker health, and the sustainability of operations in the peanut-based food processing industry.

CONCLUSION

This study proposes and applies the Ergonomic Performance Assessment (EPA) framework as a comprehensive approach to evaluate ergonomic performance, demonstrated through a case study in the peanut-based processed food industry. Within this framework, the Manufacturing Ergonomic Score (MES) was utilized as a quantitative index to measure the overall ergonomic performance across workstations. The assessment yielded a total MES value of 69.15%, which based on the Traffic Light System (TLS) employed in this study is classified as moderate performance (60–90%). This indicates that while several ergonomic elements have been implemented, there remain specific areas requiring further improvement. By integrating the Analytic Hierarchy Process (AHP), linear normalization for efficiency scoring, and Ergo-Value Stream Mapping (Ergo-VSM) within the TLS framework, the EPA approach provides a systematic and structured evaluation of ergonomic priorities at each workstation. Although the study is limited to a single site and does not include post-intervention assessments or cross-sectoral comparisons, the initial findings highlight the potential of the EPA framework supported by the MES index as a practical tool for identifying and prioritizing ergonomic risks. Future research should aim to empirically validate the effectiveness of EPA-driven interventions, expand its application across different industrial domains, and incorporate more diverse indicators to foster a holistic understanding of ergonomic conditions and their implications for both worker well-being and operational productivity.

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CONFLICT OF INTERESTS

The authors state that they do not have any competing interests.

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