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Work Systems in A Metal Casting Company Using MEAD Approach

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Abstract: Metal casting MSMEs in Indonesia often experience production inefficiencies, excessive workload, and inadequate occupational health and safety measures, resulting in reduced productivity and high worker fatigue. This study addresses these challenges by employing a macro-ergonomic framework to analyze and redesign work systems, specifically focusing on integrating cardiovascular workload (%CVL) analysis to quantify physiological strain, an approach rarely applied in small-scale industrial settings. The research was conducted at a representative metal casting MSME using the ten-step Macro-Ergonomic Analysis and Design (MEAD) method. Data collection involved direct field observations, organizational assessments, worker interviews, and physiological monitoring using wearable pulse sensors. Workload was evaluated using %CVL and energy expenditure calculations, while noise levels were measured using a sound level meter. Initial findings revealed that the average %CVL among workers reached 38.99%, categorized as "needs improvement," with notable issues including unsafe working conditions, excessive overtime, and noise exposure exceeding 95 dB. To mitigate these issues, interventions were designed, including developing standard operating procedures (SOPs) for personal protective equipment, improved supervisory practices, and an additional 10-minute work break based on rest time calculations. Post-intervention measurements showed a reduction in average %CVL to 23.35%, bringing most workers below the fatigue threshold of 30%, alongside reported improvements in safety awareness and work satisfaction. The results demonstrate that integrating %CVL-based workload analysis within a macro-ergonomic framework provides a practical and effective solution for enhancing occupational health and productivity in labor-intensive MSMEs. This approach offers a scalable model for policymakers and industry practitioners to address systemic ergonomic deficiencies in similar informal industrial sectors.

Keywords: Human, Macro-ergonomics, MEAD, Organizational, System, Work

Introduction

The work system is an essential element that determines the success and progress of a company [1]–[3]. A sound work system will support increased efficiency and productivity and minimize the risk of worker complaints or injuries during work [4], [5]. Along with technological developments and global competition, work systems are becoming more complex, regulating individual work processes and covering aspects of the organization, tools, and work environment. Therefore, companies must implement a macro-ergonomics approach to ensure the work system runs optimally.

Ceper is one of the sub-districts in Klaten Regency, Central Java, often called the center of the metal casting industry. Currently, the number of metal-casting MSMEs in Ceper reaches around 273 entrepreneurs who are members of the Batur Jaya Ceper Cooperative [6], [7]. In addition, around 300 metal-casting MSMEs are also incorporated into six industrial groups in Ceper [8]–[10]. The total workforce in the metal casting industry in Ceper is estimated to reach around 4,000 to 4,850 people [11]. Based on existing data, most of these metal-casting MSMEs use the Make to Order (MTO) method in their production process. MTO is a production strategy that produces goods based on customer orders or requests [12]–[15]. In addition, MTO allows companies to produce goods according to customer desires, ranging from unique designs, features, or functions [16]–[18]. The metal casting production process involves two main stages: metal casting and fabrication. Every MSME, in practice, always appears to have complaints and obstacles. As part of the pilot study in this research, PSL was selected as one of the MSMEs to be studied. Most of these enterprises adopt a MTO production model, which allows customization based on client specifications. While MTO offers product flexibility, it also introduces challenges in scheduling, resource allocation, and managing fluctuating workloads. These MSMEs often struggle to maintain production efficiency while accommodating order-specific variations. Limited technological resources, small production spaces, and fluctuating human resources exacerbate scheduling complexity and delay risk, especially when order volumes spike.

Although most of these MSMEs do not yet use integrated software-based planning systems, they rely on informal practices that have developed collectively. One common approach is a work queue system based on close relationships with repeat customers and deadline urgency. Scheduling is done daily by the workshop manager or owner, prioritizing orders based on product complexity and mold availability. The allocation of resources such as labor, raw materials, and machines is adjusted adaptively through direct communication between workers during morning briefings. Furthermore, flexible verbal communication routines serve as the primary mechanism for real-time schedule adjustments in the event of order changes or production disruptions. Thus, these MSMEs continue to build efficiency through collective experience and adaptive work structures formed from habit, rather than standardized work systems.

These complaints and constraints are found in the work system, affecting the company's overall performance if not immediately analyzed and improved. Five main problem factors in the work system of metal-casting MSMEs were identified through observations and interviews with workers and managers of the metal-casting MSMEs. The first factor is the human factor, which relates to workers' physical limitations and lack of expertise. The second factor is organizational factors, such as a nonoptimal work safety culture and a lack of appreciation for worker performance. The third factor is technology, in the form of limited production tools and machinery that need to be improved. The fourth factor is workers' tasks, where the workload is considered heavy and working time exceeds the provisions of government regulations. The fifth factor is the work environment, which has a high noise level, poor space distribution, and an unoptimized production space layout.

This study aims to identify the main problems in the work system of Ceper metal casting MSMEs and provide suggestions for improvement using the Macro-Ergonomic Analysis and Design (MEAD) approach. This approach is highly relevant because it integrates various elements within the work system, including workers, the organization, technology, tasks, and the work environment. As a result, the designed work system is expected to enhance effectiveness, efficiency, and workplace comfort. Despite the success of prior MEAD implementations, research applying macro-ergonomic interventions in metal casting MSMEs remains scarce, particularly with the incorporation of physiological workload assessments such as cardiovascular load (%CVL). Existing studies focus on micro-ergonomic improvements or generalized organizational changes without quantifying the physiological impact of work conditions. This gap is significant given that workers in metal casting environments often engage in prolonged manual labor under suboptimal conditions, making them particularly susceptible to fatigue, injury, and decreased performance.

Similar research has been conducted at the Ayu Arimbi Batik Center in Sleman, focusing on designing a working system using the MEAD method to improve the production output of the batik industry, which still relies on traditional administration [19], [20]. This study attempted to design a special batik pattern table that could minimize complaints from batik makers, thereby enabling work to be carried out more ergonomically. The main findings indicate that the table design reduced physical complaints among pattern makers and improved work efficiency, particularly in activities requiring static postures and repetitive movements in the batik pattern area. A macro-ergonomic approach using the MEAD method was also applied to refine the work system design in a rubber processing factory [21], [22]. Field findings identified scattered equipment, high temperatures, non-compliance with regulations, and delivery delays as the main issues. Through analysis, this study identified critical variables for improving machinery/equipment and workplace environmental conditions. Recommendations such as preventive machine maintenance and installing ventilation turbines successfully enhanced comfort, reduced fatigue levels, and minimized the risk of production errors due to demanding work conditions.

Healthcare operates within an open, complex, and dynamic system, where various elements such as patients, care teams, organizations, and the socio-political environment interact, creating significant challenges in maintaining service quality [23]. To understand and improve these systems, various conceptual frameworks such as SEIPS, Patient Work Systems, Macro-Ergonomic Analysis and Design, and Systems Engineering have been introduced, emphasizing the relationship between structure, process, and outcomes, as well as the importance of the roles of patients, families, healthcare professionals, and technology in the overall care pathway. By applying systems lens and using analytical tools such as Work System Analysis, Functional Resonance Analysis, and Failure Mode and Effect Analysis, healthcare system improvements can be directed toward making them safer, more efficient, adaptive, and oriented toward the needs of patients and healthcare professionals. Improvements to the work system at the Cracker Factory used the macro-ergonomics approach to prevent injuries and improve working conditions [24], [25]. Issues identified include uncomfortable work postures and workers experiencing dehydration due to high room temperatures. Key recommendations include regularly providing a glass of water to address mild to moderate dehydration and improving layout and ventilation to better control temperatures. The results show increased worker awareness of health and safety, as well as a reduction in physical complaints during cracker production.

The state of the art in this research aims to demonstrate a paradigm shift from a micro-ergonomic approach to a macro-ergonomic approach. Micro-ergonomics is a branch of ergonomics that focuses on the interaction between individuals and direct work elements, such as workstations, posture, workload, and work environment [26], [27]. Furthermore, the micro-ergonomic approach is considered inadequate to address the challenges of increasingly complex modern work systems. In contrast, macro-ergonomics is an ergonomic approach based on organizational design within a working system, thus covering a broader scope [28], [29]. Macro-ergonomics encompasses the study of human interaction with technology, organizational structure, cultural factors, and the overall work environment [30]–[33]. The MEAD approach is one of the most advanced and effective macro-ergonomic methods for holistically designing and evaluating work systems [34]–[36]. A unique aspect of this research is the measurement of physiological workload using the cardiovascular load method and energy consumption of workers in the metal casting MSME sector.

Although the MEAD approach has proven successful in improving work systems across various sectors, the transferability of these solutions to the context of metal casting MSMEs requires strategic adaptation. This is due to the unique characteristics of the metal casting industry, such as high physical workloads, exposure to extreme heat, and a more physical and safety-complex work environment. Some MEAD components that remain relevant and readily transferable include macro-ergonomic workload assessment tools (such as pulse rate measurements and worker perception questionnaires), workflow mapping, and identifying human-machine-environment system mismatches. However, other components, such as organizational strategies and workflow redesign, require contextual modification. Therefore, MEAD adaptation in the foundry industry is not a direct duplication but a recontextualization based on key challenges in the field.

Through this research, it is expected that metal-casting MSMEs can improve their work system based on the findings of existing problems. By applying the MEAD approach, the company is expected to create a healthier, safer, more efficient, and more productive work system for its workers. This is also a real contribution to developing macro-ergonomics-based work systems relevant to the development of the modern industrial world.

Methods

This research will be completed using a macro-ergonomics approach. Macro-ergonomics is a branch of ergonomics that addresses the individual worker and their immediate work environment and considers the broader organizational and sociotechnical systems [37]–[39]. Unlike micro-ergonomics, which focuses primarily on individual and task-level issues, macro-ergonomics is systemic and top-down, incorporating a sociotechnical systems perspective. Macro-ergonomics aims to optimize the entire work system to ensure alignment and synergy between human, technological, and organizational components. This optimization supports not only occupational health and safety but also enhances productivity and quality of work life, often referred to today as work-life balance (WLB) [40]–[43].

This study employs the MEAD (Macro-Ergonomic Analysis and Design) method, a well-established macro-ergonomic approach developed based on sociotechnical systems theory and the integration of micro-ergonomic principles [44], [45]. MEAD was created in response to the limitations of traditional ergonomic methods, which often focus narrowly on human or technological aspects without accounting for their interaction within the whole work system. MEAD combines macro- and micro-level analyses through participatory and iterative design process to promote systemic harmony. The MEAD process consists of ten stages, as shown in Figure 1 [46].

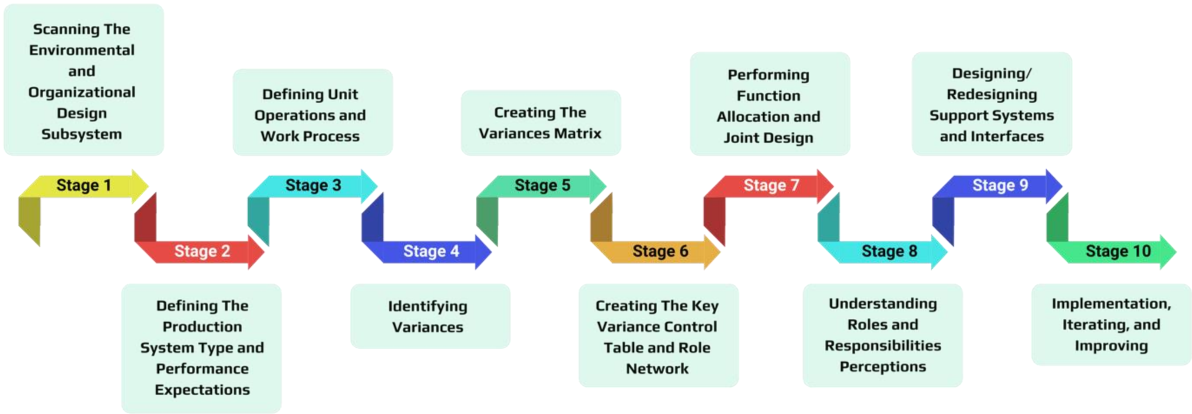

Figure 1. MEAD Steps

Ten worker respondents were selected using a purposive sampling method. The selection focused on individuals directly involved in the production process to ensure relevant insights into work system dynamics. Respondents represented various functional roles, including machine operators, quality control personnel, material handlers, and supervisors. The primary data collection tool was a structured questionnaire designed to assess key macro-ergonomic factors in the workplace. The instrument consisted of 25 items grouped into dimensions such as organizational structure, work processes, task variability, and worker perceptions. Items were measured using a 5-point Likert scale ranging from "strongly disagree" to "strongly agree". Before full deployment, the questionnaire was pre-tested with three workers who were not included in the final sample to ensure clarity and relevance. Feedback from the pre-test informed minor revisions to wording and response options. In addition to the worker questionnaire, data validation was conducted through direct input from the production manager. This validation involved a structured interview session where the preliminary findings, especially variances identified in workflow, task allocation, and support systems, were presented and discussed. The manager was asked to confirm the observed issues' accuracy and rank them based on criticality to production performance and worker well-being. This triangulation step helped ensure the reliability of findings before further analysis using the MEAD framework.

Results and Discussions

Data Collection

This research was conducted in the Ceper metal casting industry, Klaten, Central Java. One MSME was taken as a sample from several existing foundry MSMEs in this study. The MSME is PSL. PSL is a metal casting manufacturing company engaged in casting, machining, assembly, and supply. The company has a vision to be the leading metal casting company in Indonesia and a mission to provide quality products with strong commercial principles. The company implements a work system for 6 days per week. Regular working hours are 8 hours a day, from 8:00 a.m. to 4:00 p.m. WIB (West Indonesia Time), with a 1-hour break, while overtime is done at 5:00 p.m. to 10:00 p.m. WIB (West Indonesia Time) if production demand increases. The company also balances workers' responsibilities between family and work.

Field observations showed that the production floor is narrow and separated, hindering production flow. Interviews with managers revealed key issues such as a restricted working environment, grinding machine breakdowns due to minimal maintenance, and excessive workloads that trigger worker fatigue. In addition, inappropriate decision-making and poor communication within the organization led to minor conflicts. Work safety culture is also not optimal because it prioritizes workers' comfort. Questionnaire data from 10 workers reinforced these findings, with complaints about ergonomics, machinery, and fatigue.

Worker pulse data was measured using a smartwatch during work and rest to assess fatigue levels. The results showed an average work pulse rate of 117.9 bpm, with significant variation between individuals, such as Farhan, who reached 149 bpm during work. Measurements were taken three times (first morning, after a break, and second morning) to ensure data consistency. The oldest respondent, Hartanto (66 years old), had the highest resting pulse rate (86 bpm). This data indicates that workload and overtime hours affect the physical condition of workers. Noise measurements using a sound level meter (SLM) show that grinding and drilling machine noise levels exceed safe limits, especially when measured from 1 meter for 30 seconds. This high noise can disrupt workers' hearing health and increase work stress. The company does not have a concrete solution to reduce noise exposure. This condition exacerbates the ergonomic problems previously identified.

The data collection process revealed that PSL faces multidimensional challenges ranging from production layout and machine maintenance to worker welfare. Technical interventions, such as improved layout and personal protective equipment, must address work environment and noise issues. Improved internal communication and occupational safety training are also necessary to reduce conflicts and risks of accidents. Pulse data and questionnaires confirm the need to adjust workloads and overtime hours. A holistic approach is essential to balance workers' productivity and quality of life. To monitor the effectiveness of the adjusted workloads and break times, the company will implement a continuous monitoring system using wearable technology (e.g., smartwatches) to record workers' physiological responses, specifically, pulse rates and sleep recovery, every week. Monthly fatigue and job satisfaction questionnaires will be distributed to capture subjective workload and rest adequacy responses. The data collected will be evaluated by the company's internal safety team and ergonomics consultants to identify patterns of improvement or deterioration in workers' physical conditions and overall productivity. Furthermore, key performance indicators (KPIs) such as output consistency, absenteeism, incident reports, and overtime requests will be used to quantitatively assess whether the restructuring of the workload has a positive impact over time.

The company will design a regular monitoring system based on physiological data and worker perceptions to ensure that adjustments to the new workload and rest periods remain effective in the long term. Pulse rate measurements will be conducted weekly via wearable devices to detect any indications of abnormal physiological fatigue. Additionally, workload and fatigue perception questionnaires will be distributed biweekly to capture subjective responses to the work policy changes. The collected data will be analyzed using time trends to identify consistent increases in resting heart rate, decreases in job satisfaction, or increases in perceived fatigue as early indicators of policy ineffectiveness. Thresholds, or trigger points for intervention, have been established if the average resting heart rate exceeds 10% of baseline for two consecutive weeks, or the workload perception score increases above 4 (on a scale of 1–5). Once these thresholds are reached, the company will activate procedures for evaluating and readjusting work schedules, overtime intensity, and rest periods, in coordination with management and field operators. This strategy ensures that interventions are responsive, data-driven, and sustain workers' well-being and operational productivity.

Occupational safety training will be conducted quarterly (once every three months) as part of a regular safety management system. The training modules will include hazard identification, emergency response drills, proper use of Personal Protective Equipment (PPE), machine safety, and communication protocols. To evaluate effectiveness, pre- and post-training assessments will be administered to measure knowledge retention. Additionally, safety performance metrics such as reduction in near-miss incidents, accident frequency rate (AFR), and unsafe behavior observations will be tracked before and after each training cycle. Moreover, focus group discussions and feedback forms will assess workers' perceptions of the training's relevance and clarity. These results will guide continuous improvement of the training materials and delivery methods.

Data Processing

This research will be completed using the MEAD method approach. As previously explained, the MEAD method has ten steps in its processing. The following are the ten steps in the MEAD method used in this study:

Scanning Environmental and Organizational Design Subsystem

In the first stage, identifying the environment and organizational subsystems begin with presenting the company's vision and mission, reviewing the work environment conditions, and depicting the PSL organizational design. The identified organizational subsystems include the technology subsystem where production technology, workflow integration, and level of automation determine the organizational structure the personnel subsystem, which provides for the level of professionalism, demographic factors, and psychosocial factors of workers, and the external environment subsystem which highlights challenges such as the layout of the narrow production space, uncomfortable environmental conditions, and untidy layouts. In addition, the company's vision is described as "to become the leading and best metal casting company in Indonesia" and a mission emphasizing product and service quality. The company's work schedule is six days a week with normal operating hours and breaks, with the option of working overtime if production targets require it. Furthermore, field conditions were identified, such as production machine noise reaching an average of 95.6 dB, well above the 85 dB threshold, requiring special attention to worker safety and comfort.

Defining The Production System Type and Performance Expectations

The second stage defines the operating system type and determines the desired performance level. Here, a framework and standard of normal performance assumptions are created objectively and subjectively by referring to the field's time estimates and equipment requirements. PSL implements a Make-to-order business system (make-to-order) with a marketing strategy through government partnerships, vendors, and digital promotions.

Production activities at PSL encompass five main types of work, each with varying durations and equipment requirements. Metal cutting takes an average of 20 minutes using a grinding machine, while caulking also takes 20 minutes using a placemat and scrub equipment. Metal drilling or turning takes approximately 10 minutes using a drilling machine, while welding takes 20 minutes using a welding machine. The final stage, the finishing process, takes the longest, at 60 minutes, using a grinding machine and a sanding machine. These data indicate that each stage has specific time and equipment requirements, with finishing being the most time-consuming process, potentially becoming a critical point in production flow management.

Furthermore, performance expectations are described through checkpoints from raw material usage to cost management, outlined in Table 1 to represent quality, capacity, innovation, output, productivity, process value, and management. Thus, performance expectations can be monitored based on these critical checkpoints.

Table 1. Performance expectation

Checkpoint	Number of checkpoints	Quality
Input Utilization	1	The use of raw materials and the design of metal products depend on the type of consumer demand.
Capacity	2	Product capacity adapts to consumer desires.
Innovation	3	Innovations are based on the design made and the workers' creativity in finishing, such as painting and smoothing the metal.
Output Production	4	Conformity of the results desired by the consumer and the time agreed upon by the customer.
Productivity	5	Make-to-order (MTO) is the production process when consumer orders occur.
Process Value	6	Performed based on all costs required to make the ordered product. Process results can be seen from the product's suitability to the order. Profits are obtained from the sale of products.
Management	7	The management applied refers to the business owner's work system, namely, PSL.

Defining Unit Operations and Work Process

In the third stage, unit operations and work processes are described by identifying unit operations as combinations of phases that transform inputs into outputs. For PSL, these operations include cutting (cut-off wheels, hand-cutters, plasma cutters, and shearing machines), drilling (hand-drills, bench drills, and milling machines), welding (SMAW, MIG, and electrodes), and finishing (polyester putty, backing, hand grinders, and sandpaper). Furthermore, a flowchart of the PSL production process shows the flow from raw material preparation and mold removal to quality control, finishing, welding, painting, and packaging. This process flowchart shows the work stages and tasks required to produce a product, such as a streetlight pole, and the time required for each step.

The production process at PSL consists of four main stages: cutting, drilling, welding, pulverizing, and caulking, each involving a combination of specialized equipment and a specific number of workers. The cutting stage utilizes various tools, including 14-inch cutting wheels, plasma cutters, shearing machines, and measuring equipment, involving three workers. The drilling process is carried out by four workers using hand drills, bench drills, drilling and milling machines, and supporting equipment such as 3–23 mm drill bits and measuring tools. The welding stage also involves four workers using SMAW and MIG equipment, various types of welding wire, and safety equipment such as goggles, welding helmets, and gloves. Finally, the pulverizing and caulking process is carried out by four workers using polyester putty, hand grinders, and sandpaper. This data set illustrates that each stage has specific equipment and labor requirements, making resource coordination key to maintaining a smooth production flow.

Identifying Variances

The fourth stage aims to identify variances or deviations in the work system, which include deviations from operating standards, undesirable conditions, specifications, or norms. Through observations, interviews with managers, and questionnaires to workers, emerging variances were grouped into five main categories: human, organizational, technological, task, and work environment. Table 2 records specific variances such as skill limitations, physical conditions, less stringent safety culture, heavy workloads, and noise exceeding thresholds.

Table 2. Worker variance data

Names of respondents	Division	Variance factors				
		Human	Organization	Technology	Task	Working environment
Aan	Grinding	Limited expertise	Safety culture Performance appreciation	Need for more sophisticated technology		Excessive noise Layout improvements
Anang	Grinding		Safety culture Weak supervision of work	Need for more sophisticated technology	Heavy workload	Excessive noise Layout changes & additions to tool lockers
Aripin	Welding		Work time improvement Safety culture			Improved distribution process
Bashori	Welding	Physical condition	Work time improvement		Heavy workload	Additions tool lockers
Farhan	Casting		Safety culture Weak supervision of work		Heavy workload	Improved distribution process
Hartanto	Welding		Performance appreciation Work time improvement		Heavy workload	Excessive noise
Jamil	Welding		Safety culture Work time improvement	Need for more sophisticated technology		Layout changes
Joko	Drilling		Safety culture Weak supervision of work Work time improvement	Need for more sophisticated technology	Heavy workload	Excessive noise
Nanang	Molding		Performance appreciation Weak supervision of work	Need for more sophisticated technology		Layout changes
Nursoleh	Refining	Limited expertise	Work time improvement Safety culture		Heavy workload	Improved distribution process Layout changes

The questionnaire recapitulation results showed that the highest variance factors in the PSL work system were improved working hours, work safety culture, and heavy workloads, each recorded 6 times. Other organizational factors, such as lack of performance appreciation, appeared 3 times, and weak supervision of work appeared 4 times. From the technological side, the need for more sophisticated technology was recorded 5 times. At the same time, in the work environment factors, layout changes appeared 5 times, noise suppression 4 times, and distribution process improvements 3 times. Human factors such as limited skills and physical conditions were recorded 2 times each, while other variances such as work motivation, psychological characteristics, task management, and lighting were not found. These findings indicate that the main problems are more dominant in the organizational, task, and work environment aspects, directly impacting worker productivity and safety.

Creating The Variances Matrix

The fifth step is the creation of a variance matrix to map the linkages between variances and determine the key variances that have a dominant impact on other variances. Based on the production manager's validation, Table 3 illustrates the influence of one variance on another, where the variance of less strict implementation of work safety culture is linked to three other variances, the variance of heavy workload is connected to four variances, and the variance of noise exceeding the limit is related to three variances. From this matrix, the three variances- safety culture, workload, and noise- are the key variances that need to be addressed on a priority basis because they significantly impact the entire work system.

Table 3. Variance matrix

Variance Factors	Variances	Limited expertise	Physical condition	Work time improvement	Safety culture	Performance appreciation	Weak supervision of work	Need for more sophisticated technology	Heavy workload	Improved distribution process	Excessive noise	Layout changes	Total
Human	Limited expertise												0
	Physical condition												0
Organization	Work time improvement					X			X				2
	Safety culture					X	X				X		3
	Performance appreciation								X				1
	Weak supervision of work				X							X	2
Technology	Need for more sophisticated technology								X				1
Task	Heavy workload			X		X	X	X					4
Work environment	Improved distribution process							X				X	2
	Excessive noise				X			X				X	3
	Layout changes						X			X			2

Creating The Key Variance Control Table and Role Network

In the sixth stage, a variance control table and role network were created to determine where the key variances occurred, who was responsible, the parties involved, and the existing supporting activities. Table 4 shows that the variance of less strict implementation of work safety culture is spread across all production floors, with leaders and managers as those responsible, and supervision activities are only carried out occasionally. The central location for the heavy workload variance is in the fabrication production section, with leaders and managers responsible, and overtime implementation as a supporting activity. Meanwhile, the noise variance exceeding the limit occurs in the production section, with handling by leaders and managers, and temporary mitigation in the form of a 20-minute break for 3 minutes. This table shows the existing roles, supporting activities, and gaps in managing key variances.

Table 4. Variance control and role network

Key variances	Location	Handling parties	Involved parties	Existing supporting activities
Safety culture	All production floors	Leaders & managers	Managers & workers	Supervisory control is carried out occasionally in the production process
Heavy workload	Production department	Leaders & managers	Managers & workers	Additional overtime if the company is pursuing order targets
Excessive noise	Production department	Leaders & managers	Managers & workers	Workers stop every 20 minutes, once for approximately 3 minutes

Performing Function Allocation and Joint Design

The seventh stage focuses on determining the function and incorporating the improved design using the objective tree method. Based on the variance control table results, the following objective tree contains several key improvement options: establishing SOPs and increasing work supervision to improve safety culture, improving break times through workload analysis (%CVL), and procuring earplugs.

Figure 2 illustrates the hierarchical structure of objectives derived from the identified macro-ergonomic issues, starting from specific operational-level improvements to the overarching goal of work system improvement. At the lowest level, three key interventions are proposed: (1) creating Standard Operating Procedures (SOPs) and enhancing work supervision to improve procedural compliance and managerial oversight, (2) adjusting rest time based on cardiovascular load analysis to reduce worker fatigue, and (3) procuring and encouraging the increased use of Personal Protective Equipment (PPE) to enhance individual safety. These operational actions support mid-level objectives, including company policy improvement, more accurate workload analysis, and the provision of noise reduction equipment to address specific environmental hazards. These, in turn, feed into broader strategic efforts such as procuring improved work environment facilities and comprehensive improvements in organizational structure, task allocation, and environmental conditions. Ultimately, integrating all these measures contributes to the top-level objective of work system improvement, ensuring a holistic enhancement of ergonomics, safety, and productivity across the production process.

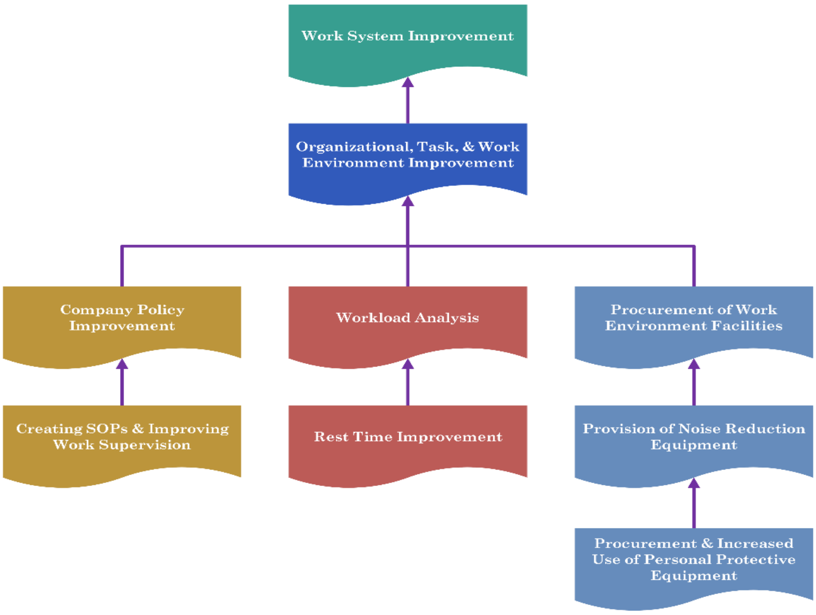

Figure 2. Objective tree

Understanding Roles and Responsibilities Perceptions

The eighth stage involves conducting a perception and responsibility analysis by assessing improvement alternatives using four criteria: scope, benefits, risk of failure, and cost. Tables 5 through 7 show the weighted scores for each alternative, which include the following: (1) creating standard operating procedures (SOPs) and increasing work supervision, (2) analyzing workload using the %CVL method, and (3) procuring noise-dampening equipment. The weighting results revealed that Alternatives 1 and 2 obtained the highest total score of +6, while Alternative 3 obtained a score of only +5. Therefore, creating SOPs and increasing work supervision and workload analysis are considered the most effective and feasible solutions to implement at PSL.

Table 5. The weighting of Alternative 1 - Company policy improvement

Scope	Benefit	Risk of Failure	Cost
Improving service quality	Improve worker comfort at work	Workers do not participate in implementing improvements	Facility procurement costs
Improved employee welfare	Preventing hazardous work accidents	The technology required is not available	Training program costs
Help the production process run more effectively	Improving productivity	Lack of willingness of workers to learn how to work properly	Lack of resources (physical & human)
Increase safety awareness	Improving human resources	Lack of business owner approval and support	Material procurement cost

Table 6. Weighting of Alternative 2 – Workload analysis

Scope	Benefit	Risk of failure	Cost
Improving service quality	Improve worker comfort at work	Workers do not participate in implementing improvements	Facility procurement costs
Improved employee welfare	Preventing hazardous work accidents	The technology required is not available	Training program costs
Help the production process run more effectively	Improving productivity	Lack of willingness of workers to learn how to work properly	Lack of resources (physical & human)
Increase safety awareness	Improving human resources	Lack of business owner approval and support	Material procurement cost

Table 7. Weighting of Alternative 3 - Procurement of Excessive Noise Equipment

Scope	Benefit	Risk of failure	Cost
Improving service quality	Improve worker comfort at work	Workers do not participate in implementing improvements	Facility procurement costs
Improved employee welfare	Preventing hazardous work accidents	The technology required is not available	Training program costs
Help the production process run more effectively	Improving productivity	Lack of willingness of workers to learn how to work properly	Lack of resources (physical & human)
Increase safety awareness	Improving human resources	Lack of business owner approval and support	Material procurement cost

Designing/Redesigning Support Systems and Interfaces

The ninth stage focused on redesigning the support subsystem, specifically determining workers' rest time requirements based on heart rate measurements and cardiovascular load (CVL) calculations. Resting and working heart rate data from ten workers were collected, and %CVL was then calculated using the formula %CVL = (100 × (DNK - DNI))/(DNM - DNI). The average %CVL of production workers was 38.99%, which is categorized as "needs improvement." Furthermore, a quadratic regression equation yielded energy consumption during work (Et = 5.661 kcal/min) and during rest (Ei = 2.93 kcal/min), resulting in a total energy consumption (K) of 2.731 kcal/min. Using the formula R = T((W - S)/(W - 1.5)), we know that workers require 66.71 minutes (rounded to 70 minutes) of rest per day. Therefore, the proposal is to add 10 minutes to the standard rest time.

The company has committed to several long-term strategies to ensure the sustainability of the improvements that led to a reduction of the average %CVL to 23.35%. First, routine evaluations will be conducted quarterly to monitor physiological workload through pulse measurements and %CVL analysis. Second, the company will institutionalize using Standard Operating Procedures (SOPs) for Personal Protective Equipment (PPE) and break schedules as part of daily operations. Third, a dedicated Safety and Health Monitoring Team will be formed to oversee implementation, gather feedback from workers, and make iterative policy adjustments based on evolving work conditions and employee input. Lastly, continuous training and awareness programs will be held biannually to reinforce the importance of workload management, safety compliance, and employee well-being. These efforts aim to embed the improvements into the organizational culture and support long-term work-life balance and productivity.

The company will prioritize creating and enforcing SOPs and enhancing work supervision to improve the safety culture among the proposed improvement options derived from the objective tree. This decision is based on the weighting results in Table 9, where this alternative scored highest in feasibility and benefit. The implementation timeline is planned in three phases: (1) SOP drafting and internal review in Month 1; (2) socialization and training for all production staff in Month 2; and (3) full enforcement, including periodic supervision and corrective feedback, starting in Month 3. Subsequent improvements, such as workload analysis refinement and noise-reduction equipment procurement, will follow, depending on resource availability and impact assessment outcomes from the initial phase

Implementation, Iterating, and Improving

In the tenth stage, implementation and system improvement proposals were formulated based on the selected alternatives, including: "Increased work supervision and creation of safety culture SOPs" and "Workload analysis". The proposed organizational policy includes creating an SOP for using PPE. This SOP contains definitions, objectives, policies for mandatory PPE use, a list of PPE types (e.g., gloves, shoes, masks, welding glasses, and ear protection), and implementation procedures. Additionally, increasing intensive supervision and recognizing outstanding workers is recommended to boost motivation. To improve break times, revised daily working hours were scheduled (Table 8), including an additional 10-minute break from 10:00 to 10:10 a.m. [47]–[50].

Table 8. Suggestions for improving working hours schedule

Day	Time	Information
Monday - Saturday	08.00 – 10.00	Work
	10.00 – 10.10	Rest
	10.10 – 12.00	Work
	12.00 – 13.00	Rest
	13.00 – 16.00	Work

After implementing the improved work system, the average resting heart rate for workers was 78.83 bpm, while the average heart rate during work decreased to 102 bpm. Cardiovascular Load (%CVL) calculations showed an average of 23.35%, which is below the fatigue threshold of 30%. Only three workers remained above this limit, namely Farhan (37.23%), Hartanto (48.37%), and Aan (31.82%), while the other workers were already in the safe category from the risk of excessive fatigue. This decrease in %CVL reflects the success of interventions such as increasing rest periods, implementing occupational safety SOPs, and more intensive supervision. These results indicate that improving work schedules and implementing ergonomic policies can significantly reduce physiological workload and improve worker health and comfort in the production environment.

Discussion

Based on data analysis and the application of the Macro-Ergonomic Analysis and Design (MEAD) framework, this study identified five main macro-ergonomic factors through semi-structured interviews with production managers and structured questionnaires administered to production workers. These factors include the work environment, technology, people, tasks, and organization, each representing critical dimensions of sociotechnical systems in the production context. The triangulation of data sources revealed several key issues across these dimensions. The most prominent macro-ergonomic challenges identified were: (1) inadequate enforcement of workplace safety culture (organizational factor), (2) workloads exceeding regulatory limits (task factor), and (3) noise levels surpassing acceptable thresholds (environmental factor). To address these issues, three primary improvement strategies were proposed: (1) the development of Standard Operating Procedures (SOPs) and enhancement of supervisory practices, (2) the provision of noise-reducing equipment such as earplugs, and (3) the optimization of work schedules and rest periods based on physiological workload analysis.

A decision matrix was developed to assess the perceived effectiveness of these proposed interventions. Results indicate that the combination of SOP formulation, enhanced supervision, and improved rest time received the highest weight, indicating strong acceptance and feasibility from both managerial and worker perspectives. During the subsystem redesign phase, objective physiological workload assessments were carried out using the Cardiovascular Load (CVL) method and energy expenditure measurements. These were performed on ten production workers across three observation cycles. The average CVL was recorded at 38.99%, classifying the workload as "needing improvement," while the average energy consumption reached 2.73 kcal/min. Based on these findings, an ideal rest time of 70 minutes per cycle was calculated, an increase of 10 minutes beyond the existing rest schedule. A simulation of this intervention showed a reduction in average CVL to 23.35%, falling below the fatigue threshold of 30%, indicating that workers experienced significantly reduced physiological strain under the proposed conditions. Organizational policy enhancements were also proposed to support these ergonomic improvements, including SOPs for consistently using Personal Protective Equipment (PPE) and strengthened managerial oversight during production. These changes are intended to ensure safe operations while fostering a culture of compliance and accountability.

Recognizing the operational implications of increasing rest time, the study also proposed several strategies to mitigate potential trade-offs between worker well-being and production efficiency. These include optimizing task allocation, introducing staggered break schedules to prevent production halts, and integrating shorter micro-breaks throughout work cycles. Furthermore, partial automation and assistive technologies could enhance individual productivity, offsetting the time added for rest. A pilot trial is recommended to evaluate the feasibility and impact of these interventions before full-scale adoption. To ensure continuous monitoring of these improvements, the study recommends wearable technology (e.g., smartwatches) to track physiological indicators such as heart rate and weekly recovery patterns. Subjective data will also be gathered through monthly fatigue and job satisfaction questionnaires. These metrics will be reviewed by the company's internal safety team and ergonomics consultants to assess trends in worker performance and health. Key performance indicators (KPIs), including output consistency, absenteeism, incident reports, and overtime requests, will be used to evaluate the overall impact of workload restructuring.

In addition, occupational safety training is scheduled to be conducted quarterly. The training curriculum will cover essential topics such as hazard recognition, emergency response, PPE usage, machine safety, and effective communication. Pre- and post-training assessments will be conducted to measure knowledge retention, and safety performance indicators such as Accident Frequency Rate (AFR) and near-miss reports will be monitored. Workers' feedback will be collected through focus group discussions and evaluation forms to refine the training content and delivery continuously.

This study's comprehensive identification of macro-ergonomic factors was made possible through a rigorous multi-method approach, integrating theoretical constructs with empirical data from multiple stakeholder levels. The combination of qualitative insights and objective physiological measurements enhanced the reliability and depth of the findings. As a result, the five macro-ergonomic domains were validated in the context of this MSME and shown to be interrelated in shaping productivity and well-being. Although increasing rest time poses operational challenges, the proposed strategies show that ergonomic improvements can be aligned with production goals through careful planning and data-informed decision-making. These findings contribute not only to the internal improvement efforts of the case company (PSL) but also offer broader implications for applying macro-ergonomic principles in MSMEs. Future research should explore broader implementation across different sectors and evaluate the long-term impacts of macro-ergonomic interventions on performance, worker retention, and sustainability.

Conclusion

This study provides a comprehensive macro-ergonomic analysis of PSL's production system using the Macro-Ergonomic Analysis and Design (MEAD) framework, identifying critical organizational, task-related, and environmental factors that hinder operational efficiency and worker well-being. The proposed interventions, including enhanced supervision, formalized safety procedures, and optimized rest schedules, offer practical solutions tailored to the constraints and realities of MSMEs. Beyond its immediate relevance to PSL, the findings contribute meaningfully to the broader body of macro-ergonomic theory and practice by demonstrating how structured ergonomic assessment can be applied in small- to medium-scale industrial settings where resources are limited but occupational risks remain high. This research underscores the importance of aligning ergonomic design with organizational policy and worker-centered strategies to promote sustainable performance improvements. Future studies are encouraged to expand the application of this model to other MSMEs across different sectors, and to conduct longitudinal assessments to evaluate the long-term impact of macro-ergonomic interventions on productivity, safety, and worker satisfaction. Through such efforts, macro-ergonomic principles can be more deeply embedded into MSME development, supporting individual enterprises and broader goals of decent work and sustainable industrial growth.

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