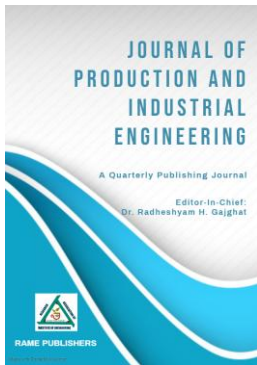


# A Review on Human Factors and Ergonomics in Manufacturing System Design and Productivity Improvement

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**Abstract:** Human factors and ergonomics play a crucial role in the design and performance of modern manufacturing systems by directly influencing worker efficiency, safety, and overall productivity. With increasing emphasis on sustainable and human-centric manufacturing, the integration of ergonomic principles into system design has gained significant attention. This review paper aims to provide a comprehensive analysis of the role of human factors and ergonomics in manufacturing system design and their impact on productivity improvement. The study focuses on key aspects such as workplace design, manual material handling, cognitive workload, human-machine interaction, and occupational health and safety. A systematic review of recent literature has been conducted to examine various ergonomic assessment tools and methodologies, including Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), and digital human modeling techniques. The findings indicate that the application of ergonomic principles significantly reduces musculoskeletal disorders, improves worker comfort, and enhances operational efficiency. Furthermore, the integration of advanced technologies such as wearable sensors and smart monitoring systems enables real-time assessment of worker performance and fatigue. However, challenges such as implementation cost, lack of awareness, and difficulty in quantifying human factors remain critical concerns. This paper contributes by synthesizing existing research, identifying key trends, and highlighting research gaps for future studies. The outcomes of this review provide valuable insights for designing safer, more efficient, and human-centric manufacturing systems.

**Keywords:** Human Factors, Ergonomics, Manufacturing Systems, Productivity Improvement, Workplace Design, Occupational Safety.

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## 1. Introduction

In modern manufacturing systems, the role of human factors and ergonomics has become increasingly significant due to the growing emphasis on productivity, safety, and worker well-being. While technological advancements have transformed manufacturing into highly automated and efficient systems, human involvement remains critical in many operations such as assembly, inspection, maintenance, and decision-making. The field of Ergonomics focuses on designing systems, tasks, and environments that fit human capabilities and limitations, thereby enhancing performance and reducing the risk of injuries. According to Reiman et al. (2021) [1], the application of ergonomic principles in workplace design leads to improved efficiency, reduced fatigue, and enhanced worker satisfaction.

Human factors in manufacturing encompass physical, cognitive, and environmental aspects that influence worker performance. Poorly designed workstations, repetitive tasks, excessive force, and awkward postures can lead to musculoskeletal disorders (MSDs), which are among the most common occupational health issues in industrial settings. Kadir et al. (2019) [2] emphasized that inadequate consideration of human factors not only affects worker health but also results in decreased productivity, increased absenteeism, and higher operational costs. Therefore, integrating ergonomic principles into manufacturing system design is essential for achieving both operational efficiency and worker safety.

The relationship between ergonomics and productivity is well established in the literature. Ergonomically optimized systems reduce physical strain, improve comfort, and enable workers to perform tasks more efficiently with fewer errors. This leads to enhanced product quality, reduced rework, and improved overall system performance. Furthermore, cognitive ergonomics plays a crucial role in supporting decision-making processes, especially in complex manufacturing environments where operators must interact with advanced technologies and control systems. Neumann et al. (2016) [3] highlighted that human-centered design approaches significantly contribute to improving system reliability and operational effectiveness.

Despite its importance, the implementation of ergonomic practices in manufacturing systems is often limited due to lack of awareness, difficulty in quantifying human factors, and perceived increase in initial costs. Many industries, particularly small and medium enterprises, tend to prioritize production targets over worker well-being, leading to suboptimal system design. However, with the increasing focus on sustainable and human-centric manufacturing, there is a growing need to systematically study and integrate ergonomics into system design and productivity improvement strategies.

The primary objective of this review paper is to analyze the role of human factors and ergonomics in manufacturing system design and their impact on productivity improvement. The study aims to examine various ergonomic principles, assessment techniques, and challenges associated with their implementation. By synthesizing existing literature, this paper provides valuable insights for researchers and industry practitioners to develop safer, more efficient, and human-centered manufacturing systems.

## 2. Human Factors in Manufacturing Systems

Human factors play a critical role in determining the efficiency, safety, and overall performance of manufacturing systems. These factors encompass the interaction between workers and their physical, cognitive, and environmental surroundings within the production environment. The effective consideration of human factors ensures that manufacturing systems are designed to align with human capabilities and limitations, thereby improving productivity and reducing the risk of errors and injuries. According to Sun et al. (2019) [4], the integration of human-centered design principles in industrial systems enhances both operational performance and worker well-being.

Physical factors are among the most prominent aspects of human factors in manufacturing. These include posture, repetitive motion, force exertion, and manual material handling. Workers engaged in tasks involving awkward postures, repetitive actions, or excessive force are more susceptible to musculoskeletal disorders (MSDs), which can significantly impact productivity and health. Bortolini et al. (2019) [5] emphasized that improper workstation design and poor task allocation often lead to increased fatigue and decreased efficiency. Therefore, optimizing physical factors through ergonomic design is essential for minimizing strain and enhancing performance.

Cognitive factors also play a vital role in manufacturing systems, particularly in tasks that require decision-making, attention, and problem-solving. As manufacturing environments become more complex with the integration of advanced technologies, the cognitive load on workers increases. Factors such as mental workload, stress, and information processing capability directly influence worker performance and error rates. Sgarbossa et al. (2020) [6] highlighted that excessive cognitive load can lead to reduced situational awareness and increased likelihood of errors. Effective system design must therefore consider human cognitive capabilities to ensure efficient and safe operation.

Environmental factors further influence worker performance and comfort in manufacturing settings. Conditions such as temperature, lighting, noise, and air quality can significantly affect both physical and cognitive performance. For instance, high noise levels can lead to communication difficulties and increased stress, while poor lighting can result in visual fatigue and reduced accuracy. Zare et al. (2016) [7] noted that optimizing environmental conditions is essential for maintaining worker comfort and enhancing productivity.

In summary, human factors in manufacturing systems encompass a wide range of physical, cognitive, and environmental elements that directly impact worker performance and system efficiency. A comprehensive understanding of these factors is essential for designing effective and sustainable manufacturing systems. By addressing these aspects, industries can achieve improved productivity, reduced health risks, and enhanced overall system performance.

### **3. Ergonomic Design Principles in Manufacturing**

Ergonomic design principles are essential for developing manufacturing systems that align with human capabilities, enhance productivity, and ensure worker safety. The application of Ergonomics in manufacturing focuses on optimizing the interaction between workers, tools, and the working environment. By incorporating ergonomic principles into system design, industries can reduce physical strain, minimize errors, and improve overall operational efficiency. According to Bolis et al. (2023) [8], ergonomic design aims to create workplaces that fit the user, rather than forcing the user to adapt to poorly designed systems.

One of the fundamental aspects of ergonomic design is workplace and workstation design. Proper workstation design ensures that tasks can be performed in neutral postures, reducing the risk of musculoskeletal disorders and fatigue. Factors such as working height, reach distance, seating arrangement, and layout of tools must be carefully considered. Sakthi Nagaraj & Jeyapaul (2021) [9] emphasized that adjustable workstations are particularly effective in accommodating workers with different physical characteristics, thereby enhancing comfort and efficiency. Well-designed workstations also reduce unnecessary movements, leading to improved productivity.

Tool and equipment design is another critical component of ergonomic principles. Tools should be designed to minimize force exertion, reduce vibration, and provide a comfortable grip to prevent strain and injury. The weight, shape, and usability of tools directly influence worker performance and safety. According to Guastello (2023) [10], ergonomically designed tools significantly reduce the risk of repetitive strain injuries and improve task efficiency. Additionally, the integration of assistive devices such as lifting aids and automated systems further enhances worker safety and reduces physical workload.

Work layout and motion economy principles also play a vital role in ergonomic design. Efficient arrangement of workstations, materials, and equipment minimizes unnecessary movements and optimizes workflow. Principles of motion economy, such as reducing excessive bending, twisting, and reaching, contribute to improved efficiency and reduced fatigue. This not only enhances productivity but also reduces the likelihood of errors. Furthermore, proper layout design facilitates smooth material flow and improves coordination between different stages of the manufacturing process.

Safety and comfort considerations are integral to ergonomic design in manufacturing systems. Ensuring a safe working environment involves minimizing exposure to hazards such as excessive noise, poor lighting, and extreme temperatures. Adequate ventilation, proper illumination, and noise control measures contribute to a healthier and more comfortable work environment. Faccio et al. (2023) [11] highlighted that comfortable working conditions improve worker concentration and reduce the risk of accidents.

In summary, ergonomic design principles in manufacturing focus on optimizing workplace design, tool usability, work layout, and environmental conditions to enhance worker performance and safety. The effective implementation of these principles leads to reduced physical strain, improved productivity, and a safer working environment. As manufacturing systems continue to evolve, the integration of ergonomic design remains a critical factor in achieving sustainable and efficient operations.

### **4. Ergonomic Assessment Techniques**

The effective integration of Ergonomics into manufacturing systems requires systematic evaluation methods to identify risks associated with human-machine interaction and workplace design. Ergonomic assessment techniques provide structured approaches to analyze worker posture, task demands, and environmental conditions, enabling the identification of potential hazards that may affect health, safety, and productivity. These techniques play a crucial role in quantifying ergonomic risks, which are otherwise difficult to measure due to the subjective and multidimensional nature of human factors. According to Doran et al. (2022) [12], standardized assessment tools are essential for evaluating postural load and guiding ergonomic interventions in industrial settings.

In manufacturing environments, workers are often exposed to repetitive tasks, awkward postures, and physically demanding activities, which can lead to musculoskeletal disorders and reduced efficiency. Ergonomic assessment methods help in systematically analyzing these conditions and prioritizing corrective actions. These techniques range from simple observational tools to advanced computer-based modeling approaches, each offering different levels of accuracy and complexity. Traditional methods such as Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), and Ovako Working Posture Analysis System (OWAS) are widely used due to their simplicity and effectiveness in field applications. In contrast, modern approaches such as Digital Human Modeling (DHM) provide detailed and predictive analysis through virtual simulations.

The selection of an appropriate ergonomic assessment technique depends on several factors, including the type of task, level of detail required, and available resources. While observational methods are suitable for quick assessments and large-scale studies, advanced digital techniques are more appropriate for detailed analysis and design optimization. Each method has its own strengths and limitations, making it essential to understand their applicability in different manufacturing scenarios.

This section presents a detailed review of commonly used ergonomic assessment techniques, including RULA, REBA, OWAS, and Digital Human Modeling, along with their applications, advantages, and limitations in manufacturing systems [13].

- **RULA (Rapid Upper Limb Assessment)**

Rapid Upper Limb Assessment (RULA) is one of the most widely used observational techniques in Ergonomics for evaluating postural risks associated with upper body movements in occupational tasks. Developed by Vijayakumar et al. (2022) [14], RULA is specifically designed to assess the exposure of workers to risk factors that may lead to musculoskeletal disorders (MSDs), particularly in the neck, trunk, and upper limbs. The method is simple, quick to apply, and does not require sophisticated equipment, making it highly suitable for field-based ergonomic assessments in manufacturing environments.

RULA evaluates worker posture by analyzing joint angles, muscle use, and external loads acting on the body. The assessment is divided into two main groups: Group A, which focuses on the upper arm, lower arm, and wrist, and Group B, which evaluates the neck, trunk, and legs. Each body segment is assigned a score based on its position and movement, and these scores are combined using a standardized scoring system to determine the overall risk level. The final RULA score ranges from 1 to 7, where higher scores indicate greater ergonomic risk and the need for immediate intervention. Shorrock & Williams (2016) [15] emphasized that RULA provides a rapid and reliable method for identifying high-risk postures in repetitive and sedentary tasks.

In manufacturing systems, RULA is commonly applied in assembly operations, inspection tasks, and other activities involving repetitive upper limb movements. It helps identify tasks that require redesign or ergonomic intervention, such as adjusting workstation height, modifying tool design, or improving task layout. The method is particularly useful for evaluating static postures and short-duration tasks, where detailed biomechanical analysis may not be feasible. According to Cardoso et al. (2021) [16], RULA has been widely adopted in industrial ergonomics due to its ease of use and effectiveness in identifying postural risks.

Despite its advantages, RULA has certain limitations. It primarily focuses on upper body posture and may not provide a comprehensive assessment of tasks involving the entire body. Additionally, the method relies on observational judgment, which can introduce subjectivity and variability in scoring. RULA also does not account for factors such as task duration and frequency in detail, which may influence the overall risk level.

In summary, RULA is a practical and efficient tool for assessing upper limb ergonomic risks in manufacturing systems. Its simplicity and quick application make it suitable for preliminary assessments and large-scale studies. However, for more comprehensive analysis, it is often used in combination with other ergonomic assessment techniques.

- **REBA (Rapid Entire Body Assessment)**

Rapid Entire Body Assessment (REBA) is a widely used ergonomic evaluation technique developed by Sue Hignett and Lynn McAtamney in 2000 to assess postural risks associated with whole-body movements in occupational tasks. Unlike RULA, which primarily focuses on the upper body, REBA provides a comprehensive assessment of the entire body, including the trunk, neck, legs, and upper limbs. This makes it particularly suitable for evaluating dynamic and physically demanding tasks commonly found in manufacturing environments. According to Wang and Abubakar (2017) [17], REBA was specifically designed to address the limitations of earlier assessment methods by incorporating a broader range of postural and task-related factors.

The REBA method involves systematic observation of worker posture during task performance, followed by scoring based on joint angles, movement, load handling, and coupling conditions. The assessment is divided into two groups: Group A evaluates the trunk, neck, and legs, while Group B focuses on the upper arms, lower arms, and wrists. Each body segment is assigned a score, which is then combined using a standardized scoring sheet to calculate the overall REBA score. Additional factors such as load, grip, and activity level are also considered, providing a more comprehensive

evaluation compared to simpler methods. The final REBA score ranges from 1 to 15, with higher scores indicating greater risk and urgency for corrective action.

In manufacturing systems, REBA is extensively used for tasks involving manual material handling, lifting, pushing, and pulling operations. It is particularly effective in identifying high-risk activities that involve awkward postures, repetitive movements, and significant physical exertion. Rajesh & Srinath (2016) [18] highlighted that REBA is highly adaptable and can be applied across a wide range of industrial tasks, making it a valuable tool for ergonomic risk assessment. The method helps organizations prioritize interventions by categorizing tasks into different risk levels, ranging from negligible to very high risk.

Despite its advantages, REBA also has certain limitations. The method relies on observational assessment, which may introduce subjectivity and variability depending on the evaluator's expertise. Additionally, while REBA considers a wider range of factors than RULA, it still provides a snapshot of posture at a specific moment and may not fully capture variations over time. The scoring process can also be slightly complex for beginners, requiring proper training for accurate implementation.

In summary, REBA is a comprehensive and flexible ergonomic assessment tool that provides valuable insights into whole-body postural risks in manufacturing systems. Its ability to evaluate dynamic tasks and consider multiple factors makes it particularly suitable for complex industrial environments. However, like other observational methods, it should be used in conjunction with additional assessment techniques for more detailed analysis.

- **OWAS (Ovako Working Posture Analysis System)**

The Ovako Working Posture Analysis System (OWAS) is a widely recognized observational method in Ergonomics used to evaluate working postures and identify ergonomic risks in industrial environments. Developed by Al-Zuheri et al. (2023) [19] in the steel industry, OWAS is designed to analyze the posture of workers during various tasks and classify them into predefined categories based on the position of the back, arms, legs, and the load handled. The method is particularly useful for assessing repetitive and physically demanding tasks commonly found in manufacturing systems.

OWAS works by systematically observing and recording worker postures at regular intervals. Each observed posture is categorized using a coding system that represents the position of different body parts. These codes are then used to determine the risk level associated with each posture. The method classifies postures into four action categories, ranging from normal (no corrective action required) to highly harmful (immediate corrective action required). This classification helps in prioritizing ergonomic interventions and improving workplace design. Brio et al. (2019) [20] emphasized that OWAS provides a practical and efficient approach for identifying harmful working postures in industrial settings.

In manufacturing environments, OWAS is widely applied in tasks such as material handling, assembly operations, and maintenance activities. Its simplicity and ease of use make it suitable for large-scale assessments and long-duration observations. The method allows for the evaluation of multiple workers and tasks without the need for complex equipment, making it cost-effective and accessible. According to Sakthi Nagaraj et al. (2019) [21], OWAS is particularly effective in identifying postural risks in repetitive tasks and providing a general overview of ergonomic conditions in the workplace.

However, OWAS has certain limitations. The method provides a relatively coarse classification of postures and may not capture detailed biomechanical stresses or subtle variations in movement. It also relies on observational data, which can introduce subjectivity and potential errors in classification. Additionally, OWAS does not explicitly consider factors such as task duration, frequency, or cognitive load, which may influence overall ergonomic risk.

In summary, OWAS is a simple and practical ergonomic assessment tool that is effective for identifying and categorizing working postures in manufacturing systems. Its ease of application and ability to analyze large-scale operations make it valuable for preliminary assessments. However, for more detailed analysis, it is often used in combination with other ergonomic assessment techniques.

- **Digital Human Modeling (DHM)**

Digital Human Modeling (DHM) represents an advanced approach in Ergonomics that utilizes computer-based simulations to analyze and optimize human interaction with manufacturing systems. Unlike traditional observational techniques such as RULA, REBA, and OWAS, DHM enables virtual representation of human operators within a simulated work environment, allowing ergonomic evaluation during the design phase itself. This proactive approach helps in identifying potential ergonomic issues before physical implementation, thereby reducing redesign costs and improving

system efficiency. According to Bridger (2017) [22], DHM provides a powerful tool for integrating ergonomic analysis into engineering design processes.

DHM systems use digital mannequins that replicate human anthropometry, biomechanics, and motion capabilities. These virtual models can be adjusted to represent different body sizes, postures, and movements, enabling designers to evaluate workplace layouts, tool accessibility, and task feasibility. Advanced DHM tools, such as Jack, CATIA Human, and Siemens Tecnomatix, allow simulation of complex tasks including lifting, reaching, and assembly operations. These simulations help in assessing joint loads, muscle forces, and postural stress, providing a detailed understanding of ergonomic risks. Greig et al. (2023) [23] highlighted that DHM enables accurate prediction of human performance and supports the design of safer and more efficient work systems.

In manufacturing systems, DHM is widely used for workstation design, assembly line planning, and process optimization. It allows engineers to test different design alternatives and identify the most ergonomic solutions without the need for physical prototypes. Additionally, DHM supports integration with other technologies such as virtual reality (VR) and augmented reality (AR), enhancing visualization and user interaction. This capability is particularly valuable in complex manufacturing environments where multiple factors influence worker performance.

Despite its advantages, DHM also has certain limitations. The accuracy of simulation results depends on the quality of input data and the assumptions used in modeling. High implementation costs, requirement for specialized software, and need for skilled personnel can limit its adoption, especially in small and medium enterprises. Furthermore, DHM may not fully capture real-world variability in human behavior and environmental conditions.

In summary, Digital Human Modeling offers a powerful and predictive approach for ergonomic assessment in manufacturing systems. Its ability to simulate and analyze human interaction in virtual environments makes it an essential tool for modern ergonomic design and optimization. However, challenges related to cost, expertise, and model accuracy must be addressed to fully leverage its potential in industrial applications.

**Table 1.** Comparative Analysis of Ergonomic Assessment Techniques [24]

Technique	Body Region Covered	Type of Method	Complexity	Application Area	Advantages	Limitations
RULA	Upper body (neck, arms, trunk)	Observational	Low	Assembly, repetitive tasks	Simple, quick, no equipment	Limited to upper body
REBA	Entire body	Observational	Medium	Manual handling, dynamic tasks	Comprehensive assessment	Slightly complex scoring
OWAS	Whole body posture	Observational	Low	Industrial, construction tasks	Easy classification, large-scale use	Less detailed analysis
DHM	Full body (virtual model)	Simulation-based	High	Design, workstation analysis	Predictive, accurate	High cost, expertise required
RULA	Static posture	Observational	Low	Office & light manufacturing	Fast evaluation	Ignores lower body detail
REBA	Dynamic posture	Observational	Medium	Healthcare, logistics	Flexible application	Observer dependent
OWAS	Load + posture	Observational	Low	Heavy industry	Simple implementation	Low sensitivity
DHM	Motion simulation	Digital	High	Product design, layout planning	Early-stage risk detection	Software dependency
Hybrid (RULA + REBA)	Combined	Observational	Medium	Complex tasks	Better coverage	Time-consuming
Sensor-based Ergonomics	Full body	Real-time digital	High	Smart manufacturing	Continuous monitoring	Expensive setup

## 5. Challenges and Research Gaps

Despite the recognized importance of Ergonomics in improving worker safety and productivity, its implementation in manufacturing systems continues to face several challenges. One of the primary issues is the lack of awareness and limited adoption of ergonomic practices, particularly in small and medium enterprises (SMEs). Many organizations prioritize short-term productivity gains over long-term benefits of ergonomic interventions, leading to inadequate consideration of human factors during system design. According to Berlin & Adams (2017) [25], insufficient awareness and training significantly hinder the effective implementation of ergonomic principles in industrial settings.

Another major challenge is the difficulty in quantifying human factors and ergonomic risks. Unlike machine-related parameters, human performance involves subjective and variable elements such as fatigue, discomfort, and cognitive load, which are difficult to measure accurately. Traditional assessment techniques such as RULA, REBA, and OWAS rely heavily on observational data, which may introduce subjectivity and variability in results. Furthermore, these methods often provide static assessments and may not capture real-time changes in worker posture or workload. Spath & Braun (2021) [26] emphasized that the lack of precise measurement tools limits the ability to integrate ergonomics effectively into manufacturing decision-making processes.

The integration of ergonomic principles with modern manufacturing technologies also presents a significant challenge. With the increasing adoption of automation and Industry 4.0 technologies, there is a need to ensure that human-machine interaction is optimized. However, limited research has been conducted on integrating ergonomics with advanced systems such as robotics, IoT, and digital twins. This gap restricts the development of truly human-centric smart manufacturing systems. Additionally, the implementation of advanced techniques such as Digital Human Modeling (DHM) requires specialized software, computational resources, and skilled personnel, which may not be readily available in all organizations.

Another critical issue is the lack of real-time ergonomic monitoring systems. Most existing methods focus on post-task analysis rather than continuous monitoring of worker conditions. With advancements in wearable sensors and smart technologies, there is potential to develop real-time ergonomic assessment systems; however, their adoption is still limited due to cost, complexity, and data management challenges. Furthermore, issues related to data privacy and system integration must be addressed for successful implementation.

**Table 2.** Literature-Based Challenges and Research Gaps in Ergonomics

Author(s)	Area of Study	Identified Challenge	Suggested Research Gap
Neumann et al., 2016 [3]	Ergonomic design	Lack of awareness	Need for training and awareness programs
Sakthi Nagaraj & Jeyapaul, 2021 [9]	Human factors	Difficulty in quantification	Development of measurable ergonomic indices
Doran et al., 2022 [12]	RULA	Subjective assessment	Need for objective tools
Wang & Abubakar, 2017 [17]	REBA	Limited dynamic analysis	Real-time assessment models
Greig et al., 2023 [23]	OWAS	Low sensitivity	Improved posture classification
Karwowski & Zhang, 2021 [27]	DHM	High cost and complexity	Affordable simulation tools
Kolus et al., 2023 [28]	Cognitive ergonomics	Mental workload measurement	Integration with AI systems
Papetti et al., 2021 [29]	Smart manufacturing	Lack of integration	AI-based ergonomic systems
Fischer et al., 2021 [30]	Industry 4.0	Human-machine gap	Human-centric automation
Werner et al., 2021 [31]	Wearable tech	Limited adoption	Real-time ergonomic monitoring

In summary, although significant progress has been made in the field of ergonomics, several challenges and research gaps remain. Addressing these issues requires the development of advanced, data-driven, and real-time ergonomic assessment methods, along with greater integration of human factors into modern manufacturing technologies. Future

research should focus on creating cost-effective, scalable, and intelligent ergonomic solutions that can be easily adopted across different industrial sectors. Such advancements will play a crucial role in achieving sustainable and human-centric manufacturing systems.

## 6. Conclusion

This paper presented a comprehensive review of the role of Ergonomics and human factors in manufacturing system design and their impact on productivity improvement. The study examined key human factors influencing manufacturing performance, including physical, cognitive, and environmental aspects, and highlighted the importance of integrating ergonomic principles into workplace design, tool development, and system layout. The findings indicate that ergonomically designed systems significantly reduce worker fatigue, minimize the risk of musculoskeletal disorders, and enhance overall efficiency and product quality. The review of ergonomic assessment techniques, including RULA, REBA, OWAS, and Digital Human Modeling, demonstrated that these methods provide valuable tools for identifying and mitigating ergonomic risks in manufacturing environments. While traditional observational techniques offer simplicity and ease of application, advanced digital approaches provide more detailed and predictive analysis. However, the selection of appropriate assessment methods depends on the nature of the task, required level of detail, and available resources. The study also identified several challenges and research gaps, such as limited awareness of ergonomic practices, difficulty in quantifying human factors, lack of real-time monitoring systems, and insufficient integration with modern manufacturing technologies. These challenges highlight the need for more advanced, data-driven, and human-centric approaches to ergonomic design and assessment. The integration of ergonomics with emerging technologies such as wearable sensors, artificial intelligence, and smart manufacturing systems offers significant potential for improving both worker well-being and system performance. In conclusion, ergonomics plays a vital role in achieving sustainable and efficient manufacturing systems by enhancing worker comfort, safety, and productivity. The effective implementation of ergonomic principles and assessment techniques can lead to improved operational performance and reduced occupational health risks. Future research should focus on developing intelligent, cost-effective, and real-time ergonomic solutions that can be seamlessly integrated into modern manufacturing environments, thereby supporting the transition towards human-centric and Industry 4.0-driven production systems.

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