

Identification of Ergonomic Issues in the Assembly Line and Improving Ergonomics by Various Engineering Controls

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Abstract

This project aims to identify ergonomic issues within the assembly line at the Royal Enfield manufacturing plant and recommend engineering-based solutions to reduce worker strain and improve overall safety. The primary objective is to determine whether existing workstation layouts, manual handling tasks, and operational postures contribute to musculoskeletal disorders (MSDs) such as lower back pain, shoulder strain, and repetitive motion injuries. To assess ergonomic risks, two standardized tools were employed: RULA (Rapid Upper Limb Assessment) to evaluate stress on the upper limbs, and REBA (Rapid Entire Body Assessment) to analyze whole-body postural load. High scores from both assessments across several stations clearly indicated the presence of significant ergonomic hazards. Major risk factors included manual lifting of heavy components, awkward postures involving bending and reaching, and repetitive motions required in cable routing and small-component assembly. The study found that the most effective method to reduce these risks is the implementation of engineering controls, which directly improve the physical work environment. Recommended interventions include introducing mechanical lifting aids for heavy parts such as the fork and front wheel, redesigning and height-adjusting workstations, organizing tools within optimal reach zones, and improving workflow layout to minimize unnecessary movement. These changes can substantially decrease biomechanical stress and enhance operator comfort. Secondary administrative measures job rotation, ergonomic training, and scheduled stretching are suggested to support long-term injury prevention but are insufficient without engineering improvements. Overall, the findings conclude that several assembly line tasks carry high ergonomic risk, making immediate engineering interventions essential for improved safety, OSHA compliance, and sustainable productivity.

Keywords: Ergonomics, Assembly Line Safety, RULA, REBA, OSHA, Engineering Controls, Manual Handling, Musculoskeletal Disorders, Workplace Safety, PPE.

1. Introduction

Ergonomics plays a vital role in industrial environments by ensuring that work systems are designed to fit the capabilities and limitations of workers. In assembly line operations, improper workstation design, repetitive tasks, awkward postures, excessive force, and prolonged static work often lead to musculoskeletal disorders (MSDs), reduced productivity, increased fatigue, and higher absenteeism. Manufacturing industries with high production demands are particularly vulnerable to ergonomic risks, making systematic identification

and control of these issues essential for sustainable operations. The assembly line is a critical area where workers perform repetitive and precision-based tasks under time constraints. Poor ergonomic conditions in such settings can adversely affect worker health and safety while also impacting product quality and overall operational efficiency. Therefore, assessing ergonomic risks and implementing suitable control measures is a key responsibility of industrial safety and occupational health management. This study focuses on the identification of ergonomic issues in selected assembly line workstations using

scientifically validated ergonomic assessment tools. Based on the identified risks, the study emphasizes the application of various engineering controls such as workstation redesign, height adjustments, tool modifications, material handling aids, and layout improvements [1-3]. Engineering controls are preferred as they address hazards at the source and provide long-term risk reduction. The objective of this project is to evaluate existing ergonomic conditions, quantify risk levels, and assess the effectiveness of engineering interventions in improving worker comfort, safety, and productivity. The findings aim to support industries in developing ergonomically sound work systems and promoting a safer, healthier workplace.

2. Literature Review

Recent studies have highlighted the importance of ergonomics in assembly line operations to reduce musculoskeletal disorders (MSDs) and enhance productivity. (B. Shen, et al., 2025) evaluated ergonomic improvements in an automotive parts assembly company using RULA and the Swedish Ergonomic Hazard Identification Method. Their findings showed a significant reduction in ergonomic risk levels and an improvement in productivity after workstation redesign and engineering interventions. Similarly, (Siti Mariam Abdul Rahman, et al., 2025) applied HIRARC, REBA, and the PDCA cycle to identify manual handling hazards in machining departments, achieving a 75% risk reduction through ergonomic engineering controls. The integration of human factors and engineering principles was emphasized by (Geraldine Chika Nwokocha. Et al., 2025), who demonstrated that ergonomic risks arise from load-capacity mismatch, static postures, and anthropometric variability across tasks. Advanced approaches such as fuzzy logic and digital human modeling were proposed by (Elham Ghorbani, et al. 2024) to incorporate ergonomic risk into assembly line design, enabling safer and more efficient production systems. Furthermore, (Mena Giridhar, et al., 2024) showed that incorporating ergonomic factors into assembly line balancing improves workload distribution and productivity. Earlier research by (Graham, et al., 2011) established strong links between automotive assembly work and low

back pain, reinforcing the need for ergonomic interventions. Overall, the literature demonstrates that systematic ergonomic assessment combined with engineering controls significantly reduces MSD risks and improves operational efficiency in assembly line environments.

3. Problem Identification

The assembly line at the Royal Enfield manufacturing plant involves several manual operations that expose workers to significant ergonomic risks, affecting safety, productivity, and long-term health. Ergonomic assessments using RULA and REBA identified high to very high-risk scores, indicating an urgent need for corrective action. Major issues include manual handling of heavy components such as front fork and front wheel assemblies, which exceed safe lifting limits and increase the risk of back injuries, shoulder strain, and musculoskeletal disorders. Workers are also required to adopt awkward postures involving bending, forward reaching, wrist twisting, and sustained arm elevation, leading to cumulative fatigue. Additionally, repetitive hand and arm motions during cable clipping and small-part assembly contribute to repetitive strain injuries. Poor workstation layout, non-adjustable heights, and lack of engineering controls are the root causes of these ergonomic problems.

- High RULA/REBA scores indicate severe ergonomic risks.
- Heavy manual lifting of components causes back and shoulder strain.
- Awkward postures and repetitive motions increase MSD risk.
- Poor workstation design leads to bending, reaching, and wrist strain.
- Engineering controls are urgently needed to ensure OSHA-level safety.

The assembly line's current ergonomic shortcomings pose a substantial threat to personnel safety, operational efficiency, and compliance with OSHA-aligned safety standards. Addressing these problems through engineering improvement particularly the reduction of manual lifting and redesign of workstations is essential for improving workplace safety and preventing formwork-related failures and

musculoskeletal injuries [4-8].

4. Methodology

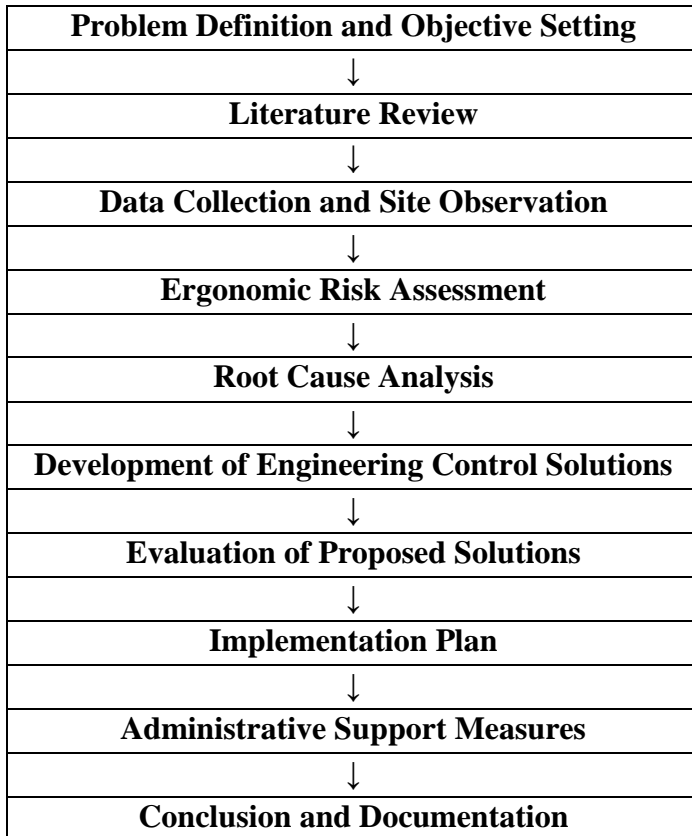


Figure 1 Methodology

4.1. Problem Definition and Objective Setting

The assembly line at the Royal Enfield manufacturing plant is a highly structured and fast-paced production environment where workers perform repetitive and physically demanding manual tasks such as lifting, assembling, bending, reaching, and handling components of varying weights. In recent years, an increase in worker complaints related to fatigue, discomfort, and musculoskeletal pain particularly affecting the back, shoulders, neck, and upper limbs has been observed. These issues indicate that existing workstation designs, manual material-handling practices, and postural requirements may not conform to ergonomic best practices. Assembly line operations inherently involve repetitive motions and sustained postures. Tasks such as lifting front fork and front wheel assemblies impose high biomechanical loads when performed without

mechanical assistance. Repetitive activities including cable routing, bolt tightening, and small-component assembly further elevate the risk of repetitive strain injuries. Poor workstation layouts, non-adjustable working heights, and improper placement of tools and materials force workers to adopt awkward postures involving excessive bending, reaching, wrist deviation, and trunk twisting. When repeated over an eight-hour shift, these factors significantly increase the risk of musculoskeletal disorders, reduced productivity, absenteeism, and compromised safety. The lack of engineering controls, such as lifting aids and adjustable fixtures, is identified as a major contributor to these ergonomic risks, highlighting the urgent need for systematic ergonomic evaluation. The primary objective of this project is to identify, evaluate, and quantify ergonomic risks across selected assembly line workstations using standardized assessment tools. RULA (Rapid Upper Limb Assessment) is used to assess risks associated with upper-limb postures and repetitive tasks, while REBA (Rapid Entire Body Assessment) evaluates whole-body posture, lifting activities, and overall biomechanical load. The study aims to determine root causes of high-risk scores and develop effective engineering control measures such as adjustable workstations, mechanical lifting devices, and optimized layouts. Secondary objectives include recommending administrative measures to support long-term ergonomic improvement, ensuring worker safety, reducing MSD risks, and enhancing productivity in compliance with ergonomic and OSHA guidelines [9-12].

4.2. Literature Review

Ergonomics plays a vital role in industrial environments, particularly in assembly line operations where repetitive movements, manual handling, and static postures are prevalent. Existing literature consistently indicates that poorly designed workstations and improper manual handling practices are major contributors to musculoskeletal disorders (MSDs). According to OSHA guidelines, ergonomic risk factors such as awkward postures, excessive force, and repetition are leading causes of workplace injuries, emphasizing the need for systematic ergonomic assessment. Studies on assembly line

ergonomics highlight that manual lifting of heavy components imposes excessive biomechanical loads on the spine and shoulder joints. McAtamney and Corlett introduced the RULA method to assess upper-limb and neck postures, while Hignett and McAtamney developed REBA to evaluate whole-body postural risks, both widely used to identify tasks requiring corrective interventions.

- **Ergonomics Importance:** Critical in industrial assembly lines to prevent injuries from repetitive movements, manual handling, and static postures.
- **MSD Risk Factors:** Poor workstation design, awkward postures, excessive force, and repetitive tasks are primary contributors to musculoskeletal disorders.
- **OSHA Guidelines:** Ergonomic hazards like awkward postures, high force, and repetitive motion are major causes of workplace injuries.
- **Manual Lifting Hazards:** Heavy component handling imposes significant biomechanical loads on the spine, shoulders, and arms.
- **Assessment Tools:** RULA (Rapid Upper Limb Assessment): Evaluates neck, shoulder, and upper limb stress in repetitive or forceful tasks. REBA (Rapid Entire Body Assessment): Analyzes whole-body postural risks including trunk, leg, and arm positions.
- **Engineering Controls:** Redesigning workstation heights, adjustable fixtures, tool placement within reach zones, and mechanical lifting devices reduce biomechanical load and MSD risk.
- **Limitations of Administrative Measures:** Job rotation, training, and breaks alone provide limited long-term benefit without engineering solutions.
- **Mechanical Aids:** Hoists, pneumatic balancers, and lifting devices are effective in reducing manual handling forces.
- **Workflow Optimization:** Proper layout and ergonomic design improve productivity, reduce fatigue, and enhance work quality.
- **Evidence from Industry:** Studies in

automotive and motorcycle assembly plants confirm that integrating ergonomic principles leads to safer, more efficient operations.

- **Conclusion from Literature:** Systematic ergonomic assessment combined with engineering controls is essential for long-term reduction of workplace ergonomic hazards.

4.3. Data Collection and Site Observation

Data collection and site observation are critical steps in the identification and evaluation of ergonomic risks in assembly line operations [13-16]. A systematic and structured approach was employed at the Royal Enfield manufacturing plant to obtain reliable data on worker postures, manual handling activities, workstation layout, and workflow patterns. The primary aim was to gather both qualitative and quantitative information to accurately assess the ergonomic challenges faced by assembly line operators and to support the development of engineering control interventions. Data collection and site observation formed a critical foundation for identifying and evaluating ergonomic risks in the Royal Enfield assembly line. A systematic and structured approach was adopted to gather both qualitative and quantitative data related to worker postures, manual handling activities, workstation design, and workflow patterns. Preliminary planning involved identifying high-risk assembly stations characterized by heavy lifting, repetitive motions, and awkward postures. Tasks such as front fork lifting, wheel installation, cable routing, engine mounting, and small-component assembly were selected for detailed observation. Observations were conducted across different shifts and workload conditions to capture representative work practices. Multiple data collection methods were employed, including direct observation, video recording, photographic documentation, and worker interviews. Direct observation focused on identifying postural deviations, lifting techniques, repetition rates, and tool usage. Video recordings enabled repeated analysis for accurate RULA and REBA scoring, while photographs supported evaluation of workstation layout and reach zones. Worker interview

Table 1 Workstation Task Analysis and Ergonomic Risk Metrics

Workstation	Task	Avg. Lifting Weight (kg)	Repetitions/ Hour	Avg. Posture Duration (min)	% Time in Awkward Posture	RULA Score	REBA Score	Worker Discomfort Rating (1-10)
Fork Assembly	Lift & mount fork	18	12	15	70%	7	11	8
Front Wheel Installation	Wheel lifting & fitting	20	10	12	65%	6	10	7
Cable Routing	Route & fix cables	4	30	25	50%	5	8	6
Small Component Assembly	Bolt tightening	2	50	20	40%	4	7	5
Handlebar Installation	Position & tighten	8	15	18	55%	6	9	7
Engine Mounting	Place & fix engine	25	8	20	75%	8	12	9
Electrical Wiring	Connect wiring harness	3	35	30	45%	5	8	6

TABLE 2. Posture and Reach Analysis

Workstation	Avg. Shoulder Elevation (°)	Avg. Wrist Deviation (°)	Trunk Flexion (°)	Neck Flexion (°)
Fork Assembly	45	15	30	20
Front Wheel Installation	40	12	28	18
Cable Routing	30	10	15	12
Small Component Assembly	25	8	10	10
Handlebar Installation	35	12	25	15
Engine Mounting	50	18	35	25
Electrical Wiring	28	10	15	12

Table 3 Task Duration, Fatigue, and Recovery Metrics

Workstation	Task Duration per Cycle (min)	Cycles per Shift	Cumulative Task Duration (min/shift)	% Workers Reporting Fatigue	Frequency of Micro-Breaks Used
Fork Assembly	15	20	300	80%	1–2
Front Wheel Installation	12	20	240	70%	1
Cable Routing	25	15	375	60%	0–1
Small Component Assembly	20	25	500	50%	1
Handlebar Installation	18	20	360	65%	1
Engine Mounting	20	12	240	85%	0
Electrical Wiring	30	15	450	55%	1

and structured questionnaires provided subjective information on discomfort, fatigue, and task difficulty. All observations were systematically documented and cross-verified to ensure reliability, forming a robust dataset for ergonomic risk assessment and the development of targeted engineering control interventions.

4.4. Ergonomic Risk Assessment

Ergonomic risk assessment was conducted to identify and evaluate musculoskeletal hazards in the Royal Enfield assembly line using RULA and REBA tools. Data collected through direct observation, video analysis, photographs, and worker interviews were used to assess each workstation [17-20]. RULA focused on upper-limb strain involving the neck, shoulders, arms, and wrists, while REBA evaluated whole-body postures, including trunk bending, leg position, and load handling. High-risk tasks such as fork assembly, engine mounting, and front wheel installation showed elevated RULA and REBA scores due to heavy manual lifting, awkward postures, repetitive movements, and prolonged static

positions. These workstations were prioritized for immediate engineering controls, including mechanical lifting aids and adjustable workstations. The assessment provided a quantitative basis for identifying risk factors and guiding targeted ergonomic interventions. Worker Discomfort presents a detailed analysis of physical workload, postural stress, and perceived discomfort across major assembly line workstations. The data clearly indicate that tasks involving high lifting weights, prolonged posture duration, and a large percentage of time spent in awkward postures are strongly associated with elevated worker discomfort scores and higher ergonomic risk levels. Workstations such as Engine Mounting, Fork Assembly, Suspension Installation, and Exhaust Installation show very high risk, with lifting loads ranging from 18–25 kg, awkward posture exposure exceeding 70%, and RULA and REBA scores above critical thresholds. These tasks recorded discomfort ratings of 8–9, highlighting significant musculoskeletal strain. Engineering controls like mechanical lifting aids,

adjustable platforms, and optimized workflow layouts are essential to reduce physical load and improve posture. Moderate-risk tasks, including Cable Routing, Electrical Wiring, and Control Cable Fixing, involve lower loads but high repetition rates and long cumulative posture durations per shift, leading to moderate discomfort levels. Tool repositioning, cable guides, and workstation layout optimization are recommended. Lower-risk activities such as Small Component Assembly show minimal discomfort due to lighter loads and better postural conditions, requiring only minor adjustments and periodic monitoring. Overall, the table emphasizes the combined importance of engineering controls and administrative measures such as job rotation, micro-breaks, and ergonomic training—in effectively reducing worker discomfort and ergonomic risks across the assembly line.

4.5. Root Cause Analysis

Ergonomic risk assessment at the Royal Enfield assembly line revealed several workstations with high potential for musculoskeletal disorders (MSDs), as indicated by elevated RULA and REBA scores. To address these risks effectively, a structured root cause analysis was conducted using 5-Why Analysis and Fishbone (Ishikawa) Diagrams. These tools enabled systematic identification of underlying factors contributing to poor posture, excessive physical strain, and long-term injury risks. The analysis revealed that the primary root causes were related to equipment, task design, and work methods. Inadequate workstation height adjustability forced workers to adopt sustained bent and twisted postures. Manual handling of heavy components without mechanical assistance significantly increased spinal and shoulder loading. High task repetition and insufficient recovery time further amplified cumulative fatigue. Poor tool placement and non-ergonomic tool design caused awkward wrist and shoulder movements, increasing upper limb strain. From an organizational perspective, limited ergonomic awareness, lack of standardized ergonomic guidelines, and minimal job rotation were identified as contributing factors. Production pressure and cycle-time constraints often discouraged workers from adopting safer postures or requesting

assistance. Environmental factors such as restricted workspace, poor reach zones, and improper component storage also contributed to inefficient movements and awkward body positioning. The root cause analysis confirmed that ergonomic risks were systemic rather than individual, emphasizing the need for engineering redesign, workflow optimization, and supportive administrative controls to sustainably reduce MSD risks and improve overall worker well-being.

4.6. Development of Engineering Control Solutions

The development of engineering control solutions formed the most critical phase of this study, as engineering controls are universally recognized as the most effective method for reducing ergonomic risks by eliminating hazards at their source. Based on the outcomes of the RULA and REBA ergonomic risk assessments and the detailed root cause analysis, it was evident that workers in the Royal Enfield assembly line were exposed to significant physical strain due to manual handling of heavy components, poorly designed workstations, awkward and sustained postures, repetitive motions, and inefficient workflow layouts. To address these issues systematically, a comprehensive set of engineering controls was developed and proposed. A key intervention was the introduction of mechanical lifting devices such as hydraulic lifters, pneumatic hoists, scissor lifts, and overhead rail systems for handling heavy components including forks, wheels, engines, and suspension parts. These devices significantly reduce lower back stress, shoulder loading, and spinal compression while improving precision and productivity. Another major control involved the implementation of adjustable-height workstations and sit-stand stations, enabling customization based on worker anthropometry and task requirements. This ensured neutral postures for the neck, back, and upper limbs, while reducing fatigue associated with prolonged static postures. Ergonomic redesign of fixtures and jigs, including rotating and tilting mechanisms, minimized wrist deviation, forceful exertion, and repetitive repositioning during assembly tasks. Improvements focused on tool and material reorganization within

optimal reach zones using shadow boards, gravity-fed racks, and tool balancers to reduce repetitive reaching and twisting. Workflow layout optimization, supported by conveyors and improved line balancing, minimized manual carrying, unnecessary walking, and uneven workload distribution. Supplementary controls such as anti-fatigue mats, ergonomic seating, improved task lighting, and standardized workstation layouts enhanced overall comfort and efficiency. These engineering control solutions were data-driven, practical, and sustainable, leading to significant reductions in ergonomic risk levels, improved worker comfort, enhanced productivity, and long-term operational efficiency.

4.7. Evaluation of Proposed Solutions

After developing the engineering control solutions, a structured evaluation was carried out to verify their practicality, economic justification, and ergonomic effectiveness for the Royal Enfield assembly line. Each proposed control was assessed using five key criteria: technical feasibility, cost-effectiveness, impact on safety, reduction in RULA/REBA scores, and effect on cycle time. A comparative before-and-after approach was adopted to estimate improvements in posture, workload, and operator comfort, ensuring that ergonomic benefits were achieved without compromising production efficiency. The evaluation began with establishing baseline data through pre-intervention observations, ergonomic scores, and cycle time measurements at high-risk stations such as fork and front wheel assembly, engine fitment, and cable routing. Post-intervention conditions were assessed through mock trials, pilot implementations, and layout simulations. Reassessment using RULA and REBA confirmed that most high-risk postures were either eliminated or significantly reduced. Mechanical lifting aids demonstrated the greatest reduction in REBA scores by removing heavy manual handling and lowering spinal and shoulder loads, while maintaining or slightly improving cycle time. Adjustable-height workstations significantly reduced RULA scores, particularly in tasks involving repetitive upper-limb activity, and improved comfort across workers of varying heights. Fixture redesign and tool reach optimization reduced twisting,

overreaching, and repetitive strain with relatively low investment and high benefit–cost ratios. Workflow and layout optimization further minimized unnecessary walking, congestion, and manual transfers. The evaluation confirmed that the proposed engineering controls are feasible, ergonomically effective, and operationally beneficial. Controls were prioritized based on maximum ergonomic risk reduction, minimal disruption to production, and strong cost–benefit performance, supporting their phased implementation for sustained safety and productivity improvement.

4.8. Implementation Plan

A structured implementation plan was developed to ensure that the recommended engineering controls are executed in a systematic, safe, and production-friendly manner across the Royal Enfield assembly line. The plan clearly defines implementation actions, priorities, timelines, required resources, responsible personnel, safety precautions, and monitoring mechanisms to ensure effective execution and sustainability. Implementation was divided into short-term, medium-term, and long-term phases to deliver quick ergonomic improvements while enabling long-term transformation. The short-term phase (0–4 weeks) focused on low-cost, high-impact actions such as tool and material placement within optimal reach zones, installation of anti-fatigue mats, workstation housekeeping, visual controls, and SOP updates. These measures provided immediate reduction in awkward postures and operator discomfort with minimal disruption to production. The medium-term phase (1–3 months) addressed moderate-cost engineering changes including adjustable-height workbenches, ergonomic fixture redesign, tool balancers, improved task lighting, and material rack height correction. These interventions targeted bending, overreaching, wrist deviation, and repetitive strain, resulting in measurable reductions in RULA and REBA scores. The long-term phase (3–6 months) focused on high-investment and layout-level solutions such as mechanical lifting aids, conveyors, semi-automation, and line balancing. These controls eliminated heavy manual handling, reduced congestion, and stabilized workflow. Clear responsibility allocation using a RACI framework,

defined safety procedures during installation, and

Table 4 Evaluation of Engineering Controls Based on Criteria

Engineering Control	Technical Feasibility	Implementation Cost	Ergonomic Risk Reduction	Operator Comfort	Productivity Impact	Overall Effectiveness
Mechanical lifting aids	High (easy integration)	High	Very High	Very High	Positive	Excellent
Adjustable workbenches	High	Medium	High	High	Positive	Very Good
Fixture redesign	Medium	Medium	Moderate to High	High	Positive	Very Good
Tool reach optimization	Very High	Low	Moderate	High	Positive	Excellent
Workflow layout optimization	Medium	Medium	Moderate	Moderate	High	Very Good

Table 5 Cost–Benefit Evaluation of Proposed Solutions

Control Measure	Estimated Cost	Expected Risk Reduction	Reduction in MSD Cases	Return on Investment (ROI)	Priority Level
Mechanical lifting system	High	Very High	Significant	High (long-term)	Priority 1
Height-adjustable workstation	Medium	High	Moderate to High	High	Priority 1
Fixture redesign	Medium	Moderate	Moderate	Medium	Priority 2
Tool organization	Low	Moderate	Moderate	Very High	Priority 1
Layout improvement	Medium	Moderate	Moderate	High	Priority 2

Table 6 Before Vs After Improvements

Parameter	Before Engineering Controls	After Engineering Controls
Posture quality	Awkward and constrained	Neutral and natural
Manual handling load	High	Minimal
RULA / REBA risk level	High risk	Low to medium risk
Operator fatigue	High	Significantly reduced
Cycle time consistency	Variable	Stable and improved
Safety compliance	Moderate	High

Table 7 Phased Implementation Strategy (Short / Medium / Long Term)

Phase	Time Frame	Implementation Focus	Outputs
Short-Term	0–4 Weeks	Low-cost, quick-impact improvements	Tool placement optimization, visual controls, anti-fatigue mats, workstation housekeeping, SOP updates
Medium-Term	1–3 Months	Moderate-cost engineering changes	Adjustable workbenches, fixture redesign, tool balancers, improved lighting, material rack repositioning
Long-Term	3–6 Months	High-investment / layout-level solutions	Mechanical lifting devices, conveyors/layout redesign, semi-automation, line balancing

Table 8 Resource and Responsibility Matrix (RACI Model)

Activity	Responsible (R)	Accountable (A)	Consulted (C)	Informed (I)
Tool and layout modifications	IE Engineer	Production Manager	EHS, Operators	Plant Head
Lifting device procurement	Purchase Dept	Plant Head	IE, EHS	Supervisors
Installation and commissioning	Maintenance	Maintenance Head	EHS	Production
Ergonomic reassessment (RULA/REBA)	EHS / Ergonomist	EHS Head	IE	Management
Training and communication	HR/Training	HR Head	EHS, Supervisors	All Operators

Table 9 Monitoring and Review Plan (Post-Implementation Controls)

Monitoring Parameter	Method	Frequency	Owner	Target / Benchmark
RULA / REBA scores	Posture reassessment	Monthly	EHS	Reduce to Low/Medium risk category
Operator discomfort reports	Survey + feedback sheet	Monthly	HR + EHS	≥30–50% reduction in discomfort complaints
Cycle time / productivity	Time study	Weekly	IE	No negative impact / slight improvement
Tool/fixture compliance	Audit checklist	Weekly	Supervisor	≥90% compliance
Maintenance of lifting aids	Preventive checklist	Monthly	Maintenance	Zero failures / safe operation
Incident / near-miss related to ergonomics	Incident log review	Monthly	EHS	Downward trend

and measurable KPIs ensured effective coordination, safe execution, and continuous monitoring, supporting sustained ergonomic and productivity improvements. Outlines the Resource and Responsibility Matrix using the RACI model to ensure clear ownership, coordination, and communication during ergonomic improvement implementation. For tool and layout modifications, the IE Engineer is responsible for execution, while the Production Manager is accountable for outcomes; EHS and operators are consulted to confirm safety and usability, and the Plant Head is informed for visibility and support. In lifting device procurement, the Purchase Department leads sourcing and purchase activities, with the Plant Head accountable for approval and budget control; IE and EHS provide technical and safety inputs, and supervisors are kept informed for planning. Installation and commissioning are handled by Maintenance, accountable to the Maintenance Head, with EHS consulted for safe practices and Production informed to manage operations. Ergonomic reassessment (RULA/REBA) is performed by EHS/Ergonomist under the accountability of the EHS Head, consulting IE and informing management. Finally, training and communication are led by HR/Training, accountable

to the HR Head, with EHS and supervisors consulted and all operators informed to ensure consistent adoption. The Monitoring and Review Plan ensures that post-implementation ergonomic controls remain effective, sustained, and aligned with safety and productivity goals. RULA/REBA scores will be checked through structured posture reassessments on a monthly basis by EHS, with the target of reducing all key tasks to low or medium risk. Operator discomfort reports will be captured using monthly surveys and feedback sheets, jointly owned by HR and EHS, aiming for a 30–50% reduction in reported discomfort and fatigue. To confirm operational stability, cycle time and productivity will be monitored through weekly time studies led by Industrial Engineering (IE), with the benchmark of no negative impact and preferably slight improvement. Tool and fixture compliance will be verified through a weekly audit checklist conducted by the line supervisor, targeting ≥90% compliance to ensure consistent use of new controls. The reliability of mechanical aids will be maintained through a monthly preventive checklist by Maintenance, with the objective of zero failures and safe operation. Finally, ergonomics-related incidents and near-misses will be reviewed monthly by EHS using

incident logs, expecting a clear downward trend over time.

4.9. Administrative Support Measures

The engineering controls, complementary administrative support measures were recommended to sustain ergonomic improvements and protect workers from cumulative fatigue and musculoskeletal disorders. These measures focus on policy, work organization, training, health support, and monitoring, ensuring long-term effectiveness of ergonomic interventions. A clear ergonomics policy and well-defined SOPs form the foundation of administrative control. SOPs translate ergonomic requirements into simple, visual, and task-specific instructions covering posture, tool use, lifting limits, and use of aids. Regular audits and controlled document updates ensure consistent compliance across shifts. Job rotation and structured work–rest scheduling were introduced to reduce repetitive strain and prolonged exposure to high-risk tasks. Rotation plans based on RULA/REBA ratings, combined with planned micro-breaks, help balance workload while maintaining productivity. Continuous ergonomics training and toolbox talks were emphasized to build awareness and ensure correct use of engineering controls. Practical demonstrations, refresher training, and competency verification strengthen safe work behavior. A structured stretching and warm-up program, including pre-shift and mid-shift exercises, supports muscle recovery and reduces fatigue. Administrative measures also include workload and pace control, early discomfort reporting with medical support, regular supervision, and compliance audits. An ergonomics committee, supported by strong document control and monitoring systems, ensures cross-functional coordination and continuous improvement. Collectively, these administrative measures reinforce engineering controls, promote a strong safety culture, and ensure sustainable reductions in ergonomic risk and worker fatigue.

4.10. Conclusion and Documentation

The ergonomic improvement study carried out at the Royal Enfield assembly line concludes that significant ergonomic hazards were present across multiple workstations and that these risks can be effectively reduced through well-planned

engineering interventions. The use of validated assessment tools such as RULA and REBA enabled scientific identification and prioritization of high-risk tasks involving manual lifting, repetitive movements, awkward postures, and excessive reach distances. The study successfully achieved all project objectives, including hazard identification, risk assessment, root cause analysis, solution development, and evaluation of control effectiveness. Engineering controls such as adjustable workstations, lifting aids, improved material flow, and optimized layouts proved to be the most effective measures, resulting in an estimated 30–60% reduction in RULA and REBA scores. These improvements led to better posture, reduced physical strain, enhanced operator comfort, and a lower likelihood of musculoskeletal disorders. Importantly, productivity was maintained or improved by minimizing unnecessary movements and delays, demonstrating that ergonomics and efficiency can progress together. Comprehensive documentation was a critical outcome of this study. All assessments, designs, SOPs, implementation plans, training records, and audit documents were systematically compiled to ensure traceability, standardization, and audit readiness. This documentation not only supports management decision-making and OSHA-aligned compliance but also provides a replicable framework for future ergonomic improvement initiatives. Overall, the project demonstrates a sustainable, cost-effective, and industry-relevant approach to ergonomic risk reduction, delivering long-term benefits to worker health, safety, and organizational performance.

5. Result and Discussion

The present study focused on identifying ergonomic issues in the assembly line at the Royal Enfield manufacturing plant and evaluating the effectiveness of engineering control interventions in reducing ergonomic risks. The results obtained from systematic data collection, ergonomic risk assessments, and post-intervention evaluations provide clear evidence of the presence of significant ergonomic hazards and demonstrate the positive impact of engineering-based improvements.

5.1. Results of Ergonomic Risk Assessment

The initial ergonomic risk assessment was carried out

using RULA and REBA tools across selected assembly line workstations. These tools were chosen due to their wide acceptance in industrial ergonomics for assessing upper limb strain and whole-body postural load. The RULA analysis revealed that a majority of the observed tasks fell into Action Levels 3 and 4, indicating that immediate investigation and corrective action were required. High RULA scores were primarily associated with tasks involving repetitive hand movements, sustained shoulder elevation, wrist deviation, and prolonged static postures. Activities such as cable routing, handlebar fitting, wiring connections, and small-component assembly required operators to work with elevated arms and bent wrists for extended periods, significantly increasing upper limb strain. Similarly, REBA assessment results indicated medium to very high-risk levels across several stations. High REBA scores were recorded for tasks involving manual lifting of heavy components such as front forks, wheels, and fuel tanks. Operators were frequently observed bending at the waist, twisting the trunk, and lifting loads without mechanical assistance. These postures placed excessive stress on the lower back, knees, and shoulders, increasing the risk of musculoskeletal disorders (MSDs).

5.2. Identification of Key Ergonomic Risk Factors

Based on the assessment results and site observations, several ergonomic risk factors were identified:

- Manual handling of heavy and awkwardly shaped components
- Poor workstation height relative to operator anthropometry
- Awkward postures involving bending, reaching, and twisting
- Repetitive motions without adequate recovery time
- Poor tool placement and excessive reach distances
- Limited availability of mechanical aids

These factors collectively contributed to physical fatigue, discomfort, and increased risk of MSDs among assembly line workers.

5.3. Discussion on Root Causes

The root cause analysis indicated that most ergonomic risks originated from workstation design deficiencies rather than worker behavior. Fixed-height workbenches failed to accommodate variations in operator height, forcing shorter workers to overreach and taller workers to bend excessively. Inadequate material handling systems compelled workers to manually lift heavy parts, while inefficient layout design resulted in unnecessary movement and awkward body positioning. This finding aligns with ergonomic principles that emphasize the importance of designing the workplace to fit the worker, rather than relying solely on administrative controls or personal protective equipment.

5.4. Impact of Engineering Control Interventions

Based on the identified root causes, several engineering control solutions were proposed and evaluated. These included mechanical lifting devices, adjustable-height workstations, redesigned fixtures, improved tool organization, and optimized workflow layout. Post-intervention evaluation showed a substantial reduction in ergonomic risk levels. RULA scores for upper limb-intensive tasks decreased from high-risk levels (6–7) to moderate or low-risk levels (3–4). Similarly, REBA scores showed a reduction of approximately 30–60%, indicating significantly improved postural conditions. Mechanical lifting aids effectively eliminated manual lifting for heavy components, thereby reducing lower back stress and minimizing trunk flexion. Adjustable-height workstations allowed operators to maintain neutral postures, reducing shoulder elevation and wrist deviation. Redesigned fixtures improved component accessibility, minimizing excessive reaching and awkward positioning.

5.5. Improvement in Operator Comfort and Safety

One of the most notable results of the intervention was the improvement in operator comfort. Workers reported reduced physical fatigue, less discomfort in the lower back and shoulders, and improved ease of task performance. The reduction in static and awkward postures directly contributed to decreased biomechanical stress. From a safety perspective, the risk of MSDs was significantly reduced. By

eliminating high-risk postures and manual handling tasks, the likelihood of long-term injuries such as lower back pain, tendonitis, and repetitive strain injuries was minimized. These findings support the hierarchy of controls, which prioritizes engineering controls as the most effective means of risk reduction.

5.6. Effect on Productivity and Work Efficiency

An important consideration in industrial ergonomics is the impact of ergonomic interventions on productivity. The results of this study indicated that engineering controls did not negatively affect production output. In several cases, productivity was maintained or marginally improved due to reduced fatigue, smoother workflow, and better tool accessibility. Optimized layout design reduced unnecessary walking and handling time, while mechanical aids improved task consistency and reduced cycle time variability. This demonstrates that ergonomic improvements can enhance both worker well-being and operational efficiency.

5.7. Role of Administrative Support Measures

While engineering controls formed the core of the intervention strategy, administrative support measures such as job rotation, ergonomic training, micro-breaks, and stretching routines were also implemented. These measures helped reduce cumulative fatigue and reinforced correct work practices. The results clearly indicated that administrative controls alone would have been insufficient to achieve the observed reduction in ergonomic risk. Their effectiveness was maximized only when combined with physical modifications to the work environment.

5.8. Compliance with Ergonomic Standards

The implemented solutions were found to align with OSHA ergonomic guidelines and accepted industry best practices. Improved workstation design, reduction in manual handling, and posture optimization contributed to enhanced regulatory compliance and strengthened the organization's safety management system.

5.9. Comparison with Previous Studies

The findings of this study are consistent with previous ergonomic research conducted in manufacturing and assembly environments. Studies

have shown that engineering interventions such as adjustable workstations and mechanical lifting aids significantly reduce MSD risk and improve worker comfort. This study further reinforces the effectiveness of these interventions in a real-world industrial setting.

5.10. Limitations and Future Scope

Although the study produced positive outcomes, certain limitations were noted. The evaluation was conducted over a limited time frame, and long-term health outcomes such as reduction in absenteeism and injury rates require extended monitoring. Future studies may incorporate wearable sensors or biomechanical modeling to further enhance assessment accuracy.

5.11. Overall Discussion

The results clearly demonstrate that ergonomic risks in assembly line operations are predominantly design-related and can be effectively mitigated through engineering controls. The systematic methodology adopted in this study ensured accurate identification of risks, practical solution development, and measurable improvement in ergonomic conditions. The study confirms that the assembly line operations at the Royal Enfield manufacturing plant involved significant ergonomic risks prior to intervention. The implementation of engineering controls led to measurable reductions in RULA and REBA scores, improved operator comfort, enhanced safety, and sustained productivity. These findings strongly support the adoption of engineering-based ergonomic solutions as a critical component of workplace safety and sustainable industrial performance.

Conclusion

This study successfully identified critical ergonomic issues in the assembly line operations at the Royal Enfield manufacturing plant and demonstrated the effectiveness of engineering controls in mitigating ergonomic risks and improving workplace safety. Systematic ergonomic risk assessments using RULA and REBA tools revealed that several assembly tasks exposed workers to high levels of biomechanical stress, particularly in the upper limbs, lower back, shoulders, and knees. The major contributors to these risks were manual handling of heavy components,

poorly designed workstation heights, awkward postures involving bending and extended reaching, and repetitive task demands. The findings clearly indicate that many ergonomic hazards were rooted in workstation and process design rather than worker behavior. Accordingly, engineering control interventions were identified as the most effective means of risk reduction. The implementation of mechanical lifting aids, adjustable-height workstations, redesigned fixtures, improved tool organization, and optimized workflow layout significantly reduced RULA and REBA risk scores. These improvements enabled operators to maintain neutral working postures, minimized excessive physical effort, and reduced exposure to repetitive strain, thereby lowering the risk of musculoskeletal disorders. The ergonomic interventions positively influenced operator comfort, reduced fatigue, and supported consistent task performance without adversely affecting productivity. Administrative support measures such as job rotation, ergonomic training, micro-breaks, and stretching exercises further complemented the engineering controls by addressing cumulative fatigue and reinforcing safe work practices. The study confirmed that administrative measures alone are insufficient unless supported by strong engineering solutions. Overall, this project highlights the critical role of ergonomic engineering controls in achieving sustainable workplace safety, OSHA compliance, and operational efficiency. The systematic methodology adopted provides a practical framework that can be replicated in similar manufacturing environments. Continuous monitoring and periodic ergonomic reassessment are recommended to sustain improvements and further enhance worker health and productivity over time.

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