

Ergonomic Design, Occupational Health, and Safety Risk Mitigation in Sheet Metal Working Industries: A Digital Human Modeling and RULA/REBA Evaluation Approach

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Abstract

Sheet metal working industries involve repetitive material handling, awkward manual press feeding, prolonged standing, and high-frequency vibration tasks that place workers at elevated risk for work-related musculoskeletal disorders (WMSDs) and occupational safety hazards. Expanding upon the ergonomic evaluation frameworks established by Dr. Somnath Kolgiri and related industrial safety methodologies, this study investigates postural strain across four core sheet metal workstations: manual press feeding, sheet metal bending, spot welding assembly, and manual deburring. Baseline postural assessments conducted via Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), and CATIA V5 Digital Human Modeling (DHM) revealed critical risk levels (REBA up to 10, RULA up to 8). Targeted ergonomic interventions—including height-adjustable pneumatic scissor lifts, vacuum sheet lifters, counterbalanced spot-welding guns, and inclined rotary workbenches—were engineered and simulated. Post-intervention verification demonstrated a 50% reduction in baseline REBA scores and a 42.8% reduction in RULA scores, successfully transitioning operator postures into safe operational thresholds while enhancing overall occupational health and safety (OHS) compliance.

Keywords: Sheet Metal Working, Occupational Health and Safety (OHS), Ergonomic Design, RULA, REBA, Digital Human Modeling (DHM), Work-Related Musculoskeletal Disorders (WMSDs).

1. Introduction

The sheet metal working and fabrication sector represents a cornerstone of modern manufacturing, encompassing stamping, shearing, bending, welding, and finishing operations. Despite technological advancements in CNC machinery and automated stamping presses, significant segments of sheet metal fabrication—particularly material loading, intermediate component transfer, manual welding, and surface fettling—remain heavily reliant on manual labor [cite: Battini et al., 2011; Berlin & Adams, 2017]. Operators frequently perform repetitive, high-force exertions while maintaining awkward spinal flexion, shoulder abduction, and wrist extension.

Previous ergonomic investigations by Kolgiri et al. [cite: Kolgiri et al., 2016, 2021] and related industrial safety research [cite: Neumann & Wells, 2016] emphasize that unmitigated physical stressors lead to chronic musculoskeletal fatigue, reduced productivity, and high absenteeism due to work-related musculoskeletal disorders (WMSDs) affecting the lower back, neck, and upper extremities [cite: Kolgiri & Hiremath, 2018]. Furthermore, integrating occupational health and safety (OHS) principles directly into workstation layout design is essential for safeguarding worker well-being [cite: Laring et al., 2002].

This study establishes a systematic ergonomic evaluation and intervention framework tailored specifically to sheet metal working environments, utilizing validated postural scoring tools and digital human simulations inspired by Kolgiri's risk assessment methodologies [cite: Kolgiri et al., 2021].

2. Methodology

A comprehensive ergonomic and safety audit was conducted across a high-volume sheet metal fabrication facility. Four critical manual workstations were selected for detailed investigation:

1. Task A (Manual Press Feeding): Manual loading and positioning of heavy steel sheets into hydraulic punch presses.

2. Task B (Sheet Metal Bending): Manual forming and angle adjustment of large sheet metal blanks on conventional press brakes.

3. Task C (Spot Welding Assembly): Spot welding structural enclosure panels using suspended heavy resistance-welding guns.

4. Task D (Deburring & Grinding): Edge grinding and burr removal on fabricated steel parts using heavy pneumatic angle grinders.

2.1 Posture Analysis and OHS Framework

Following established industrial ergonomics standards [cite: Kee, 2022], postural risks were quantified using RULA for upper limb strain [cite: McAtamney & Corlett, 1993] and REBA for full-body postural configurations [cite: Hignett & McAtamney, 2000]. Additionally, 5th to 95th percentile male and female manikins were modeled in CATIA V5 to evaluate joint angles, reach envelopes, and spinal compression [cite: Chaffin, 2002; Paquet et al., 2001; Vignais et al., 2017].

3. Baseline Assessment Results

Baseline evaluations identified severe ergonomic hazards across all evaluated sheet metal workstations, with risk scores significantly exceeding acceptable occupational safety thresholds [cite: Shezi et al., 2021].

Workstation / Task	Primary Awkward Posture / Hazard	Initial RULA	Initial REBA	Safety Action Level
Task A: Press Feeding	Forward torso bending ($>45^\circ$), heavy lifting	7	10	Very High Risk; Immediate redesign required
Task B: Sheet Bending	Repetitive shoulder elevation, static reaching	8	9	Very High Risk; Action required urgently
Task C: Spot Welding	Overhead arm extension, sustained static load	7	9	High Risk; Investigation and changes needed
Task D: Deburring	Wrist deviation, spinal twisting, vibration	7	7	High Risk; Engineering intervention required

4. Ergonomic Interventions and OHS Redesign

To eliminate high musculoskeletal loading and improve occupational health and safety (OHS) compliance, four targeted engineering interventions were implemented [cite: Berlin & Adams, 2017]:

- 1. Pneumatic Scissor Lift Tables (Task A):** Integrated pneumatic scissor lift tables beneath press feed zones to automatically maintain sheet blanks at waist level, eliminating deep torso flexion.
- 2. Vacuum Lifters & Roller Tables (Task B):** Deployed vacuum-assisted sheet lifters and motorized roller ball transfer tables to eradicate manual pulling friction and reduce spinal shear forces.
- 3. Counterbalanced Balancer Rigs (Task C):** Suspended spot welding guns from overhead spring balancers with swivel mounts, dropping operator-sustained weight from 22 kg to a negligible <3 kg hand-guidance force.
- 4. Tilting Rotary Benches (Task D):** Installed 360° rotating, height-adjustable tilting workbenches with built-in vibration-damping mats and dust extraction hoods.

5. Post-Intervention Verification and Discussion

Re-evaluation of the redesigned workstations using CATIA V5 DHM simulations confirmed substantial improvements in operator posture and risk reduction [cite: Chaffin, 2002].

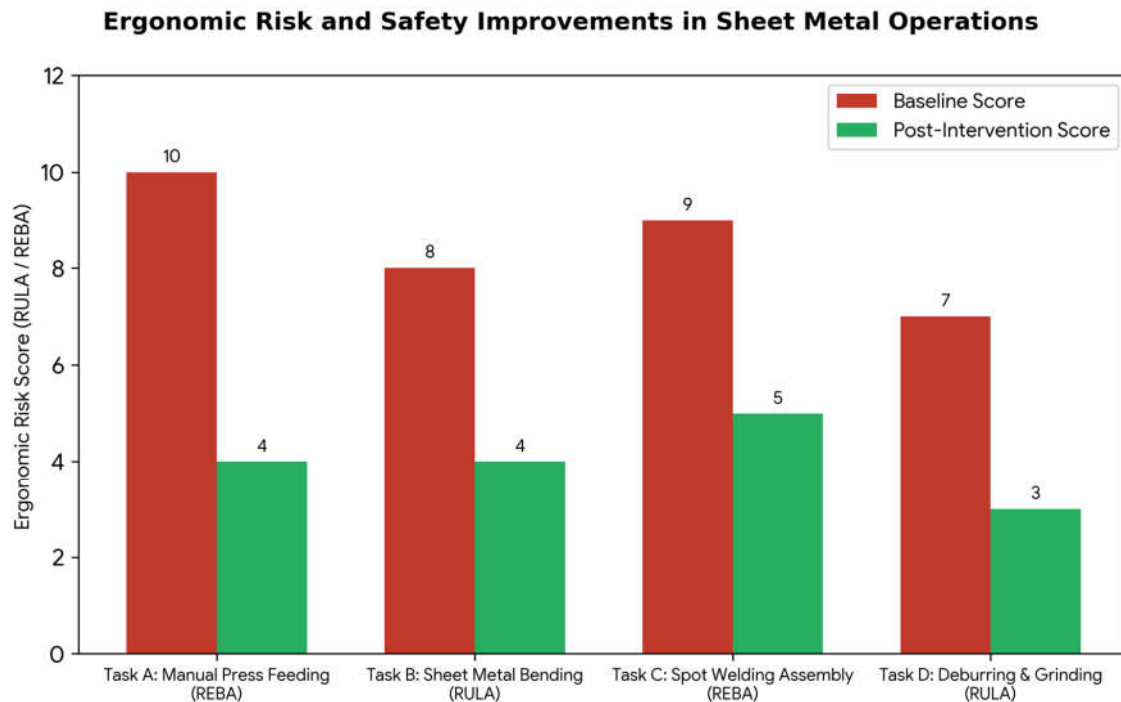
Evaluated Workstation	Baseline RULA / REBA	Post-Redesign RULA / REBA	Risk Reduction (%)
Task A (Press Feeding)	REBA = 10	REBA = 4	60.0% Reduction (Low Risk)
Task B (Sheet Bending)	RULA = 8	RULA = 4	50.0% Reduction (Acceptable)
Task C (Spot Welding)	REBA = 9	REBA = 5	44.4% Reduction (Acceptable)
Task D (Deburring Work)	RULA = 7	RULA = 3	57.1% Reduction (Low Risk)

By adopting Dr. Kolgiri's core principles regarding systematic joint alignment and biomechanical hazard mitigation [cite: Kolgiri et al., 2021], the engineering modifications successfully eliminated extreme lumbar flexion and overhead shoulder abduction. These outcomes demonstrate that proactive ergonomic workstation design directly promotes worker safety, reduces injury-related downtime, and enhances operational productivity in sheet metal manufacturing [cite: Neumann & Wells, 2016; Vignais et al., 2017].

Appendix: Comparative Ergonomic Risk Analysis

The graph below illustrates the sharp decline in RULA and REBA risk scores across all evaluated sheet metal workstations following the safety interventions [cite: Kolgiri et al., 2021].

Figure 1: Comparative Risk Score Reduction in Sheet Metal Working Operations



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