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Design and Development of a Comprehensive Ergonomic and Occupational Safety Evaluation Framework for Foundries

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Abstract

Foundries are among the most hazardous industrial workplaces because of the combined presence of molten metal, high-temperature surfaces, airborne contaminants, noise, vibration, heavy material handling, awkward working postures, repetitive activities, and physically demanding operations. Conventional occupational safety assessments often focus primarily on accident prevention and regulatory compliance, while ergonomic hazards and their interaction with workplace safety risks may receive insufficient attention. This research proposes the design and development of a comprehensive Ergonomic and Occupational Safety Evaluation Framework (EOSEF) for foundry workstations. The framework integrates ergonomic risk assessment, occupational hazard identification, quantitative risk evaluation, and prioritisation of corrective interventions into a unified assessment methodology.

The proposed framework combines established ergonomic assessment techniques, including the Rapid Entire Body Assessment (REBA), Rapid Upper Limb Assessment (RULA), the Revised NIOSH Lifting Equation where applicable, and the Occupational Repetitive Actions (OCRA) approach where relevant, with systematic occupational hazard identification and risk evaluation. It incorporates workstation characteristics, task demands, environmental exposures, worker-related factors, and existing safety controls. A weighted multi-criteria decision-making model is proposed to generate workstation risk scores and prioritise intervention measures. The framework is intended to support safety engineers, industrial hygienists, ergonomists, production managers, and occupational health professionals in identifying high-risk activities and developing evidence-based workplace improvements. The paper presents the conceptual framework, assessment methodology, proposed mathematical model, implementation procedure, and validation strategy. The framework is proposed for empirical testing in actual foundry environments; numerical effectiveness and performance improvements must be established through field validation.

Keywords: Foundry safety, industrial ergonomics, occupational risk assessment, workstation evaluation, REBA, RULA, hazard identification, musculoskeletal disorders, multi-criteria decision-making, occupational health and safety.

1. Introduction

Foundry operations are essential to manufacturing industries, including automotive engineering, heavy machinery, construction equipment, agricultural machinery, and industrial components. The production process typically involves pattern preparation, moulding, core making, melting, pouring, cooling, shakeout, fettling, grinding, finishing, inspection, and material handling. Each operation presents different combinations of physical, chemical, thermal, mechanical, and ergonomic hazards.

Workers may be exposed to radiant heat, molten metal splashes, silica-containing dust, metal fumes, excessive noise, moving machinery, lifting demands, and repetitive manual activities. The combination of these hazards can increase

the likelihood of occupational injuries, work-related musculoskeletal disorders, fatigue, reduced productivity, and long-term health problems.

Ergonomic hazards are particularly significant in foundries because many tasks require workers to bend, twist, reach, lift, push, pull, and maintain static or constrained postures. Manual handling of moulding materials, castings, tools, and components may impose substantial biomechanical loads. Repetitive grinding and finishing tasks may also produce upper-limb discomfort and fatigue.

Traditional safety assessment methods, such as job safety analysis, hazard identification, and risk assessment matrices, are useful for identifying hazardous conditions. However, they may not comprehensively quantify ergonomic exposures or evaluate the combined influence of ergonomic and conventional occupational hazards at individual workstations.

A comprehensive evaluation framework is therefore needed to integrate ergonomic assessment with occupational safety evaluation, enabling consistent comparison of workstations and systematic prioritisation of corrective actions.

This research proposes an integrated framework designed specifically for foundry environments, with the objective of improving risk identification, decision-making, and the selection of practical workplace interventions.

1.1 Problem statement

The principal problem addressed in this study is the absence of a unified and consistently applied assessment approach that evaluates ergonomic risks and occupational safety hazards together at foundry workstations. Separate assessment methods can produce fragmented results, making it difficult to compare workstations, allocate safety resources, and identify interventions that address multiple risk factors simultaneously.

The proposed framework seeks to overcome these limitations by integrating ergonomic scoring, occupational hazard evaluation, environmental exposure assessment, and risk-based intervention prioritisation.

1.2 Research objectives

The specific objectives are:

1. To identify the major ergonomic and occupational safety hazards associated with foundry operations.
2. To develop a structured workstation assessment framework integrating ergonomic and conventional occupational risk assessment methods.
3. To formulate a quantitative model for calculating and comparing workstation risk scores.
4. To establish a systematic method for prioritising corrective and preventive measures.
5. To develop an implementation protocol for applying the framework in small, medium, and large foundries.
6. To propose a validation strategy for assessing the framework's reliability, practicality, and effectiveness in reducing workplace risks.

1.3 Research questions

- Which ergonomic and occupational safety hazards are most relevant to different foundry operations?
- How can established ergonomic assessment techniques be integrated with conventional occupational risk assessment?
- Can a weighted risk-scoring model support consistent prioritisation of hazardous workstations?
- How can the framework guide the selection and subsequent evaluation of corrective measures?

2. Review of Literature

2.1 Ergonomic hazards in foundry operations

Foundry workers are frequently exposed to ergonomic stressors arising from heavy lifting, repetitive work, awkward postures, excessive reaching, forceful exertion, and prolonged standing. The Occupational Safety and Health Administration (OSHA) has documented practical ergonomic interventions for foundries, including improvements to material handling, workstation design, and work practices. Its guidance emphasises systematic identification of musculoskeletal injury risks and reassessment after corrective measures are implemented.

Ergonomic risk assessment is therefore an important component of a comprehensive occupational safety programme. However, an ergonomic evaluation alone cannot adequately address hazards such as molten metal exposure, machinery entanglement, harmful airborne contaminants, or inadequate emergency protection. These risks require additional assessment methods appropriate to their specific characteristics.

2.2 Established ergonomic assessment techniques

Several validated methods can be incorporated into a foundry workstation assessment programme.

- Rapid Entire Body Assessment (REBA): Suitable for assessing whole-body postural loading during tasks involving bending, twisting, unstable postures, and changing body positions.
- Rapid Upper Limb Assessment (RULA): Appropriate for evaluating upper-limb postures, neck positioning, trunk posture, and muscular loading during tasks such as grinding, fettling, and detailed finishing.
- Revised NIOSH Lifting Equation (RNLE): Evaluates specified two-handed manual lifting tasks using variables such as load weight, horizontal and vertical hand positions, travel distance, asymmetry, lifting frequency, and coupling quality. Its principal outputs include the Recommended Weight Limit (RWL) and Lifting Index (LI).
- Occupational Repetitive Actions (OCRA): Can be considered for repetitive upper-limb activities when the task characteristics and required data are compatible with the selected OCRA method.
- Environmental exposure assessment: Instrumental measurements can be used to evaluate relevant exposures, including noise, thermal conditions, and airborne contaminants.

The selection of an assessment method must depend on the task being examined. For example, the RNLE should not be applied indiscriminately to lifting activities outside its intended scope. Likewise, a postural score should not be interpreted as a complete measure of occupational safety.

2.3 Occupational safety and risk assessment

Conventional occupational risk assessment identifies hazards, evaluates their potential consequences and likelihood, and establishes controls. Foundry operations require particular attention to thermal hazards, dust and fumes, machine guarding, material transport, electrical systems, and emergency response.

The NIOSH publication on foundry hazards documents risks associated with processes such as melting, pouring, shakeout, grinding, maintenance, and cleaning.

The proposed framework combines these conventional safety considerations with ergonomic evaluation. Its central contribution is a common workstation assessment and intervention-prioritisation structure, rather than the replacement of established specialist methods.

2.4 Research gap

The literature and technical guidance indicate the availability of individual methods for ergonomic assessment and occupational hazard control. Nevertheless, their practical integration can be challenging because they produce different types of results, operate at different levels of analysis, and require different measurement procedures.

The research gap addressed here is the need for a unified framework that:

1. Evaluates ergonomic and non-ergonomic hazards within the same workstation review.
2. Preserves the original meaning of validated assessment scores.
3. Combines results through a transparent and reproducible decision model.
4. Identifies immediate safety priorities independently of an aggregate score.
5. Supports intervention selection and post-intervention evaluation.

The proposed framework is a conceptual design that requires field testing before its reliability and predictive performance can be established.

3. Research Methodology

3.1 Research design

The study adopts a framework-development methodology involving hazard identification, selection of established assessment techniques, development of a common scoring model, and specification of a field-validation procedure.

A mixed-method research design is proposed, combining quantitative measurements with qualitative information collected from workers, supervisors, and safety professionals.

The research process comprises five stages:

Stage 1: Workstation identification

Process mapping, task observation and worker consultation

Stage 2: Hazard and exposure assessment

Ergonomic, physical, chemical, thermal and mechanical hazards

Stage 3: Quantitative evaluation

Task-specific ergonomic scores and conventional risk ratings

Stage 4: Integrated prioritisation

Normalisation, weighting and workstation ranking

Stage 5: Intervention and validation

Engineering controls, reassessment and performance verification

3.2 Study setting and workstation selection

The framework can be tested in ferrous or non-ferrous foundries, including facilities manufacturing cast iron, steel, aluminium, or other metal components. Workstations should be selected to represent different tasks and exposure profiles.

The principal workstation categories are:

Foundry operation	Typical hazards and ergonomic concerns
Sand preparation and moulding	Dust, manual handling, repetitive movements, awkward postures
Core making	Chemical exposure, repetitive hand movements, constrained postures
Melting and metal charging	Radiant heat, heavy loads, molten metal, awkward access
Pouring	Thermal exposure, splash hazards, forceful handling
Shakeout and knockout	Dust, vibration, noise, manual force
Fettling and grinding	Hand-arm vibration, noise, dust, repetitive upper-limb loading
Finishing and inspection	Static postures, visual demands, repetitive work
Material handling	Heavy lifting, pushing, pulling, collision and crush hazards

These categories are illustrative. Actual hazards must be verified through workplace observations and measurements rather than assumed to exist at every facility.

3.3 Data collection

Data collection should combine direct observation, instrument-based measurement, document review, and worker consultation.

A. Workplace observation

Record task sequence, cycle time, lifting frequency, posture, working height, tool use, material flow, housekeeping, machine guarding, and emergency access.

B. Ergonomic measurements

Collect relevant information for the selected assessment method, including joint positions, trunk inclination, load weight, reach distance, repetition, duration, recovery time, and force requirements.

C. Environmental and physical measurements

Measure relevant exposures using appropriate calibrated instruments. Depending on the process, these may include noise levels, thermal conditions, airborne dust, respirable crystalline silica, and metal fumes.

D. Safety records

Review available injury records, near-miss reports, first-aid cases, maintenance logs, previous risk assessments, and corrective-action records.

E. Worker consultation

Use structured interviews or questionnaires to document discomfort, fatigue, task difficulty, perceived hazards, and the practicality of proposed controls. Participation should be voluntary and worker information handled confidentially.

3.4 Selection of assessment tools

Risk category	Proposed assessment approach
Whole-body posture	REBA
Upper-limb posture	RULA
Applicable two-handed lifting	RNLE
Repetitive upper-limb work	Appropriate OCRA method
Physical and mechanical hazards	Task-based hazard identification and risk matrix
Noise and airborne contaminants	Instrumental exposure assessment
Heat exposure	Appropriate thermal stress assessment
Organisational and task factors	Worker interviews and structured observation

The tools should be selected according to the characteristics of each task. Where several tools apply, their findings should be retained separately before being incorporated into the integrated model.

4. Design of the Comprehensive Evaluation Framework

4.1 Framework architecture

The proposed Ergonomic and Occupational Safety Evaluation Framework consists of six interconnected modules.

Module 1: Hazard identification

Identifies ergonomic, mechanical, thermal, chemical, physical and organisational hazards associated with each task.

Module 2: Ergonomic assessment

Applies REBA, RULA, RNLE or an appropriate repetitive-work assessment to the relevant tasks.

Module 3: Occupational exposure evaluation

Evaluates relevant noise, heat, airborne contaminants, vibration and other physical exposures.

Module 4: Integrated risk computation

Converts selected results to a common scale and calculates a weighted workstation score.

Module 5: Intervention prioritisation

Ranks corrective actions based on risk severity, urgency, feasibility and expected risk reduction.

Module 6: Monitoring and validation

Tracks corrective actions, repeats assessments and verifies whether workplace risks have decreased.

4.2 Hazard classification

For each workstation, hazards should be classified into the following domains:

- Ergonomic hazards: awkward postures, forceful exertion, repetitive movements, manual handling, prolonged standing and inadequate workstation dimensions.

- Mechanical hazards: unguarded machinery, rotating equipment, pinch points, crushing and entanglement.
- Thermal hazards: radiant heat, hot surfaces, molten metal splash and heat stress.
- Chemical hazards: metal fumes, silica-containing dust, binders, solvents and other process-specific substances.
- Physical hazards: noise, vibration, inadequate illumination and electrical hazards.
- Organisational hazards: excessive workload, insufficient recovery time, inadequate training, unclear procedures and fatigue-related factors.

The classification should distinguish hazards from their consequences. For example, repetitive lifting is a hazardous exposure, while a musculoskeletal disorder is a potential health outcome.

4.3 Ergonomic risk evaluation

The ergonomic assessment module applies task-specific scoring methods. REBA and RULA provide posture-related assessment results, while the RNLE provides quantitative lifting indices for eligible lifting tasks.

The RNLE Lifting Index is calculated as:

$$ LI=\frac{L}{RWL} $$

where:

- LI = Lifting Index;
- L = actual load weight;
- RWL = Recommended Weight Limit.

The RNLE considers multiple lifting-task variables and is intended for specific manual lifting conditions. A value of $LI\leq 1$ is a recommended target in the NIOSH guidance, not a guarantee of zero risk. Higher values indicate increased concern and the need to examine task redesign.

Ergonomic results should be documented with the task conditions, assessor, observation period, and relevant exposure information. A score should not be transferred between tasks without reassessment.

4.4 Conventional occupational risk evaluation

For hazards that can be assessed using a likelihood–severity matrix, a simple risk score can be calculated as:

$$ R_j=L_j\times S_j $$

where:

- R_j = risk score for hazard j;
- L_j = likelihood rating;
- S_j = severity rating.

For example, a five-point likelihood scale and a five-point severity scale produce a score from 1 to 25. The definitions of each rating must be documented and applied consistently.

A hazard involving a credible fatal molten-metal event must not be considered adequately controlled merely because its numerical score is low. Applicable legal requirements, critical safety controls, and intolerable-risk conditions must override routine aggregate scoring.

4.5 Normalisation of assessment results

REBA, RULA, RNLE, and conventional risk matrices have different scales and interpretations. Their raw scores should not be added directly.

For an assessment measure x_i with a defined lower and upper bound, a possible normalisation method is:

$$N_i=100\left(\frac{x_i-x_{\min}}{x_{\max}-x_{\min}}\right)$$

where N_i is the normalised value between 0 and 100.

This equation is suitable for measures in which higher values consistently represent greater risk and the bounds are valid for the chosen scale. For a measure in which higher values indicate better safety, the direction must be reversed. For ordinal ergonomic categories, a validated category mapping or expert-defined conversion is preferable to assuming that every numerical increment represents an equal increase in risk.

For RNLE, the Lifting Index is not inherently bounded above by a universal maximum. Therefore, the normalisation method should be defined in advance, justified, and tested for sensitivity. The original LI must also be retained for interpretation.

5. Mathematical Formulation of the Integrated Risk Model

5.1 Weighted composite risk score

A weighted composite score is proposed to support the comparison of workstation risk profiles. The model is a design proposal and must be calibrated and validated before operational use.

Let the assessment domains be:

- E: ergonomic risk;
- M): mechanical and physical safety risk;
- T): thermal risk;
- C): chemical and airborne exposure risk;
- O): organisational and task-related risk.

The integrated workstation risk score is defined as:

$$IR_i=\sum_{k=1}^{n}w_kN_{ik}$$

Subject to:

$$\sum_{k=1}^{n}w_k=1,\qquad w_k\geq0$$

where:

- IR_i = integrated risk score for workstation i);
- N_{ik} = normalised risk score of domain k) at workstation i);
- w_k) = relative weight assigned to domain k);
- n) = number of assessment domains.

The resulting score ranges from 0 to 100 if all domain scores have been validly normalised to that interval.

5.2 Proposed weighting structure

The following weights are illustrative starting values for demonstrating the model. They are not empirically established weights and should not be adopted as universal foundry risk priorities.

Assessment domain	Illustrative weight
Ergonomic risk	0.25
Mechanical and physical safety	0.25
Thermal risk	0.20
Chemical and airborne exposure	0.20
Organisational and task-related risk	0.10
Total	1.00

The final weights should be determined using a documented process involving occupational safety experts, ergonomists, industrial hygienists, and foundry personnel. Methods such as the Analytical Hierarchy Process (AHP) may be used to derive expert-based weights, while entropy-based weighting can be considered when sufficient reliable observational data are available.

Multi-criteria decision-making has previously been applied to foundry heat-stress evaluation, demonstrating the relevance of structured weighting and uncertainty-aware risk evaluation in this sector.

The framework should also test whether changes in the selected weights materially alter workstation rankings.

5.3 Risk categories and intervention priorities

For preliminary screening, the following categories may be used as provisional decision bands.

Integrated risk score	Proposed category	Suggested response
0–19	Low	Maintain controls and monitor
20–39	Moderate	Plan and implement improvements
40–59	High	Prioritise corrective action
60–79	Very high	Expedite intervention and management review
80–100	Critical	Immediate expert review and action under the applicable safety procedure

These bands are proposed for development and testing, not established clinical or regulatory thresholds. They must be calibrated against expert judgement, applicable standards, actual exposure data, and workplace outcomes.

Critical safeguard: The aggregate score must never override an immediately dangerous condition, a statutory exposure limit, or a required critical control. A credible risk of fatal injury or serious irreversible harm must be addressed through the appropriate safety procedure even if the integrated score falls within a lower category.

5.4 Intervention-prioritisation model

The integrated risk score can be combined with urgency, expected risk reduction, and implementation feasibility to rank proposed interventions.

One possible decision model is:

$$P_j=\alpha R_j+\beta U_j+\gamma B_j$$

where:

- P_j = intervention priority score for intervention j;
- R_j = normalised risk associated with the targeted hazard;
- U_j = urgency of intervention;
- B_j = expected risk-reduction benefit;
- α,β,γ = non-negative weights summing to 1.

All three terms must be expressed on a common scale. The weights should be justified and validated with relevant stakeholders.

Feasibility and cost can then be evaluated separately or incorporated as additional criteria. A lower-cost intervention should not automatically outrank a necessary life-saving control.

The intervention process should follow the hierarchy of controls: elimination, substitution, engineering controls, administrative controls, and personal protective equipment. Administrative measures and personal protective equipment should not be treated as automatic substitutes for feasible higher-level controls.

6. Illustrative Application to Foundry Workstations

To demonstrate the operation of the proposed model, three hypothetical workstation profiles are considered. The scores below are invented solely for mathematical illustration and are not field observations or research findings.

6.1 Example workstation assessment

Illustrative normalised risk scores, each on a 0–100 scale

Risk domain	Moulding	Pouring	Grinding
Ergonomic	65	55	75
Mechanical and physical safety	40	85	60
Thermal	30	95	35
Chemical and airborne exposure	55	50	80
Organisational and task-related	45	60	55

Applying the illustrative weights from Section 5.2 gives:

Moulding workstation

$$\begin{aligned} IR_{\mathrm{M}} &= 0.25(65)+0.25(40)\\ &\quad +0.20(30)+0.20(55)+0.10(45)\\ &= 48.25 \end{aligned}$$

Pouring workstation

$$\begin{aligned} IR_{\mathrm{P}} &= 0.25(55)+0.25(85)\\ &\quad +0.20(95)+0.20(50)+0.10(60)\\ &= 69.00 \end{aligned}$$

Grinding workstation

$$\begin{aligned} IR_{\mathrm{G}} &= 0.25(75)+0.25(60)\\ &\quad +0.20(35)+0.20(80)+0.10(55)\\ &= 62.25 \end{aligned}$$

Illustrative integrated risk scores

Moulding

48.25

Pouring

69.00

Grinding

62.25

Scores are hypothetical. Provisional categories would classify moulding as high, and pouring and grinding as very high. Immediate hazards require independent review.

The illustrative results place pouring first, followed by grinding and moulding. The pouring workstation has a high combined score because of the assumed thermal and mechanical safety ratings. Grinding has substantial assumed ergonomic and airborne exposure risks, while moulding has a comparatively lower overall score.

This example demonstrates how the model can organise multiple risk domains into a single comparison. It does not establish that pouring is always the most hazardous foundry operation, nor that the chosen weights or categories are valid for a real facility.

6.2 Interpretation of workstation results

The framework should produce two complementary outputs:

1. Integrated workstation ranking: supports comparison and allocation of assessment resources.
2. Hazard-specific priority list: identifies individual hazards requiring action regardless of the aggregate ranking.

For example, grinding may require improved local exhaust ventilation, appropriate tool selection, vibration management, and workpiece positioning. Moulding may benefit from mechanical material handling, adjustable working heights, and improved access to tools. Pouring may require robust molten-metal containment, safe transfer arrangements, suitable protective systems, and verified emergency procedures.

The actual measures must be selected after observing the process and identifying the underlying hazards.

7. Proposed Ergonomic and Safety Improvement Strategies

7.1 Workstation redesign

Workstation redesign should aim to reduce excessive reaching, trunk flexion, twisting, forceful exertion, and unnecessary manual handling. Adjustable work surfaces, suitable fixtures, accessible tools, and appropriate component positioning may reduce biomechanical demands.

7.2 Material handling improvements

Mechanical lifting devices, conveyors, manipulators, lift tables, and redesigned storage arrangements should be considered where appropriate. Lifting tasks should be assessed before and after changes, using the RNLE only when the task falls within its intended application.

7.3 Thermal risk reduction

Thermal controls may include effective furnace and pouring-area design, heat shielding where appropriate, isolation of hot surfaces, suitable ventilation, exposure management, and monitored work-rest arrangements. Heat controls should be selected based on measured conditions and the nature of the work.

7.4 Dust and fume control

Grinding, sand handling, melting, and related operations should be evaluated for airborne contaminants. Appropriate enclosure and local exhaust ventilation should be prioritised where feasible, with performance verified through exposure measurements. Respiratory protection should be selected through a suitable respiratory protection programme when required.

7.5 Mechanical safety

Machine guarding, interlocks, safe access, preventive maintenance, isolation of hazardous energy, and appropriate emergency stops should be evaluated. For molten-metal operations, particular attention should be given to transfer equipment, moisture hazards, containment, and safe exclusion zones.

7.6 Worker training and participation

Workers should be trained in hazard recognition, safe work procedures, equipment operation, manual handling, emergency response, and reporting of unsafe conditions. Worker participation is essential because employees can identify practical difficulties that may not be apparent during a brief external inspection.

Training alone, however, should not replace engineering controls where the hazard can be reduced through physical redesign.

8. Validation and Performance Evaluation

The proposed framework should be validated in actual foundries before its suitability for routine operational decisions is claimed.

8.1 Expert review

An expert panel comprising occupational safety professionals, ergonomists, industrial hygienists, and foundry engineers should review the selected criteria, assessment procedures, weights, and intervention rules.

Content validity can be assessed through structured expert ratings, documented disagreements, and revision of unclear criteria.

8.2 Inter-rater reliability

Independent assessors should evaluate the same selected tasks using standardised observation procedures. Agreement may be assessed using an appropriate statistic, such as weighted kappa for ordinal categories or an intraclass correlation coefficient for suitable numerical measures.

Disagreement should be investigated to determine whether it arises from inconsistent observation, insufficient training, unclear definitions, or genuine task variability.

8.3 Criterion and convergent validity

The integrated score should be compared with relevant independent indicators, such as expert hazard-priority rankings, instrument-measured exposures, task-specific ergonomic assessments, and available injury or discomfort records.

Because injury data are influenced by reporting practices, workforce characteristics, and exposure duration, agreement with historical injury counts alone is insufficient to validate the model.

8.4 Sensitivity and robustness analysis

The proposed weights, normalisation procedures, and category boundaries should be varied systematically to determine whether the workstation ranking remains stable. Alternative weighting methods may be compared, and the assumptions should be reported transparently.

8.5 Pre- and post-intervention evaluation

Where feasible, the framework should be applied before and after corrective measures. Evaluation indicators may include:

- Change in task-specific REBA or RULA scores.
- Change in RNLE lifting indices for applicable tasks.
- Change in measured occupational exposures.
- Change in reported discomfort or fatigue.
- Completion of corrective actions and critical-control verification.
- Changes in injury rates or lost-time cases over an appropriate follow-up period.
- Changes in task duration, product quality, or productivity where relevant.

A reduction in an ergonomic score does not automatically prove a reduction in injury incidence. Outcome measures should therefore be interpreted separately and over suitable observation periods.

9. Results and Discussion

9.1 Expected contribution of the framework

Since the framework has not yet been tested using actual foundry data, this study reports a proposed assessment methodology and an illustrative numerical application rather than empirical research findings.

The anticipated contributions are discussed below.

Integration of ergonomic and occupational safety assessments. The framework is designed to evaluate biomechanical stressors alongside thermal, chemical, mechanical, and physical hazards. This may help safety professionals identify hazards that are overlooked when ergonomic and conventional safety assessments are conducted independently.

Standardised workstation comparison. A common scoring architecture may support systematic comparison between moulding, pouring, grinding, and other foundry operations. The usefulness of this comparison will depend on consistent measurement, valid normalisation, and appropriate weighting.

Improved intervention prioritisation. The proposed model provides a structured approach for identifying workstations that require further investigation or corrective action. Independent critical-hazard checks remain essential to prevent aggregate scoring from concealing serious risks.

Support for evidence-based decisions. By retaining the underlying assessment results, the framework can help managers understand why a workstation receives a particular risk rating and which corrective actions are most relevant.

These objectives are consistent with earlier research developing risk assessment tools for foundry workers, including a study that examined a physical effort index using worker assessments and the Borg Rating of Perceived Exertion scale.

9.2 Comparison with conventional approaches

Evaluation characteristic	Conventional separate assessments	Proposed integrated framework
Ergonomic risk evaluation	Conducted using selected ergonomic tools	Retained and combined with other assessment domains
Occupational safety hazards	Evaluated through separate risk procedures	Included in a common workstation assessment
Workstation comparison	May require manual consolidation	Supported by a common normalised score
Corrective-action selection	Depends on individual assessment findings	Uses integrated ranking and hazard-specific priorities
Post-intervention evaluation	Varies between assessments	Uses a common monitoring and reassessment protocol
Validation requirements	Depend on the individual method	Includes additional validation of the combined model

The integrated framework offers a structured approach to consolidating information. However, its additional complexity must be justified by improved decision quality, usability, or risk reduction. It should not be assumed to outperform conventional approaches without comparative testing.

9.3 Limitations

Several limitations must be acknowledged.

First, the proposed weights and risk categories are illustrative and have not been calibrated using foundry field data. Second, different ergonomic tools assess different constructs, and a composite score may obscure important distinctions if normalisation is inappropriate. Third, worker discomfort, exposure measurements, incident records, and expert assessments may contain uncertainty or incomplete information.

Fourth, the framework requires trained assessors, suitable measurement equipment, and cooperation from foundry management and workers. Finally, differences in production processes, metal types, facility size, equipment, and local regulatory requirements may limit the transferability of a model calibrated at one facility to another.

Future work should investigate data-driven weighting, uncertainty analysis, and digital decision-support tools while preserving the transparency of the underlying risk assessments.

10. Future Research Directions

The framework provides a foundation for several further research activities.

1. Digital ergonomic assessment: Use video-based posture analysis or wearable sensors to support repeated assessment, subject to appropriate accuracy, privacy, and safety requirements.
2. Artificial intelligence integration: Explore whether validated historical data can support hazard prediction or intervention recommendations without replacing specialist assessment.
3. Computational exposure modelling: Integrate suitable thermal or airborne-contaminant models where these provide additional value beyond workplace measurements.
4. Uncertainty-aware decision-making: Evaluate fuzzy logic, AHP, or other multi-criteria decision-making methods for handling uncertain expert judgements.
5. Economic evaluation: Compare the costs of interventions with their measured effects on exposures, discomfort, injuries, absenteeism, and productivity.
6. Multi-foundry validation: Test the model across facilities with different processes, workforce characteristics, and production scales.

The most important next step is a field study involving real workstation observations, validated ergonomic assessments, occupational exposure measurements, and documented corrective actions. Such a study would establish whether the proposed framework is sufficiently reliable and useful for operational implementation.

11. Conclusion

This paper proposes a Comprehensive Ergonomic and Occupational Safety Evaluation Framework for Foundries to integrate ergonomic risk assessment, conventional occupational hazard evaluation, quantitative risk scoring, and corrective-action prioritisation.

The framework combines established methods, including REBA, RULA, and the Revised NIOSH Lifting Equation where applicable, with systematic evaluation of mechanical, thermal, chemical, physical, and organisational hazards. A weighted composite model is proposed to facilitate workstation comparison, while independent critical-hazard checks ensure that serious safety concerns are not obscured by aggregate scores.

An illustrative numerical example demonstrates how the model could be applied to moulding, pouring, and grinding workstations. However, the example uses hypothetical data and does not establish empirical effectiveness. The proposed weights, normalisation procedures, and decision bands require expert review, field calibration, and sensitivity analysis.

The principal contribution is the development of a structured methodology for connecting ergonomic assessment with broader occupational safety management in foundry environments. Its practical value will ultimately depend on validation against actual workplace conditions and evidence that the resulting interventions improve worker safety and health.

References

The following references provide a starting point for developing the manuscript into a journal submission. They should be supplemented with a systematic review of current peer-reviewed literature.

1. Occupational Safety and Health Administration (OSHA). (2012). Ergonomics: Solutions for the Prevention of Musculoskeletal Injuries in Foundries. U.S. Department of Labor. Official publication.

2. Waters, T. R., Putz-Anderson, V., & Garg, A. (1994; revised 2021). Applications Manual for the Revised NIOSH Lifting Equation. National Institute for Occupational Safety and Health, Publication No. 94-110. Official NIOSH manual.

3. Occupational Safety and Health Administration. OSHA Technical Manual, Section VII, Chapter 1: Ergonomics. Official technical guidance.

4. Madhan Mohan, G., Prasad, P. S. S., Mokkapati, A. K., & Venkataraman, G. (2008). Development of risk assessment tool for foundry workers. WORK, 31(4), 405–416. https://doi.org/10.3233/WOR-2008-00754.

5. Ilangkumaran, M., Karthikeyan, M., Ramachandran, T., Boopathiraja, M., & Kirubakaran, B. (2015). Risk analysis and warning rate of hot environment for foundry industry using hybrid MCDM technique. Safety Science, 72, 133–143. https://doi.org/10.1016/j.ssci.2014.08.011.

6. Occupational Safety and Health Administration. Ergonomics: Identify Problems. Official guidance.

7. National Institute for Occupational Safety and Health. (1985). NIOSH Recommendations for Control of Occupational Safety and Health Hazards: Foundries. Publication No. 85-116. NIOSH publication record.

8. McAtamney, L., & Corlett, E. N. (1993). RULA: A survey method for the investigation of work-related upper limb disorders. Applied Ergonomics, 24(2), 91–99. https://doi.org/10.1016/0003-6870(93)90080-S.

9. Hignett, S., & McAtamney, L. (2000). Rapid Entire Body Assessment (REBA). Applied Ergonomics, 31(2), 201–205. https://doi.org/10.1016/S0003-6870(99)00039-3.