

RESEARCH ARTICLE

Ergonomic governance and workplace integrity in workforce diversity: A digital approach to musculoskeletal risk assessment in Malaysian automotive manufacturing

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Abstract - The Malaysian automotive manufacturing sector remains vulnerable to work-related musculoskeletal disorders due to repetitive movements, forceful exertions, prolonged static standing, and awkward postures. Although the case study organization is a European-owned automotive assembly plant in Pahang, Malaysia that has implemented standard ergonomic interventions such as height-adjustable platforms, torque-reducing power tools, and scheduled rest breaks, workstation observations and managerial consultations reveal that older and female operators continue to experience persistent discomfort in the neck, back, shoulders, wrists, and hands. This indicates that traditional "one-size-fits-all" ergonomic frameworks fail to account for physiological and anthropometric workforce diversity, creating issues of workplace equity and governance. This study proposes the ErgoRisk System, a desktop-based decision-support framework designed for preliminary ergonomic risk screening, longitudinal documentation, and transparent governance tracking. Adapted from the principles of Rapid Entire Body Assessment (REBA), the system integrates task-based physical risk parameters with demographic risk modifiers (age, gender, height) and worker health status. This paper presents the theoretical framework, database architecture, and scoring logic of the ErgoRisk System while detailing a multi-stage empirical validation pathway. By embedding worker diversity and integrity-driven data policies into digital risk assessment, the framework supports human-centered design, operational governance, workplace equity, and corporate Environmental, Social, and Governance (ESG) compliance within Industry 5.0 manufacturing environments.

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1. Introduction

The automotive assembly industry is a vital driver of Malaysia's manufacturing sector. However, despite advancements in semi-automation, assembly operations heavily depend on manual task execution, including component fitting, overhead wiring, and pneumatic fastening (Ahmed et al., 2024; Dawi, Jopri, & Kamarudin, 2026). These tasks expose operators to established physical risk factors associated with work-related musculoskeletal disorders (MSDs), such as repetitive limb motions, high exertion forces, sustained awkward postures, and contact mechanical stress (Horina et al., 2025; Zen et al., 2024). Concurrently, the manufacturing workforce in Malaysia is experiencing significant demographic shifts, characterized by an aging operator cohort and an increasing proportion of female assembly line personnel (Hilmi et al., 2024; Rajendran, Supramanian & Selvaraj, 2026). Conventional industrial ergonomics relies heavily on generic standards derived from 20th-century anthropometric databases dominated by young male populations (Mao & Raju, 2024). When applied to a diverse workforce, these generic design standards create an inequitable distribution of biomechanical stress, raising concerns regarding governance and workplace integrity.

At the case study facility, a European-owned automotive assembly plant in Pahang, Malaysia, management implemented standardized ergonomic controls, including height-adjustable assembly benches, torque-compensation arms, and job rotation schedules. Despite compliance with national guidelines (Department of Occupational Safety and Health [DOSH], 2024; Satapathy, 2023), internal feedback indicated that over 60% of older workers (aged 50+) and 55% of female operators reported persistent weekly musculoskeletal discomfort (Rajendran, Supramanian & Selvaraj, 2026). Furthermore, existing ergonomic evaluation relies on periodic paper-based checklists and static spreadsheet logs. These traditional methods lack granular tracking, fail to link risk scores with operator demographic traits, and store data in isolated departmental silos (Zen et al., 2024; Arbelaez Garces et al., 2024). Consequently, management cannot identify demographic-specific risk "hotspots" or evaluate whether ergonomic investments equitably protect all operator groups (Dawi, Jopri, & Kamarudin, 2026). Establishing digital governance mechanisms and data integrity in occupational health is therefore essential to ensure fair treatment, auditable reporting, and non-discriminatory task allocation.

2. Literature Review

2.1 Research Novelty and Comparative Synthesis

Existing observational tools such as Rapid Entire Body Assessment (REBA) (Hignett & McAtamney, 2000), Rapid Upper Limb Assessment (RULA), and Ovako Working Posture Analysis System (OWAS) evaluate task postures independently of operator physical characteristics. Advanced digital ergonomic solutions leverage motion capture, computer vision, wearable IMU sensors, or 3D Digital Human Modeling (DHM) (Abdullah & Ramli, 2026; Agostinelli et al., 2024; Zhang

et al., 2026). While these systems offer precise posture capture, they require substantial hardware investments, raise worker privacy concerns, and focus primarily on biomechanical simulation rather than routine, demographic-sensitive administrative decision support and governance tracking. The ErgoRisk System addresses this gap by combining task-based posture screening, demographic risk weighting, centralized database logging, and automated decision support into a lightweight desktop framework. A comparative synthesis of these ergonomic assessment approaches is presented in Table 1.

Table 1

Comparative synthesis of ergonomic assessment approaches

Functional Feature	Conventional REBA / RULA	Advanced Computer Vision / DHM Software	Proposed ErgoRisk System
Primary Focus	Observational posture risk scoring	High-precision posture capture & 3D simulation	Demographic-sensitive screening & governance tracking
Demographic Integration	None (Assumes standardized human capability)	Anthropometric scaling in 3D CAD modeling	Explicit demographic risk modifiers (Age, Gender, Status)
Data Architecture	Manual paper forms or isolated spreadsheets	Local spatial files / complex motion logs	Centralized relational MySQL database
Resource Demand	Low computational cost; high manual effort	High hardware cost; sensor/camera setup required	Low computational cost; rapid supervisor data entry
Governance Utility	Static, episodic audit compliance	Engineering design phase analysis	Real-time longitudinal monitoring & ESG audit trails
Target Role	Formal diagnostic assessment	Ergonomic simulation & workstation redesign	Preliminary screening, task assignment, & decision support

2.2 Theoretical Framework and Scoring Justification

The ErgoRisk scoring architecture operates on the principle that total ergonomic exposure (E_{total}) is a function of baseline task physical demands (T_{base}) moderated by worker-specific physiological vulnerability factors (M_{dem}):

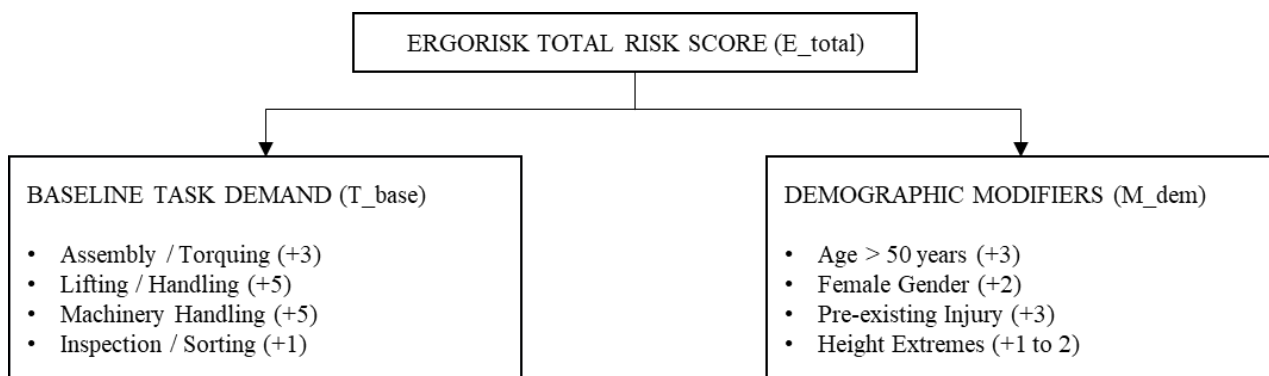
$$E_{total} = T_{base} + M_{dem}$$

The theoretical rationale for incorporating risk modifiers in the ErgoRisk System is grounded in established biomechanical and physiological evidence that explains differential susceptibility to MSDs among workers, as conceptualized in Figure 1. The age modifier ($M_{age} = +3$ for age > 50) reflects age-related physiological decline, including sarcopenia (loss of skeletal muscle mass), reduced spinal disc hydration, and decreased joint flexibility (Hilmi et al., 2024). These changes collectively reduce musculoskeletal resilience and load-bearing capacity. Empirical findings further indicate that isometric muscle strength declines by approximately 20–30% between the ages of 40 and 60, which significantly reduces static muscular endurance and increases spinal fatigue during prolonged standing and repetitive tasks (Calzavara et al., 2020; Crawford et al., 2023). Consequently, older workers are more vulnerable to cumulative biomechanical stress in assembly-line environments.

The gender modifier ($M_{gender} = +2$ for female workers) is justified by well-documented anthropometric and strength differences. On average, female operators exhibit 30–40% lower upper-body isometric strength and 15–20% smaller hand grip circumferences compared to male anthropometric norms (Mao & Raju, 2024; Mishra, 2026). In industrial settings where tools such as pneumatic devices are often designed based on male grip dimensions, female workers are required to exert proportionally higher relative force. This mismatch increases biomechanical strain and elevates the risk of conditions such as carpal tunnel syndrome and upper-extremity musculoskeletal disorders (Onawumi et al., 2023; Chen, et al., 2025).

Figure 1

ErgoRisk total risk score



The health status modifier ($M_{status} = +3$ for pre-existing injury) accounts for reduced tissue tolerance following prior musculoskeletal micro-trauma. Such conditions compromise the structural integrity of muscles, tendons, and ligaments,

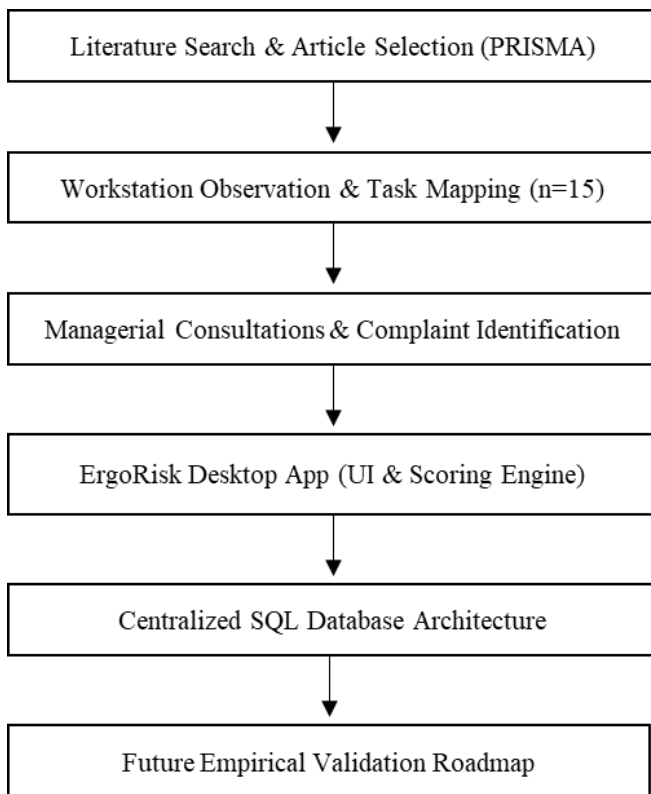
thereby lowering the threshold for injury recurrence under repetitive or forceful loading. Evidence suggests that individuals with prior musculoskeletal injuries face significantly higher risks of acute reinjury due to diminished recovery capacity and increased biomechanical sensitivity (Lagueux et al., 2023).

3. Methodology

The system architecture and methodological workflow of the ErgoRisk System are illustrated in Figure 2. The process began with literature search and article selection using the PRISMA approach, followed by workstation observation and task mapping at 15 selected workstations. Managerial consultations and complaint identification were then conducted to understand existing ergonomic issues and worker discomfort. These inputs supported the development of the ErgoRisk desktop application, which consists of a user interface and scoring engine. The system is connected to a centralized SQL database for structured data storage, governance monitoring, and longitudinal tracking. Finally, a future empirical validation roadmap is proposed to assess the system's reliability and effectiveness.

Figure 2

System architecture and methodological workflow



3.1 Systematic Literature Selection Procedure

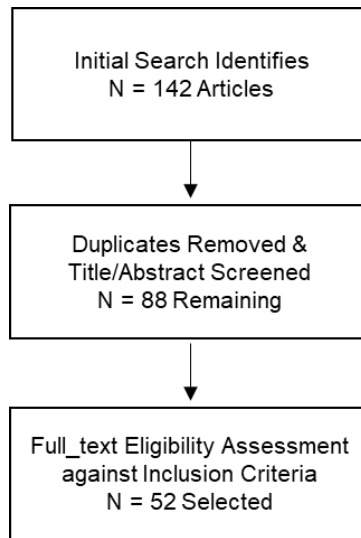
A systematic literature search was conducted across Scopus, Web of Science, and PubMed following PRISMA guidelines to establish the empirical foundation of the ErgoRisk System. The initial search identified 142 articles, which were screened for duplicates, titles, and abstracts, leaving 88 articles for further review. The inclusion criteria focused on peer-reviewed journal articles published between 2018 and 2026, related to industrial ergonomics, REBA/RULA applications, demographic workforce diversity, digital ergonomics, and empirical studies in manufacturing or assembly sectors. Non-English publications, conference abstracts, and office-based studies were excluded. Following full-text eligibility assessment, 52 articles were selected for final synthesis, as outlined in Figure 3.

3.2 Case Study Context and Data Collection

This study adopted an exploratory case-study approach at an automotive assembly plant in Pahang, Malaysia. Data collection was conducted through structured workstation observations and managerial consultations. Two ergonomic assessors observed 15 assembly line stations over 32 observation hours across two shift rotations. During the observations, postural demands, cycle times, reach distances, tool weights, and 250 task cycles were recorded. The assessment demonstrated strong inter-rater reliability, with a kappa value of 0.87. In addition, semi-structured consultations were conducted with operations managers, SHE officers, and line supervisors to identify recurring issues related to high-risk tasks, tool incompatibilities, and reporting gaps.

Figure 3

Systematic literature selection procedure

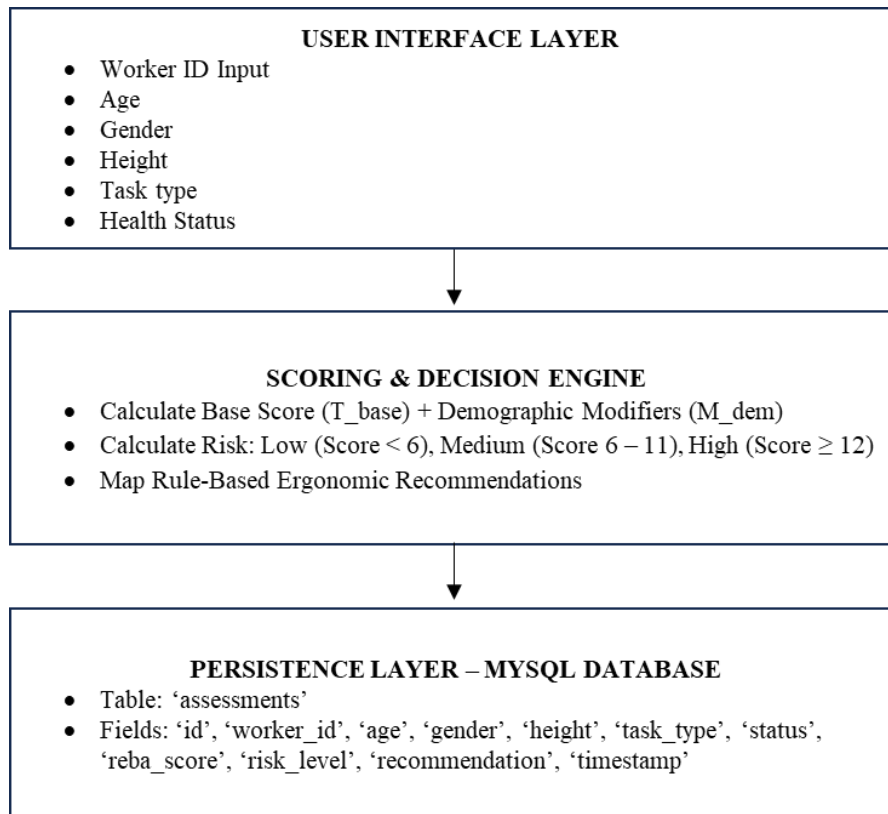


3.3 System Software Architecture

The ErgoRisk System, presented in Figure 4, was developed as a C# desktop application using Microsoft Visual Studio, with Entity Framework enabling communication with a MySQL relational database. Its software architecture consists of three main layers: the user interface layer, scoring and decision engine, and persistence layer. The user interface captures worker-related data such as worker ID, age, gender, height, task type, and health status. These inputs are processed by the scoring engine, which calculates the base ergonomic score and demographic modifiers before classifying risk levels as low, medium, or high. The results, recommendations, and timestamps are then stored in the MySQL database to maintain governance and data integrity.

Figure 4

ErgoRisk data architecture



3.4 Multi-Stage Empirical Validation Roadmap

The current ErgoRisk model represents a preliminary screening tool, systematic empirical validation that is required before consideration for formal occupational ergonomic application. A multi-stage validation roadmap was therefore proposed, as outlined in Table 2. First, usability testing assesses system acceptability and practical utility among line supervisors and safety, health, and environment (SHE) personnel using the System Usability Scale.

Second, concurrent validity will be examined through comparison with formal REBA assessments and surface electromyography (sEMG) measurements. Third, historical matching evaluates associations between ErgoRisk scores and retrospective plant musculoskeletal records. Finally, field intervention studies assess longitudinal changes in worker-reported discomfort following ergonomic interventions using the Nordic Musculoskeletal Questionnaire

Table 2

Multi-stage empirical validation roadmap

Phase 1: Usability Testing	System Usability Scale (SUS) assessment among line supervisors and SHE officers (Target > 80).
Phase 2: Concurrent Validity	cross-validation against formal REBA assessments and surface electromyography (sEMG) strain logs.
Phase 3: Historical Match	Retrospective regression analysis matching risk scores with 3-year plant MSDs medical leave logs.
Phase 4: Field Intervention	Longitudinal pre/post intervention study measuring reported discomfort via Nordic Questionnaires.

4. ErgoRisk Scoring Model and Empirical Justification

Table 3 provides the scientific and theoretical justification for the parameters incorporated into the proposed ErgoRisk assessment system. The table presents the base risk values assigned to selected work activities, including inspection, assembly, lifting, and machinery handling, according to their respective ergonomic demands. In addition, it identifies demographic and physiological modifiers, such as age above 50 years, female gender, short or tall stature, and history of pre-existing injury, which may influence workers' susceptibility to musculoskeletal strain. Each parameter is supported by biomechanical rationale, including reduced muscular strength, awkward postural loading, increased spinal compression, and heightened reinjury risk. The inclusion of relevant scientific references further strengthens the theoretical foundation of the ErgoRisk scoring framework.

Table 3

Scientific and theoretical justification of ErgoRisk parameters

Parameter/ Variable	System Value	Physiological & Biomechanical Justification	Key Scientific References
Inspection / Sorting	+1 (Base)	Neutral posture, low static load, minimal force requirement	Hignett & McAtamney (2020)
Assembly / Torquing	+3 (Base)	Repetitive arm motions, moderate static posture, vibration	Dawi, Jopri, & Kamarudin (2026)
Lifting / Handling	+5 (Base)	High spinal compressive forces exceeding NIOSH action limit	Araruna de Carvalho (2024)
Machinery Handling	+5 (Base)	Complex awkward postures, high torque exertion, dynamic load	Zen et al. (2024)
Age > 50 Years	+3 (Modifier)	20–30% decline in muscle strength; reduced recovery rate	Hilmi et al. (2024); Calzavara (2020)
Female Gender	+2 (Modifier)	Smaller grip span (15–20%); 30–40% lower upper-body strength	Mao & Raju (2024); Mishra (2026)
Height < 150 cm	+2 (Modifier)	Excessive shoulder abduction (> 45°) at fixed bench heights	Onawumi et al. (2023)
Height > 180 cm	+1 (Modifier)	Excessive trunk flexion (>30 °) at standard conveyor heights	Arbelaez Garces et al. (2025)
Pre-existing Injury	+3 (Modifier)	Lowered biomechanical tolerance threshold; elevated reinjury risk	Lagueux et al. (2023)

5. Results

5.1 Case Study Findings Across Demographic Subgroups

Table 4 presents the case study findings on ergonomic exposure patterns and musculoskeletal disorder vulnerabilities across demographic subgroups within the studied manufacturing context. Operators aged 50 years and above were found to be more susceptible to risks associated with prolonged standing, low-bin part retrieval, lower back discomfort, knee osteoarthritis, and shoulder fatigue. Female operators were particularly exposed to ergonomic risks arising from overhead reaching and the use of wide-diameter pneumatic tools, which may contribute to rotator cuff strain, carpal tunnel

syndrome, and wrist discomfort. Meanwhile, younger male operators were associated with frequent high-cycle lifting of heavy trays, increasing the likelihood of lumbar strain and wrist fatigue. Overall, these findings demonstrate that ergonomic risk exposure is not uniform across the workforce but is influenced by demographic and task-related factors.

Table 4

Ergonomic exposures and MSDs vulnerabilities by demographic subgroup

Demographic Group	Primary Workstation Mismatches Observed	Reported Musculoskeletal Symptoms	Biomechanical & Physiological Mechanism
Older Operators (Age 50+)	Sustained static standing on concrete; low-binned part fetching	Lower back pain, knee osteoarthritis, shoulder fatigue	Spinal disc compression, reduced muscle endurance, cartilage degeneration
Female Operators	Overhead reach (>140 cm); wide-diameter pneumatic tools (> 5 cm)	Rotator cuff strain, carpal tunnel syndrome, wrist pain	High relative muscle activation (> 35% MVC), excessive pinch force demands
Younger Male Operators	High-cycle lifting of unassisted component trays (> 15 kg)	Acute lumbar strain, transient wrist fatigue	Over-reliance on physical capacity; improper manual lifting technique

5.2 Intervention Matrix: Generic vs. Proposed Demographic-Sensitive Controls

Table 5 presents an intervention matrix comparing generic ergonomic controls with proposed demographic-sensitive interventions for diverse workforce needs. Existing interventions, such as fixed-height platforms, standard pneumatic tools, static storage bins, and standard rest breaks, may inadequately address variations in worker stature, gender, age, and physical capacity. The proposed controls introduce adjustable platforms, modular tool grips, angled spring-loaded bin lifts, and scheduled micro-breaks to reduce biomechanical strain and improve task suitability. These interventions demonstrate a shift from standardized ergonomic solutions toward inclusive, worker-centered design.

Table 5

Existing vs. proposed ergonomic interventions

Workstation Area	Generic Existing Intervention	Limitation for Diverse Workforce	Proposed Demographic-Sensitive Control
Chassis Assembly	Fixed-height platforms with generic step blocks	Fails to accommodate stature extremes (< 150 cm, > 180 cm)	Automated dual-axis height-adjustable platforms
Fastening Stations	Standard pneumatic torque wrenches	Grip diameter (5.5 cm) forces high pinch exertion in women	Modular tool grips (3.5 – 4.0 cm) with torque reaction arms
Part Material Bins	Static floor-mounted storage bins	Requires older workers to execute trunk flexion > 40°	Angled, spring-loaded bin lifts maintaining waist-height access
Shift Management	Standard 15-minute mid-shift rest break	Insufficient muscle recovery for older operators	Micro-break scheduling (3 mins every 45 mins) for high-load tasks

5.3 Management and System Integration

Table 6 compares conventional ergonomic management practices with the proposed ErgoRisk integrated digital framework. Conventional plant practices are primarily characterized by periodic paper-based audits, isolated documentation, limited data accessibility, and aggregate risk scoring that does not account for individual worker characteristics. In contrast, the ErgoRisk system enables real-time ergonomic screening during job reassignment, supported by a centralized MySQL database and SQL query dashboard. The framework enhances risk visibility by identifying demographic-specific trends and ergonomic hotspots. It also strengthens governance alignment through proactive ESG reporting and auditable decision documentation.

Table 6

Comparison of conventional ergonomic practice vs. ErgoRisk system

Management Dimension	Conventional Plant Practice	ErgoRisk Integrated Digital Framework
Assessment Frequency	Annual or bi-annual paper audits	Real-time screening upon job reassignment
Data Storage & Access	Isolated binder reports / local spreadsheets	Centralized MySQL database with SQL query dashboard
Risk Visibility	Aggregate station scores ignoring operator traits	Demographic-specific risk trends and hotspot identification
Governance Alignment	Reactive compliance with basic safety codes	Proactive ESG reporting and auditable decision documentation

6. Discussion

6.1 Ergonomic Adaptation in Industry 5.0 and ESG Frameworks

The paradigm shift from Industry 4.0 to Industry 5.0 marks a crucial transition from machine-centric efficiency and digital connectivity toward human-centric, sustainable, and resilient manufacturing systems (Hilmi et al., 2024; Muttaqin, 2025; Trstenjak, et al., 2025). While Industry 4.0 prioritized hyper-automation, IoT integration, and sensor-driven productivity, it frequently overlooked the physical, cognitive, and demographic boundaries of the human workforce (Abdullah & Ramli, 2026; Agostinelli et al., 2024). In contrast, Industry 5.0 re-establishes the human operator at the core of industrial operations, emphasizing that technological innovation must serve to augment human capability, safeguard well-being, and respect physiological diversity (Chen et al., 2023; Tian et al., 2024; Muttaqin, 2025).

Within this human-centric paradigm, ergonomic adaptation becomes a foundational pillar rather than a secondary compliance requirement. In assembly line environments, rigid operational setups induce severe physical strain and fatigue when forced upon heterogeneous operator groups (Hasim et al., 2025; Katirae et al., 2025; Mao & Raju, 2024). The ErgoRisk System aligns directly with Industry 5.0 principles by replacing static, universal assumptions with dynamic, demographic-sensitive digital screening. By embedding age, gender, height, and physical capacity directly into digital risk algorithms, the platform enables smart manufacturing facilities to transition toward personalized work assignment, real-time workload balancing, and adaptive workstation configuration (Chen & Fang, 2025; Arbelaez Garces et al., 2024).

6.2 ESG Governance, Corporate Ethics, and Regulatory Compliance

Workplace ergonomics is increasingly recognized as a vital strategic component of corporate Environmental, Social, and Governance (ESG) frameworks and corporate governance practices (Lin, 2026; Dawi, Jopri, & Kamarudin, 2026; Chen et al., 2025). Historically, occupational safety reporting under ESG disclosures was restricted to lagging indicators such as reportable injury rates, lost-time injury frequency rates (LTIFR), and basic safety training completion percentages (Alves & Ramos, 2022; Lin, 2026). However, modern regulatory bodies and institutional investors demand transparent, proactive disclosures under the Social (S) pillar, encompassing workplace health promotion, demographic equity, non-discrimination, and fair working conditions (Chen & Fang, 2025; Lin et al., 2026).

Applying generic "one-size-fits-all" workstation designs creates an implicit ethical mismatch: female and older operators face higher cumulative biomechanical stress and elevated MSDs risks while executing identical manufacturing tasks as their younger male peers (Hasim et al., 2025; Mao & Raju, 2024). This uneven exposure violates basic principles of workplace equity, integrity, and non-discrimination (Dawi, Jopri, & Kamarudin, 2026). The ErgoRisk System addresses this ethical gap by providing a transparent, auditable digital database that records risk profiles, tracks intervention outcomes, and supports decision-making within the plant's Safety, Health, and Environment (SHE) management structure (DOSH, 2024; Lin, 2026). Under the Governance (G) pillar, centralized MySQL logging ensures that management can demonstrate regulatory due diligence, present verifiable risk reduction trends during statutory audits, and maintain workplace integrity by preventing the misuse of demographic data for discriminatory job placement or punitive administrative actions (Lin et al., 2026; Chen et al., 2025).

6.3 System Limitations and Expected Organizational Outcomes

While the ErgoRisk System offers a structured digital decision-support framework, a rigorous scientific evaluation requires explicit acknowledgment of its current boundaries and theoretical assumptions (Lei, 2026; Zen et al., 2024). The primary limitation of the current prototype lies in the heuristic nature of its scoring parameters. Numerical modifiers such as +3 for operators over age 50 or +2 for female operators were synthesized from physiological and anthropometric literature rather than derived from empirical multivariate regression analysis within the specific assembly facility (Calzavara et al., 2020; Katirae et al., 2025; Mao & Raju, 2024). Furthermore, as an administrative screening tool, ErgoRisk is not intended to replace formal diagnostic tools (e.g., full clinical REBA/RULA audits, surface electromyography, or 3D optical motion capture) (Agostinelli et al., 2024; Zhang et al., 2026).

From an organizational perspective, the implementation of the ErgoRisk System is expected to deliver significant operational benefits, provided its conceptual scope is properly managed (Lei, 2026; Trstenjak, et al., 2025). By digitizing data entry and centralizing risk persistence in a SQL database, plant management gains real-time visibility into demographic risk "hotspots," enabling targeted capital expenditure for workstation modifications such as height-adjustable platforms and specialized tool grips (Onawumi et al., 2023; Hasanain, 2024). However, management must avoid overstating system capabilities: the ErgoRisk framework represents an initial decision-support and screening application. Assertions regarding actual reductions in MSDs incidence rates, sickness absenteeism, or compensation costs remain potential organizational outcomes that must be validated through rigorous, multi-year longitudinal field testing (Zen et al., 2024; Lagueux et al., 2023).

7. Recommendation and Future Implications

7.1 Research Findings and Core Contributions

This study addresses the critical disconnect between traditional "one-size-fits-all" industrial ergonomics and the realities of an increasingly diverse manufacturing workforce within Malaysian automotive assembly plants (Chen et al., 2023; Hasim et al., 2025; Rajendran, Supramanian & Selvaraj, 2026). By examining an automotive assembly facility in Pahang, the research highlights how generic workstation designs, male-centric tool dimensions, and static paper-based evaluation methods systematically expose older operators and female personnel to elevated musculoskeletal disorder risks (Katirae et al., 2025; Onawumi et al., 2023; Katirae et al., 2025).

To bridge this operational, governance, and ethical gap, the study introduced the ErgoRisk System, a novel desktop-based digital decision-support framework that integrates task physical demands with worker demographic modifiers (age, gender, height) and health status. The core scientific contribution of this work lies in operationalizing demographic sensitivity within digital risk assessment, converting fragmented paper audits into a centralized relational SQL database for longitudinal monitoring (Lei, 2026; Zen et al., 2024). The system advances Industry 5.0 human-centric manufacturing paradigms and provides a practical mechanism for aligning occupational health practices with corporate ESG governance and workplace integrity requirements (Muttakin, 2025; Lin, 2026; Trstenjak, et al., 2025).

7.2 Executive and Operational Recommendations

The transition from generic ergonomic practices to an inclusive, demographic-sensitive risk management framework requires strategic commitment at both executive and operational levels, as detailed in Table 7. First, automotive manufacturers should institutionalize digital ergonomic decision support by integrating the ErgoRisk desktop platform into daily safety, health, and environment (SHE) workflows, particularly during job rotation and task reassignment. This would enable proactive screening rather than relying solely on retrospective injury reporting (DOSH, 2024; Lei, 2026).

Table 7

Executive and operational governance recommendations

Governance Dimension	Strategic & Operational Action
Digital System Integration	Embed the ErgoRisk digital platform into daily SHE workflows for job reassignment screening.
Ergonomics & Ethics Committee	Form a cross-functional governance committee to review SQL data and prioritize capital spend.
Participatory Redesign	Deploy female- and senior-inclusive task teams to select modular tools and adjustable benches.
Ethical Data Policies	Establish clear data governance preventing the punitive use of worker health/demographic logs.

Second, the establishment of a cross-functional Ergonomics and Ethics Committee is essential to ensure that ergonomic decisions are not treated as isolated technical issues, but as organizational governance priorities. Such a committee, comprising SHE officers, operations managers, human resource personnel, and worker representatives, can critically review monthly risk reports, identify departmental hotspots, and prioritize intervention budgets (Lin et al., 2026; Dawi, Jopri, & Kamarudin, 2026). Third, participatory workstation redesign should be implemented to ensure that older and female operators are directly involved in developing practical solutions, including low-grip-force tools, spring-loaded bins, and height-adjustable platforms (Hasim et al., 2025; Hasanain, 2024). Finally, strict ethical data governance is necessary to ensure that demographic and physical-status data are used solely for protective adaptation, while preventing discriminatory employment practices (Lin et al., 2026; Chen et al., 2025).

7.3 Future Research and Empirical Validation Pathways

The ErgoRisk System is currently presented as a conceptual screening framework and software prototype, future research must focus on rigorous empirical validation before the model can be deployed as a standardized diagnostic tool (Lei, 2026; Zen et al., 2024). First, researchers must evaluate system usability across line supervisors and safety officers using the standardized System Usability Scale (SUS) to ensure operational feasibility in high-speed manufacturing environments (Agostinelli et al., 2024). Second, empirical studies should calibrate and validate the theoretical risk modifiers (+3 for age, +2 for gender) by performing concurrent validity testing against full observational REBA/RULA assessments, surface electromyography (sEMG) muscle activation logs, and 3D digital human modeling simulations (Abdullah & Ramli, 2026; Katirae et al., 2025; Zhang et al., 2026).

Third, future studies should conduct retrospective regression analyses linking historical plant medical leave records and MSDs incident reports with ErgoRisk database scores to verify predictive accuracy (Katirae et al., 2025; Lagueux et al., 2023). Finally, prospective longitudinal intervention trials such as evaluating pre- and post-implementation cohort discomfort using validated tools such as the Nordic Musculoskeletal Questionnaire are essential to measure actual changes in worker health, productivity, and absenteeism over extended operational cycles (Hasim et al., 2025; Rajendran, Supramanian & Selvaraj, 2026; Zen et al., 2024).

8. Conclusion

In conclusion, this study demonstrates that conventional "one-size-fits-all" industrial ergonomic interventions fail to adequately protect an increasingly diverse manufacturing workforce, particularly aging operators and female personnel in high-speed assembly environments. By integrating task physical demands with operator demographic modifiers (age, gender, height) and physical health status, the proposed ErgoRisk System establishes a proactive, data-driven approach to digital risk screening, longitudinal documentation, and workplace integrity.

The platform bridges critical operational and governance gaps by operationalizing human-centric design within Industry 5.0 paradigms and enabling transparent Environmental, Social, and Governance compliance. While the current software model represents an initial decision-support framework that requires future empirical validation, it offers

automotive manufacturing facilities a practical pathway toward inclusive workstation design, equitable task allocation, and sustainable occupational health management.

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Declaration of Competing Interests

The authors declare no conflicts of interest.

CRedit Authorship Contribution Statement

A.A.G. bin Rabuang @ Rabuan: Conceptualization; Software; Investigation; Writing - original draft

C.S.S. Koilpillai: Methodology; Supervision; Writing - review & editing; Project administration

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T. Sinnasamy: Validation; Formal analysis; Writing - review & editing

A.M. Andrew: Methodology; Software; Visualization

Availability of Data and Materials

The data supporting this study's findings are available on request from the corresponding author.

Ethics Declarations

This study did not involve human participants or animals. Ethical approval was therefore not required.

Generative Artificial Intelligence Declarations

The authors declare that generative AI and other AI-assisted technologies were used only for language editing and readability enhancement. These tools were not used to generate scientific content, ideas, analyses, or conclusions. All AI-assisted outputs were reviewed under strict human oversight. The authors take full responsibility for the accuracy, integrity, and originality of the manuscript.

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