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Strategies To Reduce Work-Related Injuries in The Saudi Manufacturing Sector

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Abstract- ***Work-related injuries remain a material operational, social, and policy concern in Saudi Arabia as the Kingdom expands advanced manufacturing under Vision 2030. Manufacturing combines high-energy machinery, manual material handling, shift work, chemical exposure, maintenance tasks, contractor interfaces, and a diverse workforce, making injury prevention a multi-causal governance problem rather than a narrow compliance issue. This review paper synthesizes recent literature published between 2020 and 2026, together with current Saudi policy and statistical sources, to identify actionable strategies for reducing work-related injuries in the Saudi manufacturing sector. The review adopts a structured narrative approach modeled on public-health and occupational-safety review formats, emphasizing burden identification, risk-factor synthesis, intervention mapping, and framework development. The synthesis shows that the Saudi context is shaped by five interacting conditions: rapid industrial expansion, uneven occupational safety maturity across firms, the concentration of injuries among male and migrant workers, persistent exposure to struck-by, caught-in, fall, and ergonomic hazards, and growing heat risk in outdoor-adjacent and non-climate-controlled work environments. Evidence further indicates that isolated training or PPE campaigns are insufficient when not supported by safer design, supervision quality, inspection capacity, near-miss learning, and reliable leading indicators. In response, the paper proposes a Saudi Manufacturing Injury Reduction Framework that integrates hierarchy-of-controls thinking, ISO 45001-oriented management systems, multilingual competency assurance, ergonomics, heat governance, contractor control, digital monitoring, and integrated surveillance. The review argues that the most effective strategy is not a single intervention but a coordinated system that aligns engineering controls, worker participation, regulatory enforcement, and production governance. The paper concludes that injury reduction should be treated as a productivity and resilience agenda, not only a legal or humanitarian obligation, and that Saudi manufacturing can improve injury outcomes substantially by moving from reactive incident response to data-driven prevention. The novelty of this review lies in its manufacturing-specific focus within Saudi Arabia, its integration of regulatory, operational, ergonomic, and digital safety dimensions, and its proposed Saudi Manufacturing Injury Reduction Framework tailored to local industrial conditions including migrant labor, Gulf heat, contractor interfaces, and industrial-city expansion. This study makes a novel contribution by integrating occupational safety, process safety, and sector-specific risks (feed, glucose, and poultry industries) into a unified framework tailored to Saudi Arabia's industrial transformation context.***

Keywords: Occupational Injuries; Saudi Arabia; Manufacturing; Safety Climate; Ergonomics; ISO 45001; Heat Stress; Worker Participation; Injury Prevention; Review Paper

I. INTRODUCTION

Work-related injuries continue to impose direct human, operational, and economic costs across industrial systems. In manufacturing, injuries are especially consequential because production relies on tightly coupled interactions among workers, machines, materials, contractors, schedules, and maintenance systems. When those interactions are poorly designed or weakly governed, small deviations can escalate into lacerations, crush injuries, fractures, burns, chemical exposures, musculoskeletal disorders, and fatalities. Recent Saudi data indicate that non-fatal occupational injuries remain a measurable national concern, even as aggregate rates improve, and official reporting shows that the manufacturing sector is among the higher-risk sectors in the Kingdom (General Authority for Statistics [GASTAT], 2025; Almuhaidib et al., 2025).

Saudi Arabia's industrial transition makes this issue strategically important. Vision 2030 and related industrial programs seek to deepen local value creation, expand non-oil manufacturing, strengthen industrial cities, and improve supply-chain resilience

(Saudi Vision 2030, 2025). As production capacity expands, the injury-prevention challenge becomes more complex rather than less complex. New production lines, SMEs entering industrial value chains, intensified contractor use, warehouse-manufacturing interfaces, and increased technology adoption all create mixed-risk environments in which traditional compliance methods may lag operational reality. National reforms have also elevated occupational safety and health as a strategic labor-market concern, with the National Council for Occupational Safety and Health (NCOSH) positioned to harmonize standards and improve compliance across sectors (NCOSH, 2025a, 2025b).

The Saudi manufacturing context has several features that justify a focused review. First, the workforce is heterogeneous in language, experience, and employment status. Prior Saudi injury studies and national trend analyses show higher injury incidence among men and among non-Saudi workers, indicating the importance of communication quality, supervision, onboarding, and task allocation (Abdel Razik et al., 2022; Almuhaidib et al., 2025). Second, manufacturing combines acute traumatic hazards with slower-burn health and ergonomic risks. Global evidence from factory, iron and steel, and industrial settings shows that ergonomic strain, repetitive tasks, fatigue, PPE non-compliance, and weak safety climate remain common contributors to injury burden (Seidu et al., 2024; Shabani et al., 2024; da Silva et al., 2026). Third, Saudi climatic conditions intensify the risk environment, especially in facilities with heat-generating processes, outdoor loading operations, and variable thermal controls. Recent global reviews indicate that occupational heat exposure elevates risks of injury, cognitive impairment, and productivity loss, which is highly relevant to industrial operations in the Gulf region (Guo et al., 2025; Nath et al., 2026; World Health Organization [WHO], 2025a).

This review therefore asks a practical question: what strategies are most likely to reduce work-related injuries in the Saudi manufacturing sector under current institutional and operational conditions? Rather than treating prevention as a generic checklist, the paper examines how strategies interact with workforce structure, organizational maturity, regulatory change, and industrial modernization.

The relevance of this review is particularly strong for Saudi industrial ecosystems such as MODON industrial cities, where SMEs, contractors, warehouses, process industries, and light-to-heavy manufacturing often coexist within shared risk environments

The objectives of this review are fourfold:

(1) to synthesize the recent evidence on the burden and pattern of work-related injuries relevant to Saudi manufacturing;
(2) to identify the main proximal and systemic determinants that sustain injury risk in industrial settings;
(3) to evaluate the strategic value of engineering, organizational, behavioral, regulatory, ergonomic, and digital interventions; and
(4) to propose an integrated framework tailored to the Saudi manufacturing context.

II. REVIEW PROCEDURE AND METHODOLOGY

This paper is a review article and follows a structured narrative review procedure modeled on the logic of the sample review format provided by the user and on integrative occupational-safety review practices. The method was designed to support three outputs: contextual understanding, intervention synthesis, and framework development. Because the objective was not to estimate one pooled effect but to generate a context-sensitive prevention agenda, an integrative review design was more appropriate than a narrowly bounded meta-analysis (Vitrano & Micheli, 2024).

The review drew on literature published from 2020 to 2026, with emphasis on peer-reviewed journal articles, systematic reviews, meta-analyses, and official institutional publications. The source base included Saudi statistical and regulatory documents, international guidance from ILO, WHO, ISO, and OSHA, and recent empirical and review studies on manufacturing safety, safety climate, heat exposure, ergonomics, PPE, labour inspection, and digital occupational-safety tools. Materials were selected when they satisfied at least one of four criteria: they

addressed Saudi occupational injury patterns; they examined manufacturing or factory risk factors; they synthesized evidence on occupational safety interventions; or they provided current policy or standards relevant to injury reduction.

The review procedure involved four steps. First, sources were screened for topical relevance to manufacturing injury prevention, industrial safety systems, or Saudi labor-market governance. Second, the literature was grouped into thematic domains: burden and injury patterns, organizational determinants, intervention categories, climate and ergonomic risks, and governance or regulatory instruments. Third, findings were compared across studies to identify recurring risk mechanisms and implementation barriers. Fourth, the synthesis was translated into a proposed framework suited to the Saudi manufacturing sector. This procedure mirrors the practical orientation seen in occupational public-health reviews that move from burden description to strategy formulation rather than stopping at descriptive epidemiology (Bondebjerg et al., 2023; Jilcha, 2023).

A conceptual limitation should be acknowledged. The literature on Saudi manufacturing injuries remains thinner than the literature on Saudi construction, and some intervention evidence necessarily comes from broader industrial or international settings. However, this does not invalidate the review. Manufacturing shares many cross-sector injury determinants with other high-risk industries—such as weak supervision, heat, fatigue, inadequate hazard controls, and poor learning systems—while also requiring adaptation to machine-intensive, shift-based, and process-dependent environments. The review therefore privileges transferability with contextual caution.

III. BURDEN AND PROFILE OF INJURY RISK IN SAUDI MANUFACTURING

The current Saudi evidence suggests both progress and unfinished work. GASTAT's 2024 workplace health and safety publication reported a non-fatal occupational injury rate of 245.7 and a fatal injury rate of 1.1 per 100,000 workers, alongside continuing variation in occupational safety capacity across workplaces, including uneven availability of dedicated OSH departments (GASTAT, 2025). At the policy level, the Ministry of Human Resources and Social Development has reported significant declines in injury and fatality indicators over recent years, supported by increased inspection and compliance efforts (MHRSD, 2025a). These trends are encouraging, but they do not eliminate sector-specific concentrations of risk.

The most relevant recent Saudi sectoral study is the national analysis by Almuhaidib et al. (2025), which found that injury incidence differed by gender, nationality, location, and sector, with manufacturing among the sectors recording comparatively higher injury rates. The study also identified falls, strikes, and collisions as leading categories of injury. Although the period covered predates some recent reforms, the sectoral pattern remains important because it indicates that manufacturing risk is not a marginal issue but part of the national injury profile.

Hospital-based evidence from Riyadh further illustrates the nature of serious traumatic occupational injuries in Saudi Arabia. Abdel Razik et al. (2022) found that upper limbs and lower limbs were frequently affected and that fractures, crush injuries, and lacerations were common among injured workers. While not limited to manufacturing, these injury types are highly consistent with machine contact, material handling, pinch points, and production-floor hazards. For manufacturing managers, this matters because the dominant injury mechanisms are often foreseeable and technically preventable.

International manufacturing evidence reinforces the concern. Shabani et al. (2024), in a systematic review and meta-analysis of iron and steel industries, reported a high global injury burden and identified night shifts and non-use of PPE as strong correlates. Seidu et al. (2024) similarly showed that factory workers in textile and fashion settings face a combination of respiratory, musculoskeletal, chemical, and psychosocial risks arising from production intensity, poor working conditions, and inadequate controls. These findings matter for Saudi manufacturing because the Kingdom's industrial diversification includes metal, plastics, food

processing, chemicals, warehousing-linked assembly, and other subsectors that combine acute and chronic exposure profiles.

The burden should also be understood qualitatively. Injuries in manufacturing disrupt output, quality, maintenance schedules, workforce morale, and contractor confidence. They create unplanned downtime, compensation and treatment costs, retraining demands, and reputational risk. Podrecca et al. (2024) showed that stronger occupational safety management, as reflected in ISO 45001 adoption, is associated with better productivity and profitability outcomes. This supports the argument that reducing injuries is not external to industrial performance; it is part of operational excellence.

3.1 Sector-Specific Risk Profile in Saudi Agri-Industrial Manufacturing

Saudi Arabia's manufacturing landscape includes rapidly expanding agri-industrial sectors such as animal feed production, wet milling and glucose processing, and poultry operations.

These industries present complex and hybrid risk environments that extend beyond conventional manufacturing hazards. They therefore require integrated occupational and process safety approaches.

In animal feed manufacturing, risks are strongly associated with combustible dust generated from grain handling, grinding, and storage processes. Dust accumulation, when combined with ignition sources, creates significant explosion hazards. Additionally, manual bagging operations, silo access, and heavy reliance on forklifts introduce risks of falls, engulfment, struck-by incidents, and musculoskeletal injuries.

In glucose and wet milling operations, high-pressure steam systems, rotating equipment, and chemical handling introduce elevated risks of burns, entanglement, and chemical exposure. Non-routine activities such as maintenance, cleaning, and process startups are particularly hazardous due to potential deviations from normal operating conditions.

In poultry and agri-processing environments, workers are exposed to biological hazards, ammonia from refrigeration systems, wet and slippery surfaces, and repetitive processing tasks. These conditions increase the likelihood of respiratory issues, slips and falls, lacerations, and cumulative ergonomic injuries.

Importantly, these sectors represent integrated risk systems, where occupational safety, process safety, food safety, and environmental risks are interdependent. Failure in one control layer may escalate rapidly into multi-dimensional incidents, reinforcing the need for holistic HSSE governance.

IV. WHY INJURIES PERSIST: A MULTILEVEL RISK STRUCTURE

4.1. Process and equipment hazards

The first layer of risk is physical and process-based. Manufacturing environments expose workers to moving parts, stored energy, forklifts, conveyors, hot surfaces, pressurized systems, cutting tools, welding zones, chemicals, and maintenance-related hazards. In many facilities, serious injuries occur not during routine operation alone but during cleaning, setup, troubleshooting, changeovers, or repair, when workers bypass normal protections to keep production moving. The literature on systemic accident causation shows that such events are rarely the result of worker error alone; they emerge from the interaction of equipment design, workflow pressure, incomplete guarding, and organizational tolerances for deviance (Dabkowski et al., 2025; Vitrano & Micheli, 2024). As manufacturing becomes more automated, human interaction with robots, cobots, automated packing systems, and moving production equipment creates new collision, entrapment, and interface risks, especially where safeguarding, sensing, and exclusion zones are incomplete.

4.2. Workforce composition, communication, and experience

A second layer of risk arises from workforce heterogeneity. Saudi industry relies heavily on multinational labor, and injury patterns show elevated risk among non-Saudi workers (Abdel Razik et al., 2022; Almuhaidib et al., 2025). In practice, this can mean different levels of task familiarity, literacy, language proficiency, and confidence to report hazards. Training that is formally delivered but poorly understood is not an effective control. Mwera

et al. (2025) found that lack of supervision and inadequate PPE use were associated with injuries among factory workers, while Santos et al. (2025) emphasized that PPE effectiveness depends not only on provision but on fit, comfort, training, and organizational support. In Saudi manufacturing, multilingual communication and competency verification are therefore more important than generic induction.

4.3. Safety climate and leadership quality

A third layer is organizational climate. Safety climate refers to workers' shared perceptions of management commitment, communication, procedural justice, and safety prioritization. Recent reviews show that climate is not a soft variable; it is strongly linked to injuries, safety behavior, and the reliability of frontline decision-making (da Silva et al., 2026; Min et al., 2024). If workers believe that output always outranks safety, they adapt accordingly. If they believe reporting near misses leads to blame rather than learning, weak signals remain hidden. In manufacturing, where repeated small deviations can precede serious harm, climate functions as a leading condition of injury prevention.

4.4. Ergonomic load and musculoskeletal risk

A fourth layer concerns ergonomics. Many manufacturing injuries are not one-time traumatic events but cumulative or hybrid injuries linked to repetitive exertion, awkward postures, lifting, standing, vibration, and tool design. Chan et al. (2022) argued that the primary prevention of work-related musculoskeletal disorders increasingly requires predictive and design-oriented approaches, including machine-learning-assisted risk detection. Greggi et al. (2024) and Seidu et al. (2024) likewise showed that work-related musculoskeletal disorders remain a major injury burden when tasks are repetitive, work-rest design is poor, and workstation design is neglected. For Saudi plants trying to scale output, ergonomic neglect can generate hidden injury costs even when acute incidents appear controlled. Ergonomic risk in manufacturing should also be understood to include prolonged exposure to noise and vibration. Continuous machine noise can impair concentration, hinder communication, increase fatigue, and weaken hazard awareness, particularly in fast-moving production settings. Likewise, hand-arm vibration from tools and whole-body vibration from vehicles or equipment can contribute to cumulative musculoskeletal strain, discomfort, reduced task precision, and long-term health effects. In manufacturing environments, these exposures interact with repetition, force, and posture, meaning that ergonomic prevention should address sensory and physical strain together rather than treating them as separate concerns.

4.5. Heat, fatigue, and shift systems

A fifth layer is physiological strain. Heat exposure increases fatigue, dehydration, cognitive errors, and injury risk. WHO (2025b) and WHO and WMO (2025) both warn that workplace heat stress is intensifying globally. Nath et al. (2026) concluded that occupational heat exposure is consistently associated with illness, reduced renal function, cognitive decline, and increased injury risk, while Guo et al. (2025) summarized evidence linking heat to injury outcomes across occupations. Manufacturing in Saudi Arabia is not always thought of through a heat lens because much of it occurs indoors; however, many facilities include loading docks, foundry or furnace environments, outdoor maintenance areas, or imperfect cooling systems. When combined with overtime and night shift rotation, heat becomes part of an injury mechanism rather than only a comfort issue.

As illustrated in Figure , increasing temperature significantly reduces productivity while increasing the likelihood of human error and injury.

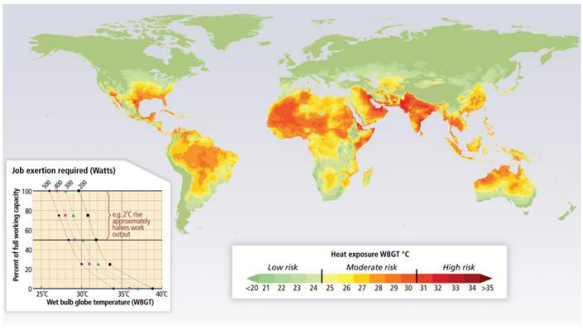

Figure 1. Figure 2. Impact of increasing temperature on worker productivity and error rates in industrial environments.

As illustrated in Figure 1, temperature increases beyond optimal thresholds lead to a decline in worker

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productivity while simultaneously increasing cognitive errors and injury risk, particularly in Gulf industrial conditions.

4.6. Weak learning systems and fragmented governance

Finally, injuries persist when organizations learn poorly. Sadeghi et al. (2025) showed the growing value of safety leading indicators across industries, while Pedrosa et al. (2025) demonstrated that near-miss management systems can strengthen safety culture in traditional manufacturing settings. Without leading indicators, management waits for injuries to reveal system weakness. Without near-miss learning, warning signals are normalized. Without contractor coordination and role clarity, responsibility becomes diffused. These governance failures are especially relevant in Saudi industrial ecosystems where large firms, SMEs, maintenance contractors, logistics providers, and temporary workers may share the same risk space. Manufacturing injury prevention should also consider psychosocial and cognitive hazards, which increasingly influence safety performance in modern production systems. High production pressure, repetitive work, long shifts, job insecurity, communication barriers, fatigue, and limited worker autonomy can all contribute to stress, distraction, reduced attention, and unsafe decision-making. In multilingual and high-tempo factory settings, psychological strain may also reduce workers' willingness to report hazards, challenge unsafe instructions, or stop work when conditions deteriorate. These psychosocial conditions do not replace physical hazards, but they can intensify them by weakening concentration, judgment, and safety communication. For this reason, manufacturing safety should account for human psychology as part of operational risk, particularly where automation, monitoring systems, performance targets, and contractor pressures shape daily work. As shown in Figure below, serious incidents are typically preceded by a large number of unsafe acts and near misses.

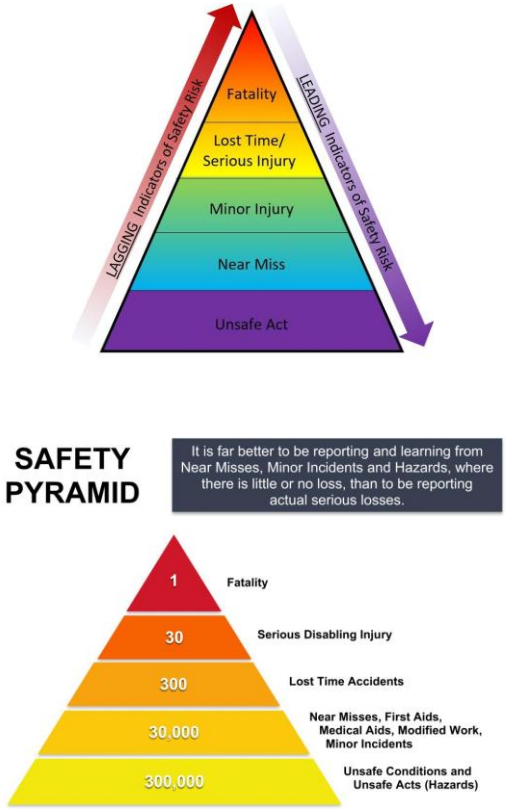

Figure 2. Relationship between unsafe acts, near misses, and major incidents.

As shown in Figure 2, this pyramid demonstrates that serious incidents are preceded by a large number of unsafe acts and near misses, reinforcing the importance of proactive safety management and leading indicators.

V. STRATEGIES TO REDUCE WORK-RELATED INJURIES

5.1. Re-centering prevention on the hierarchy of controls

The most important strategic principle is to move prevention upstream. PPE matters, but it is the last line of defense, not the core of system design. OSHA's recommended safety-management practices and ISO guidance both emphasize hazard elimination, substitution, engineering controls, administrative controls, and only then PPE as a layered approach (International Organization for

Standardization [ISO], 2023; OSHA, 2023). In Saudi manufacturing, this means redesigning machine guarding, lockout/tagout reliability, conveyor exclusion zones, access paths, ergonomic lift assists, ventilation, and chemical handling systems before relying on behavioral reminders.

This principle is supported by evidence. Santos et al. (2025) found that PPE lowers injury risk, but its effectiveness depends on availability, fit, comfort, training, and supervision. Where PPE becomes the dominant strategy, organizations often mask design problems rather than solve them. A safer Saudi manufacturing strategy should therefore prioritize machine safeguarding, interlocks, failsafes, automation for high-risk tasks, anti-collision systems, safer maintenance access, and separation of pedestrians from mobile equipment. Applying the hierarchy of controls in manufacturing also requires attention to hazard-specific controls for electrical, dust, confined-space, and chemical risks. Electrical hazards should be addressed through robust isolation procedures, arc-rated protection where necessary, equipment design safeguards, and strict control of energized work. Dust hazards require enclosure, dust extraction, ignition-source control, preventive housekeeping, and process design that reduces combustible accumulation. Confined-space risks should be managed through elimination where possible, permit systems, atmospheric testing, isolation of energy sources, standby arrangements, and rescue planning. Chemical risks require substitution, closed handling systems, local exhaust ventilation, exposure monitoring, and clear labeling and segregation. These measures are more effective than relying mainly on PPE, because they reduce exposure at the source rather than depending entirely on worker behavior.

5.2. Strengthening management systems through ISO 45001 logic

Management systems matter because injuries are generated by weak routines as much as by visible hazards. ISO 45001 provides a structure for hazard identification, legal compliance, worker participation, corrective action, performance monitoring, and continual improvement (ISO, 2023; ISO, 2024). Podrecca et al. (2024) found that certified firms performed better on productivity and profitability, suggesting that organized OHS management can align with business performance rather than compete with it. For Saudi manufacturing firms, especially medium and large enterprises, ISO 45001 should be treated less as a certificate and more as an operating discipline.

However, certification alone is insufficient. Vitrano and Micheli (2024) caution that OSH interventions often underperform when implementation quality is weak. Therefore, Saudi firms need management systems that are auditable at the level of actual practice: pre-job risk assessment, contractor control, permit-to-work discipline, incident investigation quality, corrective-action closure, and regular review of leading indicators.

5.3. Competency-based and multilingual training

Training remains essential, but it must shift from attendance-based compliance to competency-based assurance. In multilingual industrial environments, effective training requires translation, visual content, demonstrations, supervised practice, and verification of understanding. NCOSH's regulation on high-risk occupations explicitly emphasizes specialized training content, hazard communication, medical fitness, and oversight of reporting and permit systems (NCOSH, 2025b). This direction is highly relevant for manufacturing roles involving confined spaces, electrical isolation, work at height, forklift operation, hot work, chemical handling, and maintenance.

Digital and blended training also deserve a larger role. Kabiesz et al. (2025) found that modern technologies such as interactive simulations, virtual environments, and digital learning tools can strengthen occupational-safety training outcomes. For Saudi manufacturers, especially those operating across multiple sites, digital modules can standardize core content, but on-the-job verification remains necessary. The critical question is not whether training occurred; it is whether the worker can perform the task safely under production conditions.

5.4. Building safety climate, participation, and near-miss learning

A durable injury reduction strategy requires stronger safety climate. da Silva et al. (2026) identified management commitment, communication,

participation, and learning as recurrent determinants of safety climate in industrial settings. Min et al. (2024) showed that unfavorable safety climate is associated with increased occupational injuries. These findings imply that manufacturers should actively manage the social architecture of safety, not merely the technical architecture.

Practical steps include visible leadership walkarounds, protection against retaliation for reporting, structured toolbox talks, multilingual communication boards, and worker involvement in job hazard analyses. Near-miss reporting systems are especially valuable because they convert weak signals into actionable learning before harm occurs. Pedrosa et al. (2025) found that a near-miss management system improved safety culture in traditional manufacturing companies. Saudi firms should therefore treat near misses, deviations, and unsafe conditions as indicators of system health rather than as peripheral paperwork.

5.5. Ergonomics as injury prevention and productivity design

Ergonomics should be treated as a core manufacturing strategy rather than a wellness add-on. Workstations, cycle times, reach distances, tool weight, posture demands, and lifting requirements all influence injury probability and performance quality. Chan et al. (2022) argued that new predictive tools can support primary prevention of musculoskeletal disorders, while Greggi et al. (2024) emphasized that WMSDs remain widespread across work settings when exposure is repetitive or poorly controlled. In factory environments, ergonomic redesign often reduces both injury and quality defects by stabilizing movements and lowering fatigue.

For Saudi manufacturing, ergonomic priorities include mechanical assists for heavy loads, adjustable workstations, anti-fatigue flooring, rotation design that does not merely shift the same ergonomic exposure between workers, and use of sensor data to identify high-risk repetitive tasks. SMEs may lack advanced ergonomic resources, but even low-cost redesign—such as changing material height, tool placement, or handling frequency—can significantly reduce strain.

5.6. Heat-risk management for Gulf industrial conditions

Heat governance is no longer optional. WHO (2025a, 2025b) and Nath et al. (2026) indicate that heat exposure affects injury risk through dehydration, impaired concentration, and physiological overload.

Saudi authorities already enforce seasonal restrictions on direct sun exposure and publish preventive guidance, especially for high-risk work (NCOSH, 2025a). Manufacturing firms should extend this logic inside the plant. Heat stress management should include thermal monitoring, hydration access, work-rest cycles, acclimatization for new workers, maintenance scheduling for hot zones, and procedures for early symptom escalation.

This is particularly important for facilities with furnaces, casting operations, boilers, loading yards, or insufficient climate separation between process areas and personnel zones. Heat should be monitored as a safety variable, an environmental one.

5.7. Digital safety technologies and predictive prevention

Recent literature suggests that digital technologies can strengthen prevention when they are deployed to solve specific problems. Jiang et al. (2024) identified wearable devices, sensors, human-robot collaboration systems, and analytics as prominent tools in manufacturing occupational health. Dodoo et al. (2024) similarly reviewed digital innovations that support hazard detection, real-time alerts, and safer work in hazardous environments. Technology can help Saudi manufacturers track exposure patterns, monitor unauthorized access to danger zones, identify ergonomic strain, and improve emergency response.

Yet technology should not be adopted symbolically. Jiang et al. (2024) also highlighted barriers such as cost, privacy, culture, and technological gaps. The right question is not whether a plant has smart PPE or dashboards, but whether those tools reduce real exposure and improve decisions. High-value applications include forklift proximity detection, lockout verification support, heat and air-quality sensors, video analytics for restricted-zone breaches, and digital permit-to-work systems for maintenance.

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5.8. Regulatory enforcement, labour inspection, and contractor governance

Prevention also depends on external and internal accountability. Saudi labor law sets out employer obligations regarding worker safety and health, while recent reforms continue to formalize high-risk work regulation and OSH governance (MHRSD, 2025b; NCOSH, 2025b). Labour inspections remain crucial because they reinforce minimum standards and reduce the competitive advantage of non-compliance.

Bondebjerg et al. (2023) mapped a growing body of effectiveness studies on regulatory interventions, and Schubert et al. (2026) concluded that labour inspections continue to matter for workers' health and safety.

In manufacturing, contractor governance deserves particular emphasis. A large share of severe incidents occurs during maintenance, shutdowns, warehousing, outsourced transport, or specialist work. Firms should therefore extend safety systems beyond direct employees to all persons operating within the production risk envelope. Contractor prequalification, permit systems, site induction, supervision protocols, and shared incident reporting are indispensable.

Table 1. Strategy matrix for injury reduction in Saudi manufacturing.

Strategic domain	Primary controls	Expected effect	Saudi relevance
Engineering and layout	Guarding, isolation, pedestrian-mobile equipment separation, ergonomic redesign	Reduces exposure at source	High for machine-intensive and materials-handling plants
Management system	ISO 45001 routines, permits, investigations, corrective-action closure	Improves control reliability	Supports formalization across industrial cities and larger firms
People and supervision	Multilingual induction, competency verification, frontline coaching	Reduces unsafe adaptation	Critical for diverse workforce and contractor interfaces
Health protection	Heat plans, hydration, fatigue controls, work-rest design, fit-for-work checks	Lowers physiological error and illness risk	Essential in Gulf climate and hot-process facilities
Data and learning	Near-miss reporting, leading indicators, digital sensing, analytics	Shifts prevention upstream	Useful for firms scaling automation and multiple-site operations

5.9 Process Safety and Critical Risk Management

While traditional occupational safety focuses on frequent, lower-severity injuries, manufacturing sectors such as feed production, glucose processing, and poultry operations also face low-frequency, high-consequence risks. These include dust explosions, steam system failures, confined space incidents, and hazardous chemical releases.

Effective injury reduction strategies must therefore integrate process safety principles, emphasizing the identification and management of critical hazards and control barriers.

Key elements include:

- Identification of critical risks (e.g., combustible dust, pressurized systems, ammonia leaks)
- Implementation of engineering controls such as explosion venting, interlocks, and automated shutdown systems
- Use of barrier-based risk models such as Bow-Tie analysis to map causes, controls, and consequences

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- Continuous verification of critical controls, rather than reliance on procedural compliance alone
- Integration of process safety with occupational safety under a unified HSSE framework

This approach ensures that safety management addresses not only injury frequency but also catastrophic risk potential, which is particularly relevant for industrial operations in Saudi Arabia.

5.10 Digital Transformation and Predictive Safety Systems

The advancement of digital technologies presents significant opportunities to transform occupational safety in manufacturing from reactive to predictive systems. In the Saudi context, where industrial expansion is closely aligned with digitalization under national transformation programs, the integration of smart safety solutions is increasingly critical.

Digital safety systems can support:

- Real-time monitoring of hazardous conditions through sensors and IoT devices
- Predictive analytics for identifying high-risk trends using leading indicators
- Digital permit-to-work systems to control high-risk activities
- Automated alerts for unauthorized access to restricted zones
- Centralized data platforms for incident reporting, near-miss tracking, and corrective action monitoring

The use of digital tools enhances visibility, accountability, and decision-making, enabling organizations to move toward data-driven prevention strategies. However, successful implementation requires alignment with operational needs, workforce capability, and organizational culture.

VI. A SAUDI MANUFACTURING INJURY REDUCTION FRAMEWORK

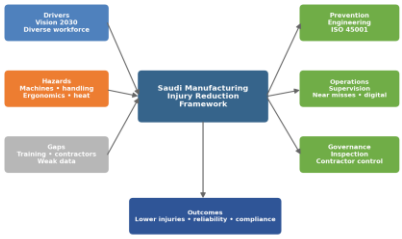

Figure 3 presents the proposed integrated framework for injury reduction in Saudi manufacturing.

As presented in Figure 3, this paper proposes a Saudi Manufacturing Injury Reduction Framework based on the reviewed evidence consisting of seven interacting pillars: (1) risk-informed design, (2) management-system discipline, (3) workforce capability and participation, (4) health and ergonomic protection, (5) digital and data systems, and (6) regulatory and supply-chain alignment and (7) process safety and critical risk management.

The first pillar, risk-informed design, addresses machine guarding, layout, process isolation, maintenance access, and engineered prevention. The second pillar, management-system discipline, embeds ISO 45001 logic into planning, permits, investigations, and continual improvement. The third pillar, workforce capability and participation, emphasizes multilingual competency assurance, supervision, near-miss reporting, and strong safety climate. The fourth pillar, health and ergonomic protection, expands prevention beyond acute trauma to include musculoskeletal strain, heat stress, fatigue, and fitness for work. The fifth pillar, digital and data systems, uses sensors, wearables, analytics, and leading indicators to detect risk earlier. The sixth pillar, regulatory and supply-chain alignment, links plant-level practice with Saudi labor law, NCOSH regulations, inspections, and contractor governance.

The framework is intentionally constraint-aware. It recognizes that Saudi manufacturers differ in size, maturity, technology readiness, and workforce composition. Large industrial firms may implement

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integrated dashboards and advanced sensing systems, whereas SMEs may begin with stronger inspections, structured toolbox talks, simple ergonomic redesign, and multilingual hazard communication. What matters is not adopting every tool at once, but building a coherent prevention system in which controls support one another. Within this framework, manufacturing-specific hazards such as arc flash, combustible dust, confined-space entry, hazardous chemical exposure, noise and vibration, psychosocial strain, and human-robot interaction are treated as priority exposure clusters requiring integrated engineering, organizational, training, and monitoring controls.

A seventh pillar, process safety and critical risk management, is incorporated to address high-consequence industrial hazards that are not fully captured within traditional occupational safety frameworks. This pillar emphasizes barrier integrity, critical control verification, and prevention of catastrophic events such as explosions, toxic releases, and major system failures. Its inclusion reflects the evolving risk profile of Saudi manufacturing, particularly in process-intensive sectors.

VII. DISCUSSION

Three conclusions emerge from the review. First, injury prevention in Saudi manufacturing should be framed as a systems problem. The evidence does not support the idea that injuries are primarily the result of frontline carelessness. Rather, injuries reflect the cumulative effect of design weaknesses, production pressure, communication gaps, inadequate leading indicators, and incomplete organizational learning (Vitrano & Micheli, 2024; Sadeghi et al., 2025). This means prevention policy should focus on system capability, not blame.

This reinforces the need to move beyond compliance-based safety toward assurance-based systems that continuously verify the effectiveness of critical controlsSecond, Saudi manufacturing should resist the false choice between safety and productivity. Podrecca et al. (2024) and Jilcha (2023) both suggest that structured safety systems can reinforce operational performance. Stable production depends on reliable people, reliable equipment, and reliable process discipline. A plant with frequent injuries is not simply less safe; it is also less resilient, less predictable, and often less efficient.

Third, the Saudi context requires adaptation rather than wholesale borrowing. International evidence is valuable, but implementation must account for Gulf heat, migrant labor patterns, varying OSH maturity across enterprises, and the current trajectory of national reform. This is why multilingual training, contractor alignment, and heat governance deserve unusual prominence in the proposed framework. It is also why regulatory coordination matters. NCOSH, MHRSD, industrial-city authorities, and firms themselves all influence whether prevention remains reactive or becomes systematic.

From a policy perspective, a practical next step would be to develop manufacturing-specific injury surveillance dashboards that combine lagging indicators with leading indicators such as near misses, hazard-correction closure times, training verification, ergonomic redesign completion, and contractor non-conformance rates. From an enterprise perspective, firms should prioritize the top exposure clusters on their sites rather than rolling out broad but

shallow campaigns. For many plants, the quickest gains may come from machine safeguarding, mobile-equipment separation, heat protocols, and supervisor capability.

7.1 Industrial Insight from Integrated Manufacturing Operations

Practical industrial observations from integrated manufacturing environments indicate that a significant proportion of incidents do not arise from lack of knowledge alone, but rather from deviations in execution, production pressures, and insufficient supervision of high-risk activities.

In many cases, workers are aware of procedures but adapt them under operational constraints such as time pressure, equipment limitations, or unclear instructions. This gap between "work as imagined" and "work as performed" is a critical contributor to incident occurrence.

Furthermore, contractor-managed activities—such as maintenance, cleaning, and logistics—often present elevated risk due to variability in training, supervision, and safety culture. These conditions highlight the importance of shifting from compliance-based safety models to assurance-based systems, where critical controls are actively monitored and validated in real time.

These observations are consistent with incident investigation findings across industrial organizations, where deviations from procedures and weak supervision are repeatedly identified as key causal factors.

VIII. LIMITATIONS AND FUTURE RESEARCH

This study is subject to several limitations. First, the availability of sector-specific occupational injury data within Saudi manufacturing remains limited, particularly for specialized industries such as feed production, wet milling, and poultry processing. As a result, some conclusions rely on international evidence adapted to the Saudi context.

Second, the study adopts a narrative review methodology, which, while suitable for integrative analysis, does not provide quantitative effect size estimation. Future research may benefit from empirical studies, longitudinal data analysis, and case-based validation of proposed frameworks.

Further research is also recommended in areas such as:

- Integration of process safety and occupational safety systems
- Application of artificial intelligence in hazard prediction
- Evaluation of digital safety platforms in industrial environments
- Sector-specific risk modeling for agri-industrial operations

IX. CONCLUSIONS

This review paper examined strategies to reduce work-related injuries in the Saudi manufacturing sector and found that effective prevention depends on coordinated action across engineering, management, workforce, health, digital, and regulatory domains. The literature indicates that Saudi manufacturing risk is concentrated around foreseeable mechanisms: strikes and collisions, machine and material-handling hazards, ergonomic strain, weak safety climate, inadequate supervision, and heat-related impairment. Recent Saudi reforms and improving national indicators provide a favorable policy backdrop, but sector-specific risk remains substantial.

The central conclusion is that Saudi manufacturing should move decisively from reactive incident response to integrated prevention. PPE and training remain necessary, but they are insufficient when used in isolation. The strongest strategy is a layered prevention model built on safer design, ISO 45001-style management discipline, competency assurance, worker participation, ergonomic redesign, heat governance, digital risk detection, and accountable contractor management. If these elements are aligned, injury reduction can become a driver of operational reliability, workforce trust, and industrial competitiveness. In that sense, preventing work-related injuries is not peripheral to industrial policy in

Saudi Arabia; it is part of building a modern manufacturing economy.

In alignment with Saudi Vision 2030, occupational safety should be positioned not only as a compliance requirement but as a strategic driver of industrial competitiveness, workforce sustainability, and operational resilience. As Saudi manufacturing continues to expand, integrating safety into core business strategy will be essential for achieving long-term economic and social objectives.

The integration of process safety within occupational safety frameworks represents a critical evolution for high-risk manufacturing sectors

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