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The Role of Occupational Safety in Improving Mechanical Maintenance Efficiency and Reducing Industrial Accidents

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Abstract

Mechanical maintenance is an essential industrial function that ensures the reliability, availability, and safe operation of machinery and equipment. However, maintenance activities expose workers to various occupational hazards, including unexpected machine start-up, hazardous energy release, moving mechanical parts, falling objects, slips, falls, and ergonomic risks. The effective integration of occupational safety measures into mechanical maintenance practices is therefore important for protecting workers, improving maintenance performance, and reducing industrial accidents.

This paper examines the role of occupational safety in improving mechanical maintenance efficiency and reducing industrial accidents. It adopts a qualitative, literature-based analytical approach to examine maintenance-related hazards, preventive safety measures, risk assessment methods, worker training, maintenance planning, and safety management systems. Previous research indicates that maintenance-related accidents are influenced by technical, human, and organizational factors, including inadequate planning, insufficient training, unsafe work practices, and deficiencies in hazard control. The paper highlights the importance of preventive maintenance, risk-based decision-making, lockout/tag out procedures, appropriate personal protective equipment, and continuous safety improvement. It also proposes practical indicators for evaluating maintenance safety and efficiency. The paper concludes that integrating occupational safety into every stage of mechanical maintenance can contribute to a safer working environment, more reliable equipment, reduced operational disruption, and improved organizational performance.

Keywords: Occupational safety, mechanical maintenance, industrial accidents, risk assessment, preventive maintenance, lockout/tag out, maintenance efficiency.

1. Introduction

Industrial machinery and mechanical equipment are fundamental components of manufacturing, processing, energy production, transportation, and other industrial activities. Their continuous and reliable operation depends on effective maintenance practices that preserve equipment functionality, prevent deterioration, and minimize unplanned downtime.

Mechanical maintenance involves inspection, lubrication, adjustment, repair, replacement of components, testing, and restoration of equipment. Although these activities are necessary for maintaining operational reliability, they may expose workers to significant occupational hazards, particularly when machinery contains hazardous energy, when maintenance tasks are performed under time pressure, or when appropriate safety procedures are not followed.

Research on industrial maintenance has demonstrated that maintenance-related accidents can result from interactions among technical failures, human actions, organizational arrangements, and deficiencies in planning. A review of 183 major accident investigation reports found that maintenance was associated with 80 of the investigated accidents, highlighting the importance of maintenance-related factors in industrial accident prevention (Okoh & Haugen, 2014).

Occupational safety should therefore be considered an integral part of mechanical maintenance rather than a separate administrative activity. Effective safety procedures can help prevent injuries, protect equipment, reduce interruptions caused by accidents, and support the efficient completion of maintenance tasks.

Accordingly, this paper examines the relationship between occupational safety and mechanical maintenance efficiency, focusing on the identification and control of hazards, preventive measures, safety management practices, and indicators that can be used to evaluate performance.

2. Research Problem

Mechanical maintenance activities frequently require workers to interact directly with machinery, tools, electrical systems, pressurized components, and other potentially hazardous equipment. Inadequate hazard identification, improper isolation of energy sources, insufficient worker training, and poor coordination may increase the likelihood of occupational accidents.

Furthermore, industrial organizations may prioritize the rapid restoration of equipment over the systematic implementation of safety procedures. Such an approach can expose maintenance workers to avoidable risks and may ultimately increase equipment damage, downtime, and operational costs.

The central research problem is therefore expressed in the following question:

How does the implementation of occupational safety measures contribute to improving mechanical maintenance efficiency and reducing industrial accidents?

The following subsidiary questions are also considered:

1. What are the principal occupational hazards associated with mechanical maintenance?
2. Which safety procedures are most relevant to preventing maintenance-related accidents?
3. How can occupational safety contribute to maintenance quality, equipment reliability, and reduced downtime?
4. What indicators can industrial organizations use to evaluate the effectiveness of maintenance safety practices?
5. What organizational and technical challenges may limit the effective implementation of occupational safety measures?

3. Research Objectives

The main objective is to analyze the role of occupational safety in improving mechanical maintenance efficiency and reducing industrial accidents.

The specific objectives are to:

1. Identify the main occupational hazards associated with mechanical maintenance activities.
2. Explain the importance of risk assessment and hazard control in maintenance operations.

3. Examine the relationship between occupational safety procedures and maintenance performance.
4. Discuss the contribution of preventive and predictive maintenance to equipment reliability and risk reduction.
5. Identify the responsibilities of management, maintenance personnel, and safety professionals.
6. Propose practical recommendations for improving safety practices in mechanical maintenance workshops and industrial facilities.
7. Develop measurable indicators for monitoring occupational safety and maintenance efficiency.

4. Significance of the Research

The significance of this research can be considered from three perspectives.

4.1 Scientific significance

The research contributes to understanding the relationship between occupational safety management and mechanical maintenance performance. It brings together concepts from maintenance engineering, industrial risk management, and occupational health and safety.

4.2 Practical significance

The findings and recommendations may assist industrial organizations in identifying maintenance-related hazards, improving work procedures, strengthening safety training, and reducing preventable interruptions.

4.3 Organizational significance

Integrating safety into maintenance planning may help organizations protect employees, preserve equipment, improve maintenance coordination, and support more reliable industrial operations.

5. Research Methodology

This paper adopts a qualitative, descriptive-analytical methodology based on a review of published literature.

The analysis draws on peer-reviewed research concerning occupational risks in industrial maintenance, maintenance-related accidents, risk assessment, and hazardous energy control. Relevant publications include studies by Lind et al. (2008), Okoh and Haugen (2014), Carrillo-Castrillo et al. (2015), and Park et al. (2024).

The selected literature is examined to identify recurring maintenance hazards, contributing accident factors, preventive safety practices, and relationships between safety management and maintenance performance.

The analysis is organized around four principal themes:

Identification and assessment of maintenance hazards.

* Implementation of technical and administrative safety controls.
* Integration of occupational safety with maintenance planning and execution.
* Evaluation of safety and maintenance performance indicators.

The paper does not present original survey results, experimental measurements, or plant-specific accident statistics. Its conclusions are analytical interpretations of the reviewed literature and established safety principles. Consequently, the proposed relationships should not be interpreted as quantified causal effects unless supported by further empirical investigation.

6. Theoretical Framework

6.1 Concept of occupational safety

Occupational safety refers to the policies, procedures, technical measures, and organizational practices intended to prevent work-related injuries and dangerous incidents.

In industrial environments, occupational safety includes hazard identification, risk assessment, safe work procedures, worker training, emergency preparedness, equipment guarding, and the use of appropriate protective equipment.

The International Organization for Standardization's ISO 45001 standard provides a framework for occupational health and safety management systems. It emphasizes leadership, worker participation, hazard identification, risk control, compliance obligations, and continual improvement.

6.2 Concept of mechanical maintenance

Mechanical maintenance comprises the technical and managerial activities required to preserve or restore machinery and equipment to a condition in which they can perform their intended functions.

Maintenance activities are commonly classified into the following categories:

Corrective maintenance: Actions undertaken to restore equipment after a fault or failure has occurred.

Preventive maintenance: Planned interventions carried out at predetermined intervals or according to established maintenance schedules to reduce the probability of failure.

Predictive maintenance: Maintenance decisions based on equipment condition data, such as vibration measurements, temperature readings, lubricant analysis, and other diagnostic indicators.

Condition-based maintenance: Maintenance initiated when monitored equipment conditions indicate that intervention is necessary.

These strategies differ in their planning requirements and operational implications. Their safety performance depends on equipment condition, task complexity, the quality of risk assessment, and the effectiveness of the controls applied.

6.3 Concept of maintenance efficiency

Mechanical maintenance efficiency refers to the ability to complete maintenance activities safely and effectively while making appropriate use of time, labor, materials, and equipment.

It may be evaluated through indicators such as:

* Mean time to repair (MTTR).
* Mean time between failures (MTBF).
* Equipment availability.
* Planned maintenance compliance.
* Unplanned equipment downtime.
* Maintenance rework rates.
* Occupational injury and near-miss rates.

Efficiency should not be assessed solely by the speed of completing a repair. A task completed quickly but without appropriate isolation, inspection, or testing may expose workers to unacceptable risks and result in subsequent failures.

A more comprehensive approach evaluates safety, technical quality, equipment reliability, and resource utilization together.

7. Occupational Hazards in Mechanical Maintenance

Mechanical maintenance exposes workers to hazards that vary according to the machinery, work environment, maintenance task, and energy sources involved.

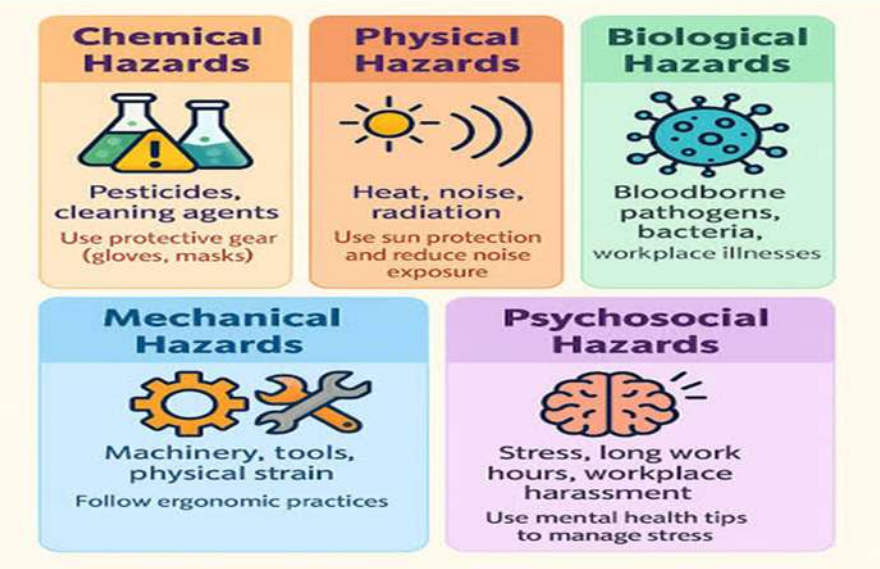

Figure 1: Risk involved in mechanical maintenance work

7.1 Mechanical hazards

Mechanical hazards arise from moving parts, rotating shafts, belts, gears, cutting tools, and machinery capable of crushing, trapping, or striking workers.

Potential consequences include lacerations, fractures, crushing injuries, and amputations.

Relevant preventive measures include effective machine isolation, guarding, safe tool selection, and verification that hazardous movement has stopped before work begins.

7.2 Hazardous energy and unexpected machine start-up

Maintenance work may involve electrical, mechanical, hydraulic, pneumatic, thermal, chemical, or gravitational energy.

If energy sources are not properly isolated, equipment may start unexpectedly or release stored energy while a worker is performing maintenance.

Lockout/tag out procedures are designed to control hazardous energy by isolating energy sources, applying appropriate locks and warning tags, and verifying that the equipment is in a safe state before work begins.

The specific procedure must reflect the equipment design, applicable regulations, and the organization's established energy-control program.

7.3 Slips, trips, and falls

Oil spills, poorly arranged tools, uneven surfaces, inadequate lighting, and obstructed walkways may cause workers to slip, trip, or fall.

Work at height introduces additional hazards, particularly when inspecting overhead equipment or repairing elevated machinery.

Preventive measures include good housekeeping, suitable access equipment, inspection of work platforms, appropriate fall-protection measures, and clear separation of pedestrian and equipment movement routes.

7.4 Ergonomic hazards

Maintenance personnel may lift heavy components, work in restricted spaces, adopt awkward postures, or repeat physically demanding movements.

These activities may contribute to musculoskeletal disorders and reduced work capacity.

Risk reduction measures include mechanical lifting aids, appropriate work positioning, task redesign, suitable tools, and training in safe material handling.

7.5 Chemical, thermal, and environmental hazards

Lubricants, solvents, cleaning agents, hot surfaces, welding activities, and pressurized systems may expose workers to chemical, thermal, fire, or explosion hazards.

Control measures should include suitable ventilation, chemical handling procedures, appropriate protective equipment, temperature control, pressure isolation, and specific permits where required.

Lind et al. (2008) emphasized the importance of risk assessment, safe working practices, and coordination in managing occupational risks associated with industrial maintenance.

8. The Role of Occupational Safety in Improving Mechanical Maintenance Efficiency

8.1 Reducing unplanned downtime

Accidents during maintenance can interrupt work, require emergency responses, damage equipment, and delay the return of machinery to service.

Systematic hazard identification and safe work procedures help prevent avoidable incidents that interfere with maintenance schedules.

However, safety procedures must be integrated into work planning so that the time required for isolation, verification, inspection, and testing is appropriately included in the maintenance schedule.

8.2 Improving maintenance quality

Safe maintenance procedures encourage workers to follow defined steps, use suitable tools, verify equipment conditions, and complete inspections before returning machinery to operation.

This systematic approach may reduce errors, incomplete repairs, and repeated interventions.

Quality control and safety verification should therefore be incorporated into maintenance work orders and completion records.

8.3 Supporting preventive and predictive maintenance

Preventive and predictive maintenance can help identify equipment deterioration before it develops into a major failure.

Examples include vibration analysis for rotating machinery, temperature monitoring for bearings, lubricant analysis, and inspection of mechanical components.

Early identification of deterioration may allow maintenance to be scheduled under controlled conditions instead of being performed urgently after a failure.

Nevertheless, preventive maintenance does not automatically eliminate accidents. Every intervention still requires an appropriate assessment of its specific hazards.

8.4 Reducing human error

Inadequate training, fatigue, poor communication, unclear work instructions, and time pressure can contribute to unsafe actions.

Standardized procedures, clear task responsibilities, toolbox talks, supervision, and verification steps can help reduce these risks.

Safety measures should also address organizational conditions rather than attributing every accident solely to individual worker behavior.

8.5 Improving equipment reliability and availability

Equipment reliability depends on technical condition, maintenance quality, operating conditions, and the effectiveness of maintenance planning. When safety requirements are integrated into maintenance processes, organizations can establish more consistent procedures for inspection, repair, testing, and equipment handover.

These practices can support reliable operation, although their actual effects should be evaluated using equipment performance data.

9. Essential Occupational Safety Measures in Mechanical Maintenance

9.1 Job safety analysis

Job safety analysis (JSA) involves dividing a maintenance task into steps, identifying hazards associated with each step, assessing the associated risks, and defining appropriate controls.

For example, replacing a rotating-machine bearing may involve isolation, dismantling, component removal, installation, alignment, and testing. Each stage should be examined for mechanical, energy-related, ergonomic, and environmental hazards.

9.2 Lockout/tag out procedures

Lockout/tag out is a fundamental control for maintenance tasks involving hazardous energy.

A typical energy-control process includes:

1. Identify all relevant energy sources.
2. Notify affected personnel and shut down the equipment according to the established procedure.
3. Isolate the equipment from its energy sources.
4. Apply appropriate lockout devices and warning tags.
5. Release or control stored energy.
6. Verify the effectiveness of isolation before work begins.
7. Complete maintenance and inspect the work area.
8. Restore energy according to the approved procedure after personnel are clear and the required checks are complete.

The exact sequence and responsibilities must follow applicable regulations and equipment-specific procedures. Lockout/tag out should never be replaced by reliance on a stop button alone.

9.3 Personal protective equipment

Personal protective equipment (PPE) may include safety footwear, protective eyewear, gloves suitable for the specific task, hearing protection, helmets, and respiratory protection where indicated by risk assessment.

PPE should be selected according to the hazards identified and should complement, rather than replace, engineering and administrative controls.

For example, gloves suitable for handling components may present an entanglement risk around rotating machinery. Selection and use must therefore follow task-specific safety requirements.

9.4 Training and competency development

Maintenance personnel should receive training appropriate to their responsibilities and the hazards associated with their work.

Training topics may include hazardous energy control, machine guarding, safe lifting, hand-tool safety, chemical handling, emergency procedures, and safe use of maintenance equipment.

Competence should be verified through practical assessment and supervision, not merely attendance at training sessions.

9.5 Maintenance planning and coordination

Before work begins, supervisors should ensure that the work scope, required resources, permits, isolation arrangements, spare parts, and responsibilities are clearly established.

Coordination becomes particularly important when several teams work simultaneously on interconnected equipment.

Research on simultaneous operations in industrial plant maintenance highlights the need for systematic hazard identification and risk assessment when different tasks are performed concurrently (2024 study published in *Sustainability*, Article 9277).

10. Relationship Between Safety and Maintenance Performance

Occupational safety and maintenance efficiency should be treated as complementary objectives.

The relationship can be examined through four main dimensions:

Table 1: The Relationship Between Occupational Safety and Maintenance Efficiency

Safety practice	Expected Operational Contribution	Suggested Indicator
Hazard Identification and Risk Assessment	Better task planning and fewer unexpected interruptions	Percentage of high-risk tasks assessed
Lockout/Tagout and Energy Verification	Reduced exposure to unexpected start-up and hazardous energy	Compliance with energy-control procedures
Preventive and Predictive Maintenance	Early detection of deterioration and fewer emergency interventions	Planned versus unplanned maintenance hours
Worker Training and Competency Assessment	Improved procedural consistency and task execution	Percentage of personnel assessed as competent
Housekeeping and Tool Control	Reduced slips, trips, and avoidable work delays	Housekeeping inspection results
Post-Maintenance Testing and Inspection	Improved repair verification and equipment handover	Maintenance rework rate

These relationships describe expected contributions rather than guaranteed outcomes. Their effectiveness depends on implementation quality, management commitment, worker participation, and the characteristics of the industrial environment.

10.1 Suggested performance indicators

Organizations can monitor safety and maintenance performance using a balanced set of indicators.

Safety indicators

* Number and rate of recordable occupational injuries.
* Lost-time injury frequency, calculated using a clearly defined reporting basis.
* Number of near-miss reports and the proportion investigated.

* Compliance with required risk assessments and energy-isolation procedures.
* Completion of corrective actions arising from safety inspections.

Maintenance indicators

* Mean time to repair (MTTR).
* Mean time between failures (MTBF).
* Equipment availability.
* Percentage of planned maintenance completed on schedule.
* Unplanned downtime.
* Percentage of maintenance tasks requiring rework.

These indicators should be interpreted together. For example, an increase in near-miss reports may reflect improved reporting culture rather than an increase in underlying hazards. Likewise, a reduction in reported injuries should be considered alongside reporting quality, workforce exposure, and preventive-control performance.

11. Discussion

The reviewed literature supports the view that maintenance-related accidents cannot be explained solely by individual mistakes. They may result from interacting technical, human, and organizational factors, including equipment condition, maintenance planning, work coordination, and the effectiveness of hazard controls.

Carrillo-Castrillo et al. (2015) analyzed 11,190 reported maintenance-related accidents in the manufacturing sector of Andalusia, Spain, covering 2003–2012. Their study demonstrated the value of assessing risk according to the tasks performed and the mechanisms through which accidents occur.

Okoh and Haugen (2014) also showed the importance of maintenance-related factors in major industrial accidents. Their analysis indicates that maintenance planning, organizational arrangements, and the condition of protective barriers deserve attention alongside technical repair activities.

These findings support an integrated approach in which occupational safety is considered during maintenance preparation, execution, testing, and return to service.

From a practical perspective, industrial organizations should avoid evaluating maintenance teams exclusively on repair speed or equipment availability. Such narrow criteria may create pressure to bypass safety procedures. Performance assessment should instead combine safe execution, repair quality, equipment reliability, and efficient resource use.

The analysis also indicates that the effectiveness of safety measures should be assessed through actual workplace data. Although established safety principles provide a strong basis for preventive action, the magnitude of their effect on accident rates, downtime, and maintenance costs will vary across organizations and requires context-specific evaluation.

12. Recommendations

Based on the reviewed literature and the analysis presented, the following recommendations are proposed:

1. Integrate occupational safety requirements into all mechanical maintenance plans and work orders.
2. Conduct task-specific risk assessments before undertaking maintenance activities, particularly high-risk work.
3. Establish and enforce documented lockout/tagout and hazardous energy-control procedures.

4. Verify that workers have the required training, authorization, and practical competence for assigned tasks.
5. Strengthen preventive and predictive maintenance programs to identify equipment deterioration before it leads to major failures.
6. Ensure that machine guards, lifting equipment, tools, and personal protective equipment are appropriate and maintained in serviceable condition.
7. Improve housekeeping, workshop organization, lighting, ventilation, and access arrangements.
8. Establish clear coordination procedures for simultaneous maintenance activities and contractor work.
9. Investigate accidents and near misses to identify technical, human, and organizational contributing factors.
10. Monitor safety and maintenance indicators together, rather than treating them as separate performance objectives.
11. Encourage worker participation in hazard identification, safety reviews, and the improvement of maintenance procedures.
12. Evaluate the effectiveness of implemented controls periodically and revise procedures when workplace conditions or equipment change.

13. Limitations and Future Research

This paper is based on a qualitative analysis of published literature and does not include original field measurements or a representative sample of industrial organizations.

Consequently, the analysis cannot establish a numerical estimate of how much occupational safety measures improve mechanical maintenance efficiency or reduce accidents in a particular facility.

Future research could examine mechanical maintenance workshops in Libyan industrial organizations, using structured questionnaires, interviews, workplace inspections, and maintenance records. Such a study could investigate whether the implementation of risk assessment, lockout/tag out, preventive maintenance, and worker training is associated with changes in accident rates, equipment downtime, and maintenance rework.

A field study should define its population, sampling procedure, measurement instruments, ethical considerations, and statistical analysis plan before collecting data.

14. Conclusion

Occupational safety is an essential component of effective mechanical maintenance. Maintenance activities expose workers to mechanical hazards, hazardous energy, falls, ergonomic strain, and other risks that may lead to serious injuries and operational disruption.

The reviewed literature indicates that effective maintenance safety depends on a combination of technical controls, suitable work procedures, risk assessment, worker competency, maintenance planning, and organizational commitment. These measures can support safer task execution and contribute to equipment reliability and operational continuity.

However, safety and maintenance efficiency should not be viewed as competing objectives. A well-planned maintenance task should allow sufficient time and resources for safe isolation, hazard control, repair, inspection, and testing.

The central conclusion is that integrating occupational safety into the full maintenance process provides a sound basis for reducing preventable risks while supporting

maintenance quality and industrial performance. Further empirical research is needed to quantify these relationships in specific industrial settings, particularly within Libyan mechanical maintenance workshops and facilities.

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