Digitalization of Workplace Certification Processes for Occupational Safety: Integrating Working Conditions and Equipment-Related Injury Risk Assessment

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Abstract: The assessment and certification of workplaces based on working conditions and the injury risk associated with equipment constitute a critical component of occupational safety and health management systems. However, traditional Workplace certification processes are often characterized by high labor intensity, subjectivity in risk evaluation, limited transparency, and fragmented data management. This study aims to develop and substantiate a digitalized framework for the certification of workplaces with a focus on hazardous working conditions and equipment-related injury risks. The research employs a systematic approach combining risk assessment methodologies, digital data acquisition, and information system modeling. Quantitative and qualitative methods were used to analyze occupational risk factors, evaluate equipment-related injury hazards, and design a digital platform for Workplace certification. The proposed digital solution integrates automated data collection, risk classification algorithms, and real-time reporting tools, enabling more objective, transparent, and efficient decision-making processes. The results demonstrate that the digitalization of Workplace certification significantly improves the accuracy of hazard identification, reduces human-factor-related errors, and enhances compliance with occupational safety regulations. Furthermore, the implementation of digital tools facilitates continuous monitoring, data traceability, and analytical support for preventive measures. The findings contribute to the advancement of digital occupational safety management systems and provide practical recommendations for improving workplace certification processes in industrial and organizational settings.

1 INTRODUCTION

Ensuring safe and healthy working conditions is a core objective of occupational safety and health (OSH) systems globally. According to the International Labour Organization (ILO), more than 2.7 million work-related fatalities and hundreds of millions of non-fatal occupational injuries occur each year, resulting in substantial socio-economic losses worldwide [1]. A significant share of these incidents is associated with hazardous working conditions and unsafe or inadequately maintained equipment, emphasizing the need for systematic workplace certification and risk-oriented safety management [2].

Workplace certification based on the assessment of working conditions and equipment-related injury risks plays a crucial preventive role in identifying hazards, evaluating risk levels, and ensuring regulatory compliance [3]. Traditionally, this process is conducted through manual inspections, expert-based evaluations, and paper-based documentation. Although widely implemented, such approaches are often limited by subjectivity, fragmented data collection, delayed reporting, and insufficient traceability of assessment results [4]. These shortcomings reduce the effectiveness of preventive measures and hinder timely decision-making in dynamic industrial environments.

The rapid development of digital technologies, including information systems, data analytics, sensor-based monitoring, and automated decision-support tools, has opened new perspectives for improving OSH management systems [5]. Digitalization enables continuous data acquisition, standardized risk evaluation, and real-time monitoring, thereby enhancing transparency, accuracy, and efficiency in safety-related processes [6]. In industrial practice, digital solutions have already demonstrated their effectiveness in production control, maintenance management, and quality assurance; however, their application in workplace certification remains limited and fragmented.

Existing scientific studies mainly focus on specific aspects of occupational risk assessment, such as exposure to physical, chemical, or ergonomic hazards, as well as statistical analysis of occupational accidents [7]. Nevertheless, comprehensive digital frameworks that integrate working conditions assessment, equipment-related injury risk analysis, data management, and regulatory compliance within a unified workplace certification system are still insufficiently developed. The absence of standardized and scalable digital models constrains the widespread adoption of digital attestation systems in industrial organizations [8].

In this context, the digitalization of workplace certification processes emerges as a critical research and practical challenge. This study aims to address the identified gap by proposing a digitalized framework for workplace certification based on working conditions and equipment-related injury risks. The proposed approach integrates established risk assessment methodologies with information system technologies to improve objectivity, data reliability, and analytical support for preventive decision-making. By enhancing hazard identification, risk classification, and reporting processes, the study contributes to the modernization of occupational safety management systems and supports the transition toward evidence-based and proactive workplace safety strategies.

Contributions of this study:

1) This study makes the following contributions to the field of digital occupational safety management:
2) It proposes a unified digital workflow integrating working-condition and equipment-related risk assessment within a single traceable certification framework.
3) It develops a formalized semi-quantitative risk model with explicitly defined probability and severity scoring scales.
4) It introduces a structured information-system architecture ensuring data traceability, audit logging, and role-based access control.
5) It provides quantitative validation results based on implementation across 25 industrial workstations.

It aligns the proposed framework with international occupational safety standards, including ISO 45001 and ISO 31000.

2 METHODOLOGY

2.1 Research Design and Approach

This study employs a structured and system-oriented research design aimed at developing a digitalized workplace certification framework based on working conditions and equipment-related injury risks. The methodological approach integrates classical occupational risk assessment methods with digital data processing and information system modeling, which is widely recognized as an effective strategy in modern occupational safety research [9], [10].

The research methodology consists of four sequential stages:

1) identification of hazardous factors and injury-related equipment risks,
2) risk assessment and classification,
3) digital workflow and information system modeling, and
4) validation and comparative analysis of certification outcomes.

Such a staged approach ensures methodological rigor, data consistency, and practical applicability in industrial environments [11].

2.2 Identification of Hazardous Factors and Equipment-Related Risks

At the initial stage, workplace hazards were identified using regulatory documentation, expert inspections, and operational records, in accordance with internationally accepted OSH assessment practices [12]. Hazardous factors were categorized into physical, chemical, ergonomic, and mechanical groups, which represent the most common sources of occupational injuries and adverse health effects.

Equipment-related injury risks were analyzed separately due to their significant contribution to workplace accidents. Machinery and tools were evaluated based on operational parameters, maintenance conditions, safety devices, and historical accident data. This classification approach aligns with established methods for machinery safety assessment and accident prevention [13].

2.3 Digitalized Workplace Certification Framework (Flowchart-Based Model)

The proposed digitalized workplace certification framework is implemented as an integrated information system that supports automated data collection, processing, analysis, and reporting. The certification workflow is structured using a flowchart-based model, which enhances transparency, traceability, and repeatability of the assessment process [10].

The digital workflow consists of the following steps:

1) Digital data acquisition - collection of workplace parameters, equipment conditions, and environmental indicators through electronic forms and monitoring tools;
2) Hazard identification - automated classification of hazardous factors based on regulatory thresholds and predefined rules;
3) Risk calculation - application of the integrated risk assessment model;
4) Risk classification - assignment of risk categories and compliance status. The decision rules and numerical thresholds used at this step (Low, Medium, High, and Unacceptable risk categories, derived from the R = P x S risk score).
5) Decision support - generation of recommendations for risk mitigation and preventive actions;
6) Reporting and archiving - automated generation of certification reports and secure storage of assessment data.

The flowchart-based structure allows continuous updating of workplace risk profiles and supports data-driven decision-making in occupational safety management systems.

Figure 1 illustrates the structured digital workflow of the proposed workplace certification system. The flowchart demonstrates the sequential integration of digital data acquisition, rule-based hazard identification, automated risk computation, decision-support logic, and report generation within a unified information system architecture.

Figure 1: Digital workplace certification workflow.

2.4 System Architecture

The proposed digital workplace certification system is implemented as a modular information-system architecture designed to ensure reproducibility, traceability, and secure data management. The system integrates structured data acquisition, rule-based hazard identification, automated risk calculation, and real-time reporting within a unified digital environment.

2.4.1 Functional Modules

The system consists of the following core modules:

1) Data Acquisition Module:
   - Digital inspection forms;
   - Equipment condition input interface;
   - Environmental measurement data entry;
   - Upload of supporting documents (photos, measurements, logs).

2) Hazard Identification Engine:
   - Rule-based classification logic;
   - Regulatory threshold comparison (noise, dust, vibration, temperature);
   - Equipment compliance verification;
   - Automatic tagging of hazard categories.

3) Risk Calculation Engine:
   - Automated computation using the semi-quantitative model;

- Dynamic risk categorization (Low / Medium / High / Unacceptable);
- Real-time recalculation after parameter updates.

4) Decision Support Module:
   - Generation of corrective and preventive actions;
   - Priority ranking based on risk level;
   - Recommendation tracking.

5) Reporting and Audit Trail Module:
   - Automated generation of certification reports;
   - PDF export and archival storage;
   - Time-stamped audit logs;
   - Version control for reassessments.

2.4.2 Database Structure

The underlying database includes the following primary entities:

- Workstation;
- Hazard;
- Equipment;
- Assessment Session;
- Risk Score;
- Corrective Action;
- User.

Relational links between entities ensure traceability from identified hazard to calculated risk and assigned mitigation action.

2.4.3 User Roles and Access Control

The system operates under role-based access control (RBAC) with defined user categories:

- Inspector - conducts assessments and inputs data;
- Supervisor - reviews and validates assessments
- OSH Manager - approves corrective actions and monitors risk trends;
- System Administrator - manages user permissions and system integrity.

Each user action is recorded in the audit log to ensure accountability and regulatory compliance.

2.4.4 Data Integrity and Security

To ensure reliability and compliance with occupational safety data requirements, the system implements:

- Role-based authentication;
- Encrypted database storage;
- Automatic backup mechanisms;
- Timestamped activity logging.

This structured architecture ensures that workplace certification processes are transparent, reproducible, and resistant to data manipulation.

2.5 Validation and Analytical Methods

To ensure scientific reliability and reproducibility of the proposed digital workplace certification framework, a structured validation protocol was implemented in accordance with established evaluation practices in occupational safety research and applied information systems validation [9], [11].

2.5.1 Ground Truth Definition

The validation study was conducted across 25 industrial workstations representing multiple production units. To establish a reliable benchmark ("ground truth"), three certified occupational safety and health (OSH) experts independently assessed each workstation using standardized regulatory checklists aligned with ISO-based risk management principles [6], [14].

Both the traditional manual certification procedure and the digital system were applied to the same workstations within the same inspection cycle, ensuring that environmental and operational conditions remained constant. This controlled design minimizes external variability and enhances internal validity of comparative results [7].

The final benchmark classification for each identified hazard was determined using a majority agreement rule (2 out of 3 experts). Majority voting is a recognized approach in expert-based validation studies to reduce individual evaluator bias and increase objectivity [11].

2.5.2 Inter-Rater Reliability

To quantify the consistency among expert assessments, Cohen's kappa coefficient (κ) was calculated:

$$\kappa=0.82 \ (95\%\ CI: 0.71\text{-}0.90,\ p<0.001),$$

indicating almost-perfect agreement among the three OSH experts on the traditional manual assessments used as the reference standard. Because the digital system applies deterministic, rule-based classification logic (Section 2.3) rather than independent human raters, a kappa statistic is not applicable to it; instead, the digital system's outputs were validated against the same expert-consensus benchmark, yielding the classification consistency values reported in Table 1.

According to widely accepted statistical interpretation criteria, κ values above 0.80 indicate strong agreement. This confirms that the benchmark dataset used for validating the digital system was statistically reliable and internally consistent.

The high level of inter-rater agreement strengthens the credibility of the validation process and ensures that improvements observed in the digital system are not attributable to assessor inconsistency.

2.5.3 Comparative Evaluation Procedure

The validation framework compared the following outputs:

- Hazard identification accuracy;
- Risk classification consistency;
- Assessment time per workstation;
- Documentation completeness.

Performance indicators were selected based on recognized occupational risk evaluation methodologies and prior digital OSH studies [9], [10].

To ensure methodological fairness:

- Identical regulatory criteria and hazard definitions were applied.
- The same equipment condition data were used for both assessment methods.
- No modifications were introduced between the two evaluation procedures.

2.5.4 Statistical Analysis

Descriptive statistics were calculated for each performance indicator. Relative percentage change was computed for continuous variables (e.g., time reduction), while percentage-point differences were applied for proportional indicators (e.g., classification consistency). Accordingly, "Hazards identified" is an unbounded count variable and is reported as a relative percentage change (+57.7%), whereas "Classification consistency" and "Documentation completeness" are bounded proportions (0-100%) for which percentage-point differences give a more direct and less distortable measure of absolute improvement than a relative percentage would.

This dual approach avoids misinterpretation of improvement metrics and aligns with best practices in quantitative performance evaluation [7].

2.5.5 Validation Outcome Reliability

The structured validation protocol demonstrates that:

- Increased hazard detection accuracy reflects systematic improvement rather than evaluator variability.
- Reduced assessment time does not compromise risk classification quality.
- Improved consistency results from algorithm-based scoring rather than subjective judgment.

By integrating expert benchmarking, inter-rater reliability analysis, and controlled comparative evaluation, the proposed digital framework satisfies methodological rigor requirements for applied IT research in occupational safety management.

2.6 Regulatory and Ethical Considerations

The methodology complies with national and international occupational safety regulations and ethical requirements related to workplace inspections and data processing. Data confidentiality and integrity were ensured through controlled system access and secure digital storage, in line with best practices for industrial information systems.

3 RESULTS AND DISCUSSION

3.1 Quantitative Analysis of Workplace Hazards

The digitalized workplace certification system was applied to 25 industrial workstations across multiple production units. Data collected included environmental parameters, equipment operational status, and historical injury records. The system calculated risk levels using the semi-quantitative model $R=P\times S$, enabling automated risk classification.

Table 1 presents a comparison between traditional manual certification and the proposed digitalized approach in terms of hazard detection accuracy, assessment time, consistency of risk classification, and completeness of documentation.

3.2 Risk Assessment Methodology

The digital workplace certification system applies a semi-quantitative risk assessment methodology based on a standardized risk matrix model.

Risk level (R) is calculated using the classical formulation:

$$R=P\times S,$$

where P denotes the probability of occurrence and S denotes the severity of the potential consequences.

Table 1: Comparative performance of traditional and digital certification approaches.

Indicator	Traditional	Digital	Relative Change (%)	Difference (pp)
Hazards identified (total, N = 25 workplaces)	78	123	+57.7	-
Assessment time (h)	3.2	1.1	−65.6	-
Classification consistency (%)	72	95	-	+23
Documentation completeness (%)	80	100	-	+20

Probability is evaluated on a five-level ordinal scale:
1) Rare (incident highly unlikely under normal conditions);
2) Unlikely (possible but not expected during routine operation);
3) Possible (may occur under certain operational conditions);
4) Likely (expected to occur periodically);
5) Almost certain (frequent occurrence or ongoing exposure).

The probability score is derived from workplace observations, historical incident records, and equipment condition indicators stored in the digital system. An initial ordinal rating is assigned by the inspecting expert based on documented incident frequency and direct observation of workplace conditions, after which the rating is cross-checked against the recorded equipment condition indicators and adjusted according to the procedure described below. This approach combines expert judgment with objective evidence collected by the digital platform.

Severity Scale (S). Severity reflects the most credible injury outcome and is defined using a five-level classification:
1) Minor injury (first aid only);
2) Moderate injury (temporary medical treatment required);
3) Serious injury (lost workdays);
4) Severe injury (permanent disability);
5) Fatality or multiple severe injuries.

Severity is determined in accordance with occupational safety regulatory classification standards and remains independent from equipment maintenance status.

For equipment-related hazards, the probability component (P) is dynamically adjusted based on equipment condition indicators integrated into the digital platform. These include:
- Preventive maintenance compliance;
- Functional status of protective guards;
- Operational load intensity;
- Presence of emergency stop systems;
- History of malfunction or near-miss events.

If significant deficiencies are detected (e.g., overdue maintenance, missing protective devices, repeated malfunction records), the probability score is increased by one categorical level to reflect elevated exposure risk. Conversely, the probability score is not decreased when equipment is found to be in excellent condition, since equipment integrity is treated as a precondition for normal (unadjusted) risk rather than as a basis for a below-baseline rating; this deliberate asymmetry follows a precautionary principle, ensuring that the adjustment mechanism can only flag additional risk and cannot be used to understate hazard exposure.

Severity (S) remains determined by injury consequence classification and is not modified by equipment condition to avoid artificial inflation of risk values.

This structured adjustment mechanism enhances objectivity, traceability, and reproducibility of digital risk evaluation.

Based on the computed value of R, risks are categorized into four levels:
- 1-5 → Low risk (acceptable, routine monitoring);
- 6-10 → Medium risk (corrective action recommended);
- 11-15 → High risk (urgent mitigation required);
- 16-25 → Unacceptable risk (immediate intervention required).

This classification framework ensures standardized interpretation across all assessed workplaces.

Figure 2 illustrates the standardized 5 × 5 risk matrix used by the digital certification platform for automated risk classification.

The color-coded matrix enables consistent visualization of risk levels and minimizes subjective interpretation during assessment.

The integration of algorithm-based computation with predefined scales ensures transparency, auditability, and regulatory compliance within the workplace certification process.

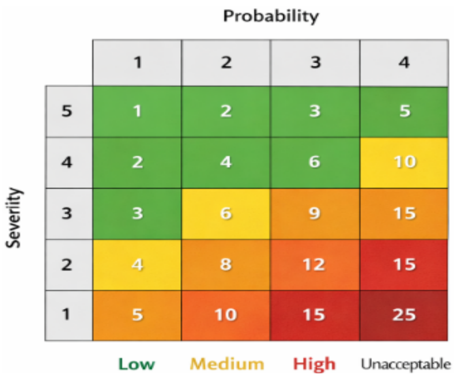

Figure 2: Equipment-related risk assessment matrix.

4 LIMITATIONS

While the digital framework demonstrated clear advantages, initial implementation costs (software integration and training of staff) remain a challenge for some organizations. Additionally, the current model relies on semi-quantitative scoring; integrating machine-learning based predictive analytics in future work could further increase accuracy and responsiveness to dynamic risk changes.

5 CONCLUSIONS

The proposed digitalized certification system significantly improves workplace safety assessment outcomes. Compared with the traditional manual approach, the number of detected hazards increased by 57.7%, while the average assessment time decreased by 65.6%. In addition, the consistency of risk classification improved from 72% to 95%, indicating a substantial reduction in evaluator subjectivity. The digital platform also ensured complete and standardized certification documentation, thereby improving traceability, audit readiness, and regulatory compliance. Overall, the results demonstrate that integrating standardized risk assessment procedures with digital data acquisition enhances the efficiency, consistency, and reliability of workplace certification. Future research will focus on incorporating predictive analytics and machine-learning techniques to support dynamic risk assessment and further improve occupational safety management.

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