

"Integrated Weld Quality Assurance in Human-Centric Missions: Advancing Reliability and Global Compliance in Industry 5.0"

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Abstract: This paper explores the evolving maturity and dynamism of welding and fabrication in modern industry, emphasizing the critical role of quality management and standardization in welded construction. As a primary method for joining materials, welding requires strict adherence to international standards to ensure safety and performance. These standards vary globally, necessitating the expertise of a Responsible Welding Coordinator to ensure compliance, particularly in high-responsibility projects. The proposed Integrated Weld Quality Assurance (IWQA) framework incorporates standardized audits, compliance assessments, and proactive implementation strategies to enhance operational efficiency, minimize defects, and support cost-effective production. The model also recommends the appointment of a Welding Health and Safety Lead to ensure the integration of Quality (ISO 9001), Occupational Health and Safety (ISO 45001), Environmental (ISO 14001), and Weld Quality Management Systems (ISO 3834). Aligned with the human-centric vision of Industry 5.0, the IWQA framework leverages emerging technologies such as Artificial Intelligence (AI), Internet of Things (IoT), and augmented reality for welder training, enabling real-time quality monitoring and continuous improvement. Furthermore, the framework embeds circular economy principles, emphasizing energy efficiency, eco-friendly materials, and waste reduction to promote long-term sustainability. This integrated approach not only supports environmental responsibility but also strengthens workplace safety, operational reliability, and global compliance. Overall, this research presents a scalable, standards-aligned model that supports high-quality, sustainable, and socially responsible welding operations, contributing meaningfully to the future of smart manufacturing under Industry 5.0

Keywords: welding Training, virtual reality (VR), augmented reality (AR), welding Process, education reform, learning effectiveness, skill development, automation, environment, sustainable development, green growth welding, ISO management systems, QMS, EMS, OHSMS, WQM, reliability, resource, code & standard (EN, ISO), Welding Research, welding safety, Up-skilling.

I. Introduction

In the evolving landscape of Industry 5.0, the welding sector is undergoing a significant transformation, integrating smart technologies with human-centric values to ensure quality, safety, and sustainability. Welding, being a critical process in manufacturing and construction, demands high levels of precision, responsibility, and compliance with international standards. The complexity of modern welding operations, combined with varied national regulations, necessitates a structured approach to quality management and skilled coordination.

This paper introduces a novel framework, "The Integrated Weld Quality Assurance" (IWQA) model within the Human-Centric aims to unify Quality Management Systems (QMS), Occupational Health and Safety (OHS), Environmental Management Systems (EMS), and Weld Quality Management (WQM) under one integrated system. It emphasizes the role of the Welding Coordinator, the implementation of 10S methodology, Weld Quality Circles, and a Welding Suggestion Scheme, all of which collectively promote process reliability and continuous improvement.

Moreover, by embedding circular economy principles and leveraging advanced technologies such as AI, IoT, AR simulators, and predictive analytics, the proposed system aligns welding practices with global sustainability goals. This introduction sets the foundation for a comprehensive model that supports world-class manufacturing by enhancing weld quality, safety performance, and environmental responsibility in line with ISO 3834 and other international standards.

Research Objectives

- To design a comprehensive "Integrated Weld Quality Assurance" (IWQA) aligning with Industry 5.0 goals.
- To enhance process reliability and predictive quality assurance in welding operations.
- To integrate human-centric safety systems and ergonomic considerations.
- To align weld quality practices with global standards (ISO 3834, ISO 9606, ISO 45001).
- To propose a roadmap for green, intelligent, and globally compliant welding systems.

II. Methodology

This research employs a qualitative and systems-based methodology to develop the "Integrated Weld Quality Assurance" (IWQA). It integrates practical industrial observations, standard-based compliance (ISO 3834, ISO 9001, ISO 45001, etc.), and expert validations to ensure relevance, accuracy, and real-world applicability. The approach emphasizes human involvement, skill

development, and continuous improvement, making the model adaptable to modern welding environments and aligned with sustainable quality practices.

III. Literature Review:

A comprehensive review of international welding standards, quality management systems, safety frameworks, and Industry 5.0 technologies was conducted to identify gaps in existing practices and establish a foundation for the proposed integrated model.

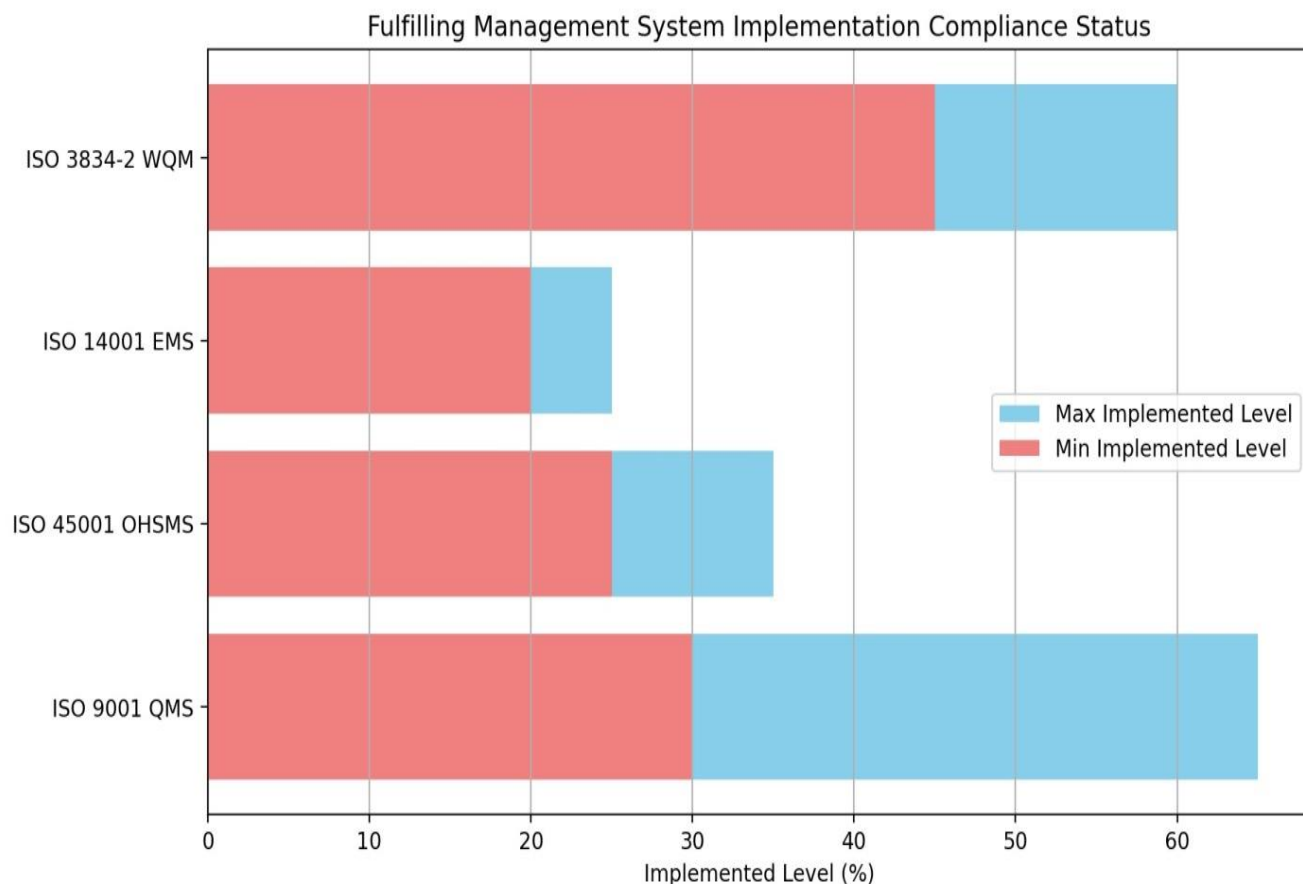


Fig: 01 – Collective Status of Management System Compliance

Framework Development

The TWQA model was designed by incorporating:

- 10S Methodology (Sort, Set in Order, Shine, Standardize, Sustain, Safety, Security, Skill, Satisfaction and Sustainability) and Initiatives Employees engagement with involvement and ownership assignment-based promotion scheme.
- Weld Quality Circle (WQC) for participative problem-solving and continuous improvement, also supporting participation of knowledge sharing event.
- Welding Suggestion Scheme (WSS) for bottom-up innovation from operators,
- Role definition of Responsible Welding Coordinator (RWC) with cross-functional responsibility across QMS, OHS, EMS, and WQM.

System-Based Development through Clause-Driven Actions

The "Integrated Weld Quality Assurance" (IWQA) Manual integrates multiple ISO standards to form a robust, international weld quality framework:

ISO 9001: Focuses on leadership (5.1), planning (6.3), risk-based thinking (6.1), competence (7.2), corrective actions (8.7), performance evaluation (9.1), and continual improvement (10.2, 10.3).

ISO 45001: Enhances worker safety through consultation (5.4), competence (7.2), operational control (8.1.2), emergency planning (8.2), and incident management (10.2, 10.3).

ISO 14001: Ensures environmental integration with planning (6.2.2), competence (7.2), emergency response (8.2), performance evaluation (9.1), and continual improvement (10.2, 10.3).

ISO 3834 – Quality Requirements for Fusion Welding of Metallic Materials

- Clause 10: Welding and related activities
- Clause 11: Inspection and testing
- Clause 12: Nonconformities and corrective actions
- Clause 16: Calibration and validation of measuring, inspection, and test equipment

Sustainability Assessment and Green Welding Development

The circular economy principles; energy efficiency, material reuse, and waste minimization - are embedded into the green welding model to ensure long-term environmental impact reduction. This approach not only aligns with global sustainability goals but also fosters responsible innovation in welding and fabrication.

Major Supporting Points:

Energy-Efficient Welding Techniques:

Adoption of low-heat input processes (e.g., friction stir welding, hybrid laser-arc welding) to reduce energy consumption.

Use of automated and intelligent welding systems to optimize energy usage and minimize idle power.

Material Reuse and Resource Optimization:

Implementation of residual metal recovery systems and recycled filler materials in production cycles. Emphasis on design-for-disassembly and reuse of welded components in modular construction and repair.

Waste Minimization and Emissions Control:

Integration of fume extraction systems and low-emission consumables to reduce environmental pollutants. Real-time monitoring of gas flow rate, slag formation, and spatter to minimize post-weld clean-up waste.

Life Cycle Assessment (LCA):

Comprehensive LCA methodology applied to evaluate the carbon footprint and ecological impact of welding operations. Data-driven improvements in process planning and sustainable material selection.

Green Skill Development and Training:

Training programs promoting eco-friendly welding practices, awareness of sustainable standards, and green certifications (e.g., ISO 14001). Engagement of the workforce in green culture adoption, particularly under Industry 5.0's human-centric vision.

Key Challenges in Implementing "The Integrated Weld Quality Assurance" (IWQA);

Compliance Complexity: Aligning diverse global welding standards (e.g., ISO 3834, ISO 14731, ISO 9606 and ISO 9712) poses integration and interpretation challenges across regions.

Technology Adoption Gap: Integrating AI, IoT, and AR tools demands high investment and training, especially for SMEs.

Human-Centric Shift: Adopting a culture focused on safety, up-skilling, and worker participation requires mindset change and continuous engagement.

Sustainability vs. Cost: Implementing eco-friendly, energy-efficient practices increases initial costs, challenging economic feasibility.

Lunching Integrated ISO Systems for Weld Quality Management;

Integrating ISO 3834, ISO 9001, ISO 45001, and ISO 14001 forms the foundation for developing an Integrated Weld Quality Assurance (IWQA) system within a human-centric Industry 5.0 framework. This approach not only enhances the overall quality and compliance of welding processes but also aligns with sustainable and worker-focused manufacturing goals.

Key Advantages of the Integrated IWQA System:

ISO 3834 – Ensures welding-specific quality requirements, including procedure qualification, welder certification, and material traceability.

ISO 9001 – Establishes a robust Quality Management System (QMS) to ensure consistent product and service quality.

ISO 45001 – Promotes a proactive Occupational Health and Safety Management System (OHSMS), protecting workers involved in hazardous welding environments.

ISO 14001 – Supports Environmental Management, ensuring eco-friendly practices in welding operations and waste management.

Standardization of 10S Practices:

10S Practices ensures workplace efficiency, safety, and quality through structured organization. To avoid inconsistent adoption, it requires customized training, strong leadership, periodic audits, and alignment with ISO systems. Active employee involvement and recognition programs are key to sustaining a culture of continuous improvement and operational excellence.

Resistance to Change:

Technicians and welding professionals may resist adopting new quality systems, especially those involving documentation, audits, or digital monitoring, if not accompanied by incentives and awareness programs.

This research introduces a "Integrated Weld Quality Assurance" (IWQA); framework embedded within a Human-Centric, designed to advance safety, skills, and sustainability in smart welding manufacturing under Industry 5.0. By integrating international welding standards, circular economy principles, digital technologies, and the 10S methodology, the study aims to overcome existing challenges in weld quality, process reliability, and global compliance. The proposed system emphasizes the role of welding coordinators and structured quality circles, promoting a unified, eco-friendly, and scalable approach for world-class welding excellence.

Data Collection Plan Statement for Industry 5.0 Adaptation in the Welding Sector

To effectively support the implementation of a "Integrated Weld Quality Assurance" (IWQA); framework aligned with Industry 5.0 principles, this study proposes a structured data collection plan focused on capturing key insights from the welding industry.

The data collection process aims to assess current practices, identify technological gaps, and evaluate readiness for smart manufacturing transformation. This plan will involve qualitative and quantitative approaches, including surveys, structured interviews, site observations, and case studies with stakeholders such as welding coordinators, welders/Operators, safety officers, quality managers, and industry trainers.

Data will be collected from diverse sectors - marine, structural, automotive, heavy engineering, and fabrication; covering small-to-medium enterprises (SMEs) and large industries.

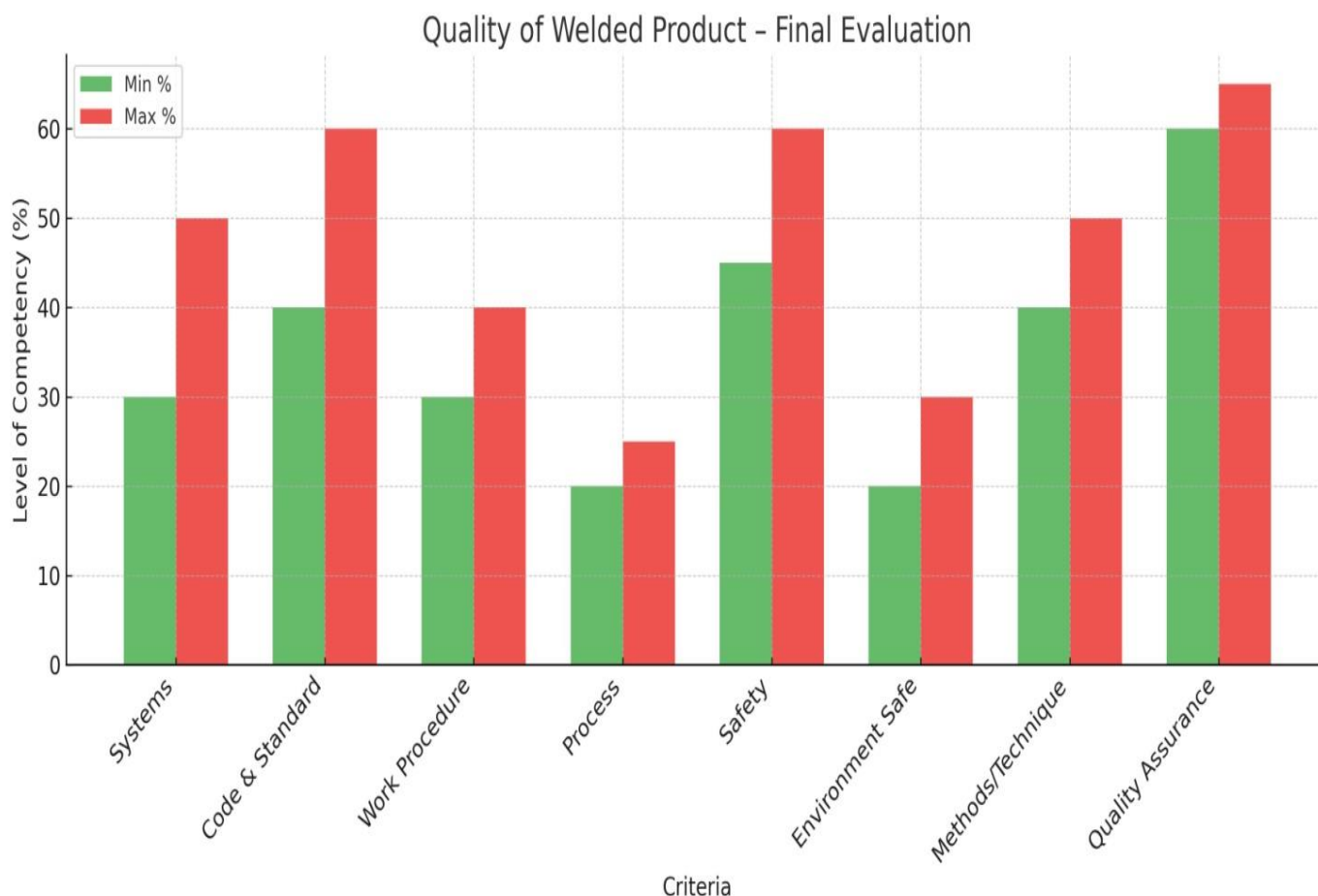


Fig: 02 – Current quality level competency of welded products

The data will focus on:

- Current adoption of Industry 4.0/ 5.0 technologies (AI, AR/VR, IoT in welding)
- Skill levels and training needs (up-skilling)
- Quality assurance and QMS integration practices
- Use of eco-friendly and circular economy-based welding materials
- Health, safety, and sustainability measures in place
- Effectiveness of Weld Quality Circles and suggestion schemes
- Role and responsibility awareness of Welding Coordinators
- The collected data will inform a readiness index for Industry 5.0 adaptation and guide the development of a scalable and eco-conscious.

This research presents a comprehensive, human-centric framework for implementing "Integrated Weld Quality Assurance" (IWQA); Aimed at advancing smart welding manufacturing in alignment with Industry 5.0 principles. By emphasizing the integration of technological innovation, sustainable practices, and safety-focused operations, the study introduces a holistic system that enhances process reliability, global standard compliance, and workplace well-being.

The framework leverages a 10S methodology; providing a structured pathway for improving welds quality and production efficiency. The proposed model embeds Weld Quality Circles and Welding Suggestion Schemes to encourage bottom-up innovation and continuous improvement, ensuring active participation from shop-floor welders to top-level management.

Additionally, the research advocates for a dedicated Welding Coordinator, in line with ISO 14731 and ISO 3834, to oversee quality, health, environmental, and safety systems (QMS, EMS, OHSMS) and ensure compliance with welding qualification as per international codes (e.g., ISO 9606).

Circular economy principles are incorporated to foster eco-friendly welding practices, including optimized material usage, energy conservation, and waste minimization. Data collection from industries, coordinators, and skilled professionals underpins this adaptable and scalable model, making it suitable for SMEs and large manufacturing enterprises alike.

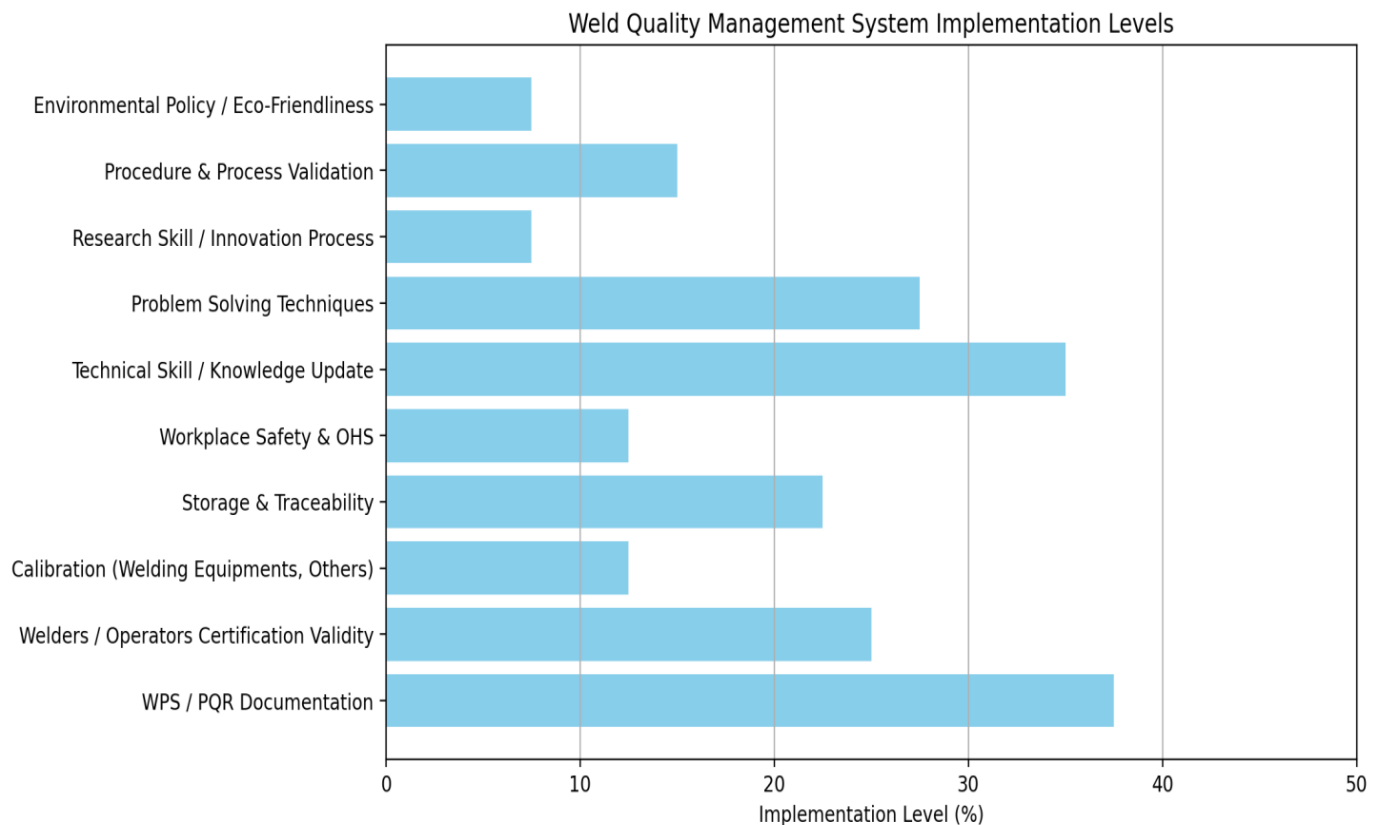


Fig: 03 – "Inconsistent Welding Output Without an Integrated System"

Proposed Model: Key Features and Expected Outcomes Statement

The proposed "Integrated Weld Quality Assurance" (IWQA); framework, is designed to align with the core values of Industry 5.0 by integrating advanced technologies, sustainability principles, and workforce-centered strategies into welding operations.

Key Features include:

(a) Human-Centric Safety Layers: Incorporation of real-time monitoring systems, smart personal protective equipment (PPE), and ergonomic workspace design to reduce risk and enhance occupational health.

(b) Intelligent Process Control: Deployment of IoT sensors and AI-driven inspection systems to provide real-time alerts, optimizes welding parameters, and improves defect detection.

(c) Digital Traceability: Implementation of integrated digital dashboards that ensure end-to-end documentation, traceability, and audit readiness for every weld operation.

(d) Sustainable Practices: Use of green welding materials, adoption of energy-efficient machinery, and alignment with circular economy principles to reduce environmental impact.

(e) Skill Empowerment: Seamless inclusion of training modules, Mixed Reality (MR) simulations, and skill validation tools within the QMS for continuous up-skilling of welding personnel.

10.2 Stakeholder Expectations for Organizational Development:

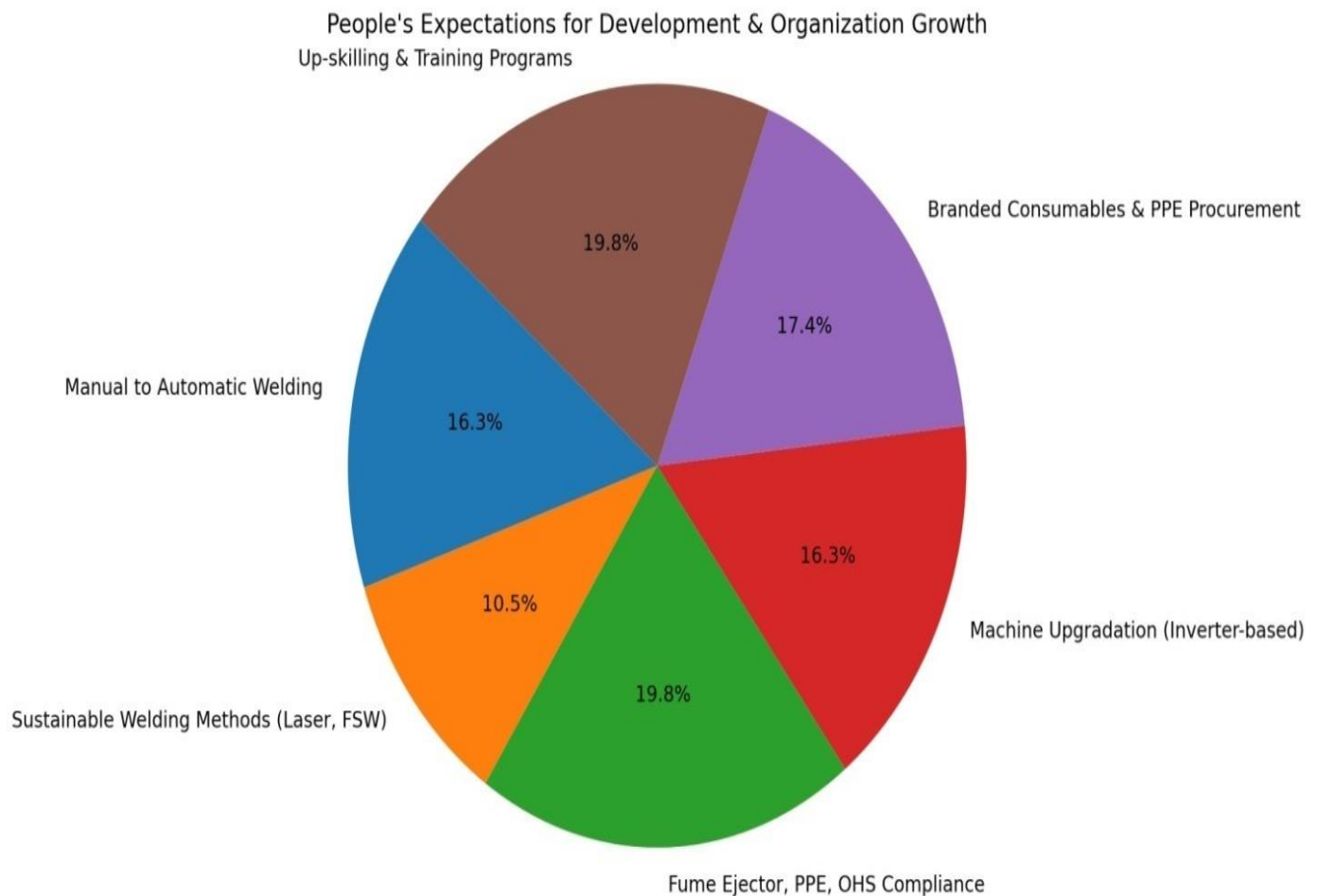


Fig: 04 – Stakeholder Expectations for Organizational Development

IV. Recommendation:

This study proposes a Human-Centric "Integrated Weld Quality Assurance" (IWQA); model tailored for Industry 5.0. The framework integrates smart technologies, ergonomic safety, sustainable practices, and skill development to enhance weld quality, worker safety, and global compliance. With features like AI-driven monitoring, green welding, and it aims to create a scalable, eco-friendly solution for smart manufacturing in the SMEs (Small and Medium-sized Enterprises) by improving productivity, efficiency & quality, also large fabrication industries.

"Integrated Weld Quality Assurance" (IWQA); Implementation process;

To ensure robust weld quality management under "Integrated Weld Quality Assurance" (IWQA); we emphasize the following key actions:

Establish Weld Quality Objectives: Clearly defined and measurable goals aligned with ISO 9001 and ISO 3834 standards to drive continuous improvement.

Develop Welding Procedures: Formulate and implement standard Weld Procedure Specifications (WPS) to ensure process uniformity and compliance.

Welder/Operators Qualification & Training: Certify welders through appropriate tests and provide regular requalification and up-skilling to maintain high-quality workmanship.

Implement Welding Quality Procedures: Ensure consistent execution through structured documentation, monitoring, and corrective actions.

Maintain Comprehensive Records: Capture all welding activities, inspection results, and traceability data as evidence of compliance.

Promote a Culture of Quality: Engage all stakeholders in maintaining safety, performance, and customer satisfaction across all welding processes.

Inspection & Quality Control: Implement systematic inspections at Pre-Welding, In-Process, and Post-Welding stages following IWQA;

Documentation & Traceability: Maintain detailed records of assemblies, inspection reports, consumables, and welder qualifications.

Non-Conformance & Corrective Actions: Identify defects, perform Root Cause Analysis (RCA), and apply corrective solutions.

Audits & Continuous Improvement: Conduct regular audits, review processes, and implement improvements for enhanced weld quality.

Latest Technology Updating:

This structured procedure ensures compliance with "Integrated Weld Quality Assurance" (IWQA); improved quality control, and enhanced client satisfaction.

Digital Weld Monitoring Systems: Utilize real-time monitoring tools to track voltage, current, and heat input for improved weld consistency.

Automated Welding Solutions: Integrate Robotic Welding and CNC Systems to enhance precision, reduce human error, and increase productivity.

Mixed Reality (MR) and VR Training: Adopt MR/VR Simulation for immersive welder training, improving skill development and technique mastery.

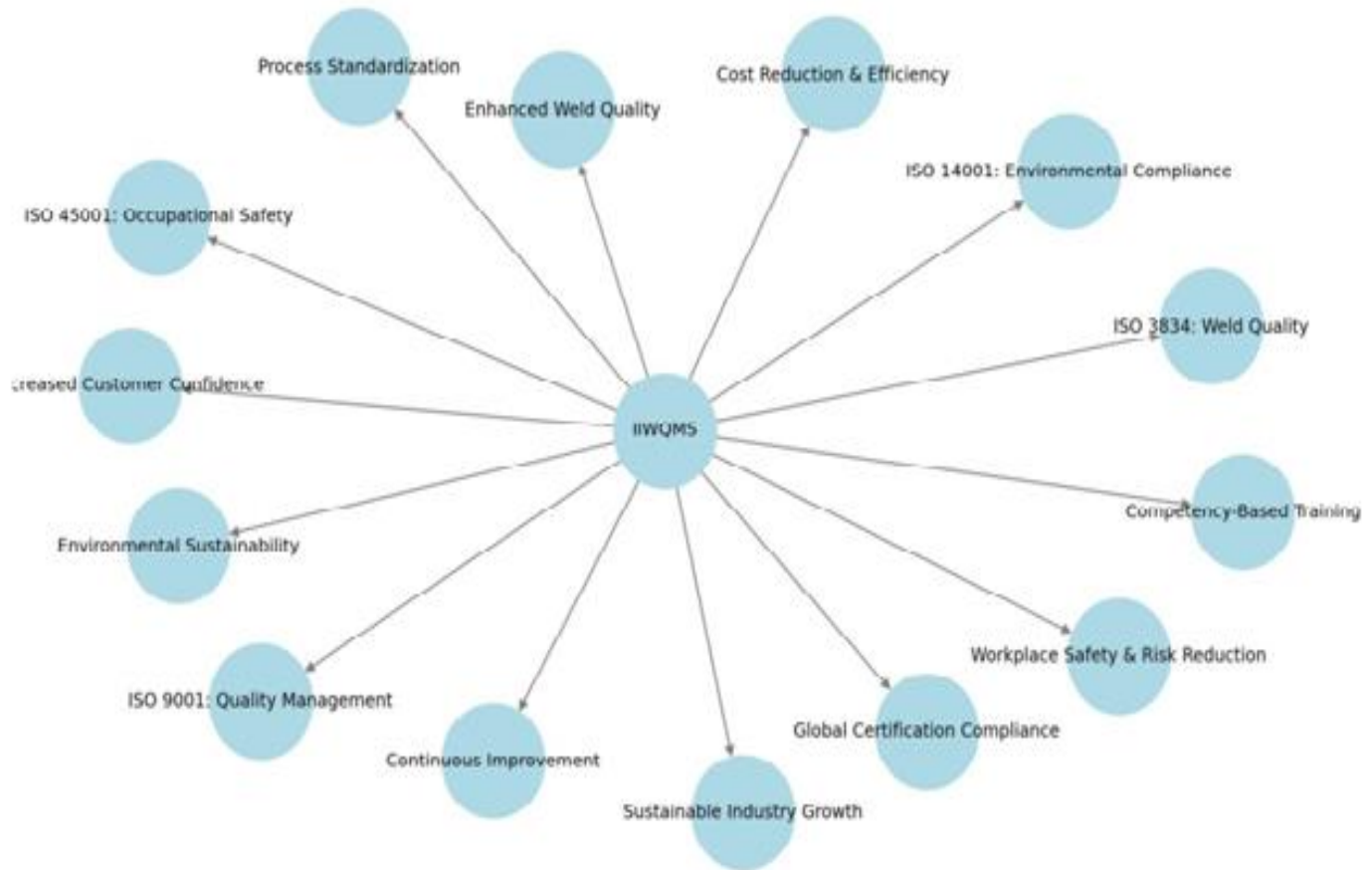
AI-Based Defect Detection: Implement AI-driven inspection systems for automated defect identification and predictive maintenance.

IoT-Enabled Welding Equipment: Use smart welding machines with IoT sensors for data-driven performance analysis and remote monitoring.

Digital Documentation Systems: Introduce cloud-based platforms for seamless data management, traceability, and easy access to quality records.

Laser Scanning for Weld Profile Analysis: Employ 3D laser scanners to inspect weld profiles, ensuring precise measurements and defect detection.

Incorporating these advanced technologies will strengthen "Integrated Weld Quality Assurance" (IWQA); compliance, improve weld quality, and optimize overall production efficiency. IWQA integrates 10S Implementation (Sort, Set in Order, Shine, Standardize, Sustain, Safety, Security, Skill, Satisfaction and Sustainability) with Green Welding principles to promote sustainable fabrication practices; it enhances human-machine collaboration for smarter eco-conscious welding excellence. This strategic implementation will not only enhance product quality and worker safety but will also foster innovation, reduce environmental impact, and improve competitiveness in a global smart manufacturing landscape. An Integrated System ensures that all quality processes, documentation, and assessments are aligned with ISO; while ensuring compliance with regulatory and client-specific requirements.



Poster: 02 - Demonstrating the Benefits of the IIWQMS

V. Conclusion:

In conclusion, this research presents an innovative approach to welding manufacturing by "Integrated Weld Quality Assurance" (IWQA) framework. The integration of ISO 3834 (Weld Quality Management), ISO 9001 (Quality Management System), ISO 45001 (Occupational Health and Safety Management System), and ISO 14001 (Environmental Management System)—forms the foundation of a comprehensive IWQA. Aligned with Industry 5.0 principles, the model promotes operational efficiency, safety, and sustainability. By incorporating structured processes such as Weld Quality Circles (WQC), Welding Suggestion Schemes (WSS), and the 10S methodology, it encourages continuous improvement and team collaboration. This framework equips industries with the tools to meet evolving challenges, enabling smarter, safer, and more sustainable manufacturing practices in the welding sector.

VI. Acknowledgment:

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