

TRANSFORMING LPG CYLINDER DISTRIBUTION THROUGH INTEGRATED MANAGEMENT AND COMPLIANCE SYSTEMS: VALIDATION OF OPERATIONAL OUTCOMES

Israel Alejandro Murillo-Calderón¹

Received 18.09.2025.

Revised 19.11.2025.

Accepted 18.12.2025.

Keywords:

Quality and safety management, LPG distribution, Key Performance Indicators (KPI), Operational risk prevention, Energy logistics.

Original research

ABSTRACT

This study presents the design and validation of an integrated quality and safety management system for the distribution of Liquefied Petroleum Gas (LPG) in cylinders as a structural intervention for sustainable energy logistics. The model is grounded in ISO 9001:2015, NFPA 58, and national regulatory frameworks. An implementation across 50 LPG distribution depots enabled performance evaluation through structured audits, regulatory checklists, and Key Performance Indicators (KPIs), and was monitored throughout a 12-month period. Results demonstrated substantial operational improvements, including marked increases in regulatory compliance and an 80% reduction in incident frequency.

The integration of KPI monitoring tools strengthened traceability and decision-making, while a sensitivity analysis ($\pm 3\%$ and $\pm 5\%$) confirmed the robustness of post-implementation outcomes, with improvements sustained under realistic uncertainty conditions. Overall compliance exceeded 90% across all evaluated standards, demonstrating institutional transformation and operational resilience. The proposed model is replicable and scalable in regions where LPG cylinders remain a primary energy source, contributing to sustainable energy planning by integrating technical regulation, operational risk management, and continuous improvement into a unified governance framework.



© 2026 Journal of Engineering, Management and Information Technolog

1. INTRODUCTION

The distribution of Liquefied Petroleum Gas (LPG) in cylinders remains a primary energy source in numerous countries where natural gas pipeline networks are either limited or altogether absent (INEN, 1998). In such environments—characterised by fragmented infrastructure and heterogeneous regulatory frameworks—LPG distribution depots represent the critical operational interface between the logistical system and the end-user (Troncoso & Da Silva, 2017). However, a lack of standardised operational procedures,

regulatory compliance deficiencies, and limited integration of quality and safety management systems have perpetuated systemic vulnerabilities, directly impacting logistical efficiency and industrial safety (Troncoso & Da Silva, 2017).

To address this scenario, the present study proposes an Integrated Dual Management System for Quality and Operational Safety, specifically designed to optimise the operational performance of LPG cylinder distribution depots (Raslavičius et al., 2014). This model consolidates the principles of ISO 9001:2015—focusing on process improvement and traceability—with the technical

¹ Corresponding author: Israel Alejandro Murillo-Calderón
Email: mcia41359@ute.edu.ec / israel.murillo1406@gmail.com

requirements of NFPA 58, an internationally recognised standard for the safe handling and storage of LPG (Raslavičius et al., 2014). Furthermore, it incorporates current Ecuadorian regulations (NTE INEN 1534:2015, NTE INEN 1535:1998, NTE INEN 1536:1998), as well as the national Occupational Health and Safety Regulation, thereby achieving multisectoral regulatory alignment (Vásconez et al., 2018).

The system was designed, implemented, and validated through a case study involving 50 LPG distribution depots in Ecuador, strategically selected to ensure geographic and operational diversity (Gould & Urpelainen, 2018). The validation process included structured technical audits, regulatory compliance checklists, and evaluation via Key Performance Indicators (KPIs), enabling a precise assessment of the model's impact in terms of regulatory adherence, risk control, and institutionalisation of best practices (Elnajjar et al., 2013).

Beyond the Ecuadorian context, this proposal represents a robust methodological tool with high replicability potential in countries where LPG in cylinders continues to serve as an essential energy vector. Its modular design and standards-based approach facilitate adaptability across diverse regulatory and operational scenarios, promoting the harmonisation of technical criteria in logistically dispersed environments (Andadari et al., 2014).

Finally, this study contributes to the applied research field of integrated normative systems within a process-based management framework, laying the groundwork for future advancements in operational digitalisation, ISO 45001 integration, and the reinforcement of technical governance throughout the LPG supply chain (INEN, 2015).

2. LITERATURE REVIEW EXPERIMENTAL INVESTIGATION

2.1 Operational Structure of the LPG Cylinder Distribution Chain

The Liquefied Petroleum Gas (LPG) cylinder distribution chain represents a complex logistical network with high technical risk due to the physicochemical properties of the product and its widespread domestic, commercial, and industrial use. This system is composed of interdependent operational stages—storage, bottling, transportation, retail distribution, and final delivery—all of which must comply with stringent safety, quality, and regulatory requirements (Camacho Vargas et al., 2025).

In the Ecuadorian context, the chain comprises five primary stages: (i) primary storage facility, (ii) bottling plant, (iii) intermediate bulk depot, (iv) retail distribution depot, and (v) final sales or home delivery point, illustrated on Figure 1. Each node within this network entails specific technical demands governed by both national and international standards intended to ensure operational safety, service quality, and product integrity (Gould et al., 2018).

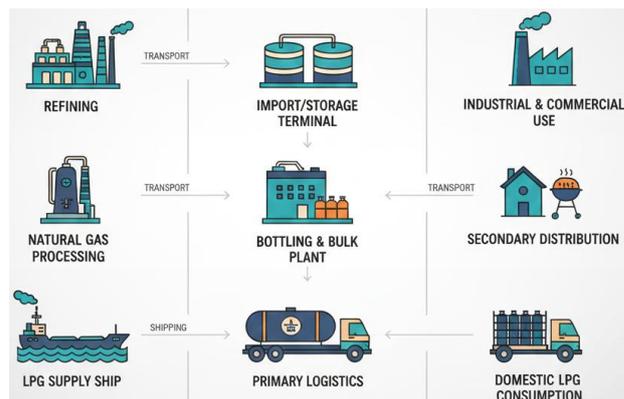


Figure 1. LPG Cylinder Distribution Chain

Initially, LPG is stored under pressure in spherical or horizontal cylindrical tanks at primary storage terminals, with strict monitoring of temperature, fill levels, internal pressure, and forced ventilation. The gas is then transported in tanker trucks to bottling plants, where it is decanted into steel cylinders via automated or semi-automated filling systems, incorporating weight validation, leak detection, and seal integrity verification (Elnajjar et al., 2013).

Filled cylinders are subsequently transferred to wholesale depots and redistributed to retail distribution centres. These facilities handle cylinder reception, temporary storage, direct sale, and doorstep delivery, requiring adherence to technical specifications such as proper ventilation, risk signage, separation of full and empty cylinders, the use of Personal Protective Equipment (PPE), and visual inspection of cylinder integrity (Altubaishe & Desai, 2023).

During transportation, cylinders must remain upright and securely fastened to avoid tipping, impact, or gas leakage. Vehicle design, labelling, and personnel training are crucial elements regulated by standards such as NTE INEN 1535:1998 and NFPA 58. Delivery personnel are also expected to perform basic safety inspections, detect valve or seal anomalies, and respond to incidents in line with established protocols (Raslavičius et al., 2014).

Ensuring full traceability throughout the entire distribution chain is essential for regulatory compliance, operational improvement, and incident prevention. In this regard, the integration of quality and safety management systems—especially those aligned with ISO 9001 and NFPA 58—emerges as a strategic imperative to elevate the logistical standard of LPG distribution systems.

Ultimately, the proper functioning of the LPG cylinder distribution chain requires not only the coordinated execution of technical, logistical, and regulatory processes but also a systemic governance model that embraces quality, safety, and sustainability as interdependent pillars. Optimising this chain is thus a critical enabler for secure energy provision and regulatory harmonisation across both national and international contexts (Ouyang et al., 2022).

2.2 The ISO 9001 Framework for Quality Management in Energy Logistics Operations

ISO 9001:2015 delineates the requirements for a Quality Management System (QMS) applicable to any organisation, aiming to enhance process efficiency, ensure regulatory compliance, and promote continual improvement. Within the context of energy logistics—particularly the distribution of Liquefied Petroleum Gas (LPG) in cylinders—this standard provides a structured framework to standardise critical operations such as reception, storage, handling, transport, and final delivery (ISO, 2015).

At its core, ISO 9001 is underpinned by principles including process-based management, risk-based thinking, evidence-driven decision-making, strong leadership, and stakeholder engagement. When applied to the LPG distribution chain, these principles enable the development of measurable and replicable protocols, reduce operational variability, strengthen documentary traceability, and facilitate both internal and external audits (Zio, 2018).

Specifically, the QMS architecture within LPG operations incorporates documented procedures for critical control points, incident reporting mechanisms, training logs, and supplier evaluation systems (Ingason, 2015). This integration not only reinforces service quality but also ensures strict adherence to safety regulations pertinent to hazardous materials management (Psomas & Antony, 2015).

The implementation of ISO 9001 in LPG logistics enables organisations to systematically identify inefficiencies, respond proactively to deviations, and embed a culture of technical accountability (Bakhtiar et al., 2023). In doing so, it positions quality not merely as a regulatory obligation but as a strategic pillar for operational resilience and stakeholder confidence (Camango & Cândido, 2023).

2.3 Foundations of NFPA 58 Code for the Handling, Storage, and Distribution of LPG

The NFPA 58 Liquefied Petroleum Gas Code, issued by the National Fire Protection Association, constitutes one of the most authoritative international frameworks governing the safe handling, storage, and distribution of liquefied petroleum gas (LPG) (NFPA, 2023).

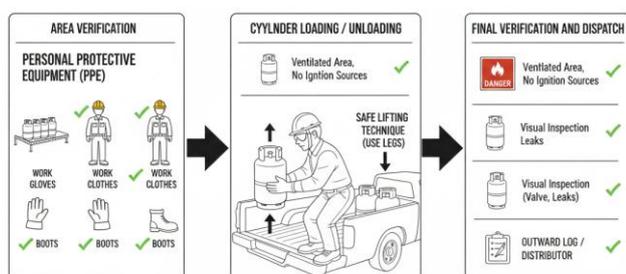


Figure 2. Standardised safety for Handling, Storage, and Distribution of LPG

This code outlines precise technical directives for facility design, cylinder arrangement, ignition protection, ventilation systems, material compatibility, safety devices, and emergency response protocols. Figure 2 illustrates a standardised safety scheme within the LPG cylinder distribution chain (Hugo et al., 2024).

NFPA 58 serves not only as a complementary reference to national frameworks—such as those enforced in Ecuador—but also as a global benchmark for harmonising safety criteria across complex logistical environments. Its structured application significantly mitigates risks related to gas leaks, fires, and explosions, thereby enhancing operational safety standards for both technical personnel and end-users (Petersen, 2019). The code's prescriptive approach ensures a systematic reduction of technical failures, reinforcing safety governance through compliant infrastructure, certified equipment, and clearly delineated operational procedures (Wu et al., 2021).

By integrating NFPA 58 into a broader dual management system, organisations can strengthen their capacity to enforce proactive safety controls and develop risk-informed operational models aligned with global best practices.

2.4 Regulatory Alignment with Ecuadorian Legal Frameworks

In Ecuador, the LPG cylinder distribution sector is regulated by a set of technical standards issued by the Servicio Ecuatoriano de Normalización (INEN), in conjunction with national labour legislation on occupational safety and health. These instruments constitute the mandatory legal foundation for the development and implementation of integrated management systems. The principal normative components are as follows:

- NTE INEN 1534:2015: Governs the storage of LPG cylinders, mandating specific requirements related to natural ventilation, hazard signage, minimum separation between cylinders and flammable structures, and the designation of clearly marked safety zones (INEN, 2015).
- NTE INEN 1535:1998: Defines technical specifications for the transport and distribution of LPG cylinders via vehicular means, including mandatory anchoring mechanisms, hazard identification signage, approved transport routes, and fire suppression systems (INEN, 1998a).
- NTE INEN 1536:1998: Regulates operational protocols within filling and storage plants, encompassing structural safety measures, pressure control systems, maintenance practices, and standardised operational signage (INEN, 1998b).
- Occupational Health and Safety Regulation (SST): Established under Executive Decree 2393, this legislation mandates the provision and use of personal protective equipment (PPE), continuous staff training, risk assessments for occupational exposure, and maintenance of safe and ergonomic working

environments (Presidencia de la República del Ecuador, 2024).

The technical alignment between these national regulations and internationally recognised standards such as ISO 9001 and NFPA 58 facilitates the development of integrated, adaptable, and technically robust management systems tailored to the LPG distribution context. Such convergence not only ensures regulatory compliance but also enhances process resilience, improves risk traceability, and supports the operational standardisation of distribution depots across diverse geographic settings (Ahmad & Puppim de Oliveira, 2015).

2.5 Conceptual Relationship between Total Quality Management (TQM), Safety Governance and Key Performance Indicators (KPIs)

Total Quality Management (TQM) constitutes a holistic management philosophy grounded in continuous improvement and sustained organisational commitment to process efficiency and quality outcomes (Garza-Reyes et al., 2015). Within the context of Liquefied Petroleum Gas (LPG) distribution logistics, the implementation of TQM enhances the integration of operational control with risk governance, thereby raising compliance thresholds and mitigating the probability of critical operational failures (Vásconez et al., 2021). This approach ensures that every layer of the organisational structure actively contributes to quality objectives through standardisation, documentation, and procedural discipline (Wilson & Campbell, 2020).

Safety governance, meanwhile, refers to the organisation's capability to systematically structure, monitor, and evaluate control mechanisms associated with industrial safety (Domingues et al., 2015). It encompasses leadership accountability, regulatory compliance, and the embedding of risk management principles within the operational framework (Talha, 2004). Effective safety governance aligns strategic oversight with day-to-day execution, ensuring that safety protocols are not only implemented but institutionalised (Kaur et al., 2019).

Key Performance Indicators (KPIs) act as empirical instruments within the integrated management system, enabling real-time measurement of system efficacy (Murshed, 2021). Metrics such as regulatory compliance rates, personnel training coverage, incident frequency ratios, and cylinder inspection efficiency provide critical insights into the operational and safety performance of LPG distribution networks (Anand & Grover, 2015). These indicators support evidence-based decision-making and enable proactive interventions, reinforcing the system's resilience and adaptive capacity (Karl et al., 2018).

The convergence of TQM, safety governance, and KPI-based monitoring forms a robust foundation for the continuous enhancement of quality and safety standards within hazardous material supply chains (Giannakis et al., 2019). This conceptual synergy is vital to fostering a culture of excellence, particularly in logistics sectors

where failure can entail high human, environmental, and economic costs (Lim et al., 2022).

3. METHODOLOGY

3.1 Study Scope

This study implemented an integrated dual-management system for quality assurance and operational safety across 50 LPG cylinder distribution operational units, monitored over a 12-month period. The sample design captured a strategic range of operational contexts, spanning geographic distribution, throughput capacity, infrastructure robustness, and regulatory maturity, allowing the model to be evaluated for functional performance, repeatability, and systemic applicability under real-world operating conditions.

3.2 Development of the integrated Quality and Safety Management System

An integrated management model was designed to fuse the principles of ISO 9001:2015 with the technical and safety requirements outlined in NFPA 58, tailored to Ecuador's regulatory framework. The system incorporated quality assurance mechanisms across all critical processes of the LPG distribution chain while embedding operational safety governance aligned with both legal and technical standards. The model was architected to ensure scalability and adaptability to medium-complexity operational environments, without compromising technical rigour or compliance.

3.3 System Architecture: Process Mapping, Documentation and Control Mechanisms

The architecture of the dual system was structured into three technical pillars:

1. **Process Mapping:** Identification and sequencing of critical processes including reception, storage, cylinder handling, dispatch, transport, and final delivery to end-users.
2. **Technical Documentation:** Development of Standard Operating Procedures (SOPs), role-specific operational manuals, risk matrices by process stage, and technical flowcharts aligned with ISO 9001 and NFPA 58 requirements.
3. **Operational Controls:** Deployment of on-site verification mechanisms including structured checklists, incident logs, preventive action plans, and non-conformity registers with full traceability.

This framework enabled the standardisation of routines while facilitating compliance audits and continuous performance monitoring.

3.4 Definition of Technical Key Performance Indicators (KPIs)

A set of Key Performance Indicators (KPIs) was defined to monitor system implementation, assess maturity, and support decision-making. These indicators were

categorised across three core domains, as shown in Table 1.

Table 1. Technical KPI Structure for LPG Distribution Operations

KPI Category	Technical Indicator	Unit of Measure	Evaluation Frequency
Regulatory Compliance	SOP and normative conformity rate	%	Monthly
Operational Performance	Average cylinder loading and dispatch time per unit	Minutes	Weekly
Safety Performance	Frequency of reported safety incidents	Incidents per month	Monthly

The KPIs were designed to ensure continuous monitoring, facilitate inter-depot benchmarking, and provide traceable evidence for corrective and preventive actions.

3.5 Validation Tools for the Integrated System

Three complementary tools were employed to validate the implementation of the dual management system:

1. Internal Compliance Audits: Conducted using structured checklists aligned with ISO 9001, NFPA 58, and applicable Ecuadorian NTE INEN standards.
2. Incident and Non-Conformity Logs: Pre- and post-implementation event records were analysed to identify root causes, apply targeted corrective actions, and validate performance improvements.
3. Stakeholder Feedback: Structured feedback from operators and supervisors was collected to assess clarity of procedures, effectiveness of training, and perceived operational enhancements.

3.6 Baseline vs. Post-Implementation Comparative Analysis

A quantitative comparative methodology was employed to assess the effectiveness of the system through the contrast of pre- and post-intervention KPI values. Baseline measurements were recorded in the month prior to implementation, while final evaluations were conducted at the end of the sixth month. This approach enabled the assessment of:

- Percentage improvement in regulatory compliance and system performance.
- Reduction in the frequency and severity of operational incidents.
- Convergence of operational performance across participating depots.

Additionally, a depot-specific prioritisation matrix was used to identify critical risks and operational gaps, enabling tailored improvement actions and scaling strategies for broader national implementation in subsequent phases.

3.7 Sensitivity Analysis Implementation

A sensitivity analysis was applied to evaluate the robustness of post-intervention results under realistic operational variability. Controlled perturbations of $\pm 3\%$ and $\pm 5\%$ were introduced to the key performance indicators (KPIs), following uncertainty ranges consistent with quality assurance and safety management practices. The procedure allowed verification of the stability of the model's outputs when subjected to typical fluctuations in measurement, operational conditions, and compliance. This methodological step ensured that performance improvements were not dependent on ideal or static parameters but remained valid under representative field variability (Liu et al., 2024).

4. RESULTS

This section outlines the findings derived from the design, implementation, and validation of the dual management system for quality and operational safety in the distribution of Liquefied Petroleum Gas (LPG) cylinders in Ecuador. The proposed model was developed in accordance with the international standards ISO 9001 and NFPA 58 and rigorously aligned with Ecuadorian technical regulations (NTE INEN 1534:2015, NTE INEN 1535:98, NTE INEN 1536:98) as well as the national Occupational Health and Safety Regulation (SST).

The system was deployed and assessed through a structured application involving 50 strategically selected LPG distribution depots across diverse geographic and operational contexts. Data was collected through technical audits, regulatory compliance checklists, and performance measurement tools.

The analysis focuses on four key dimensions: (i) pre- and post-implementation compliance with national and international standards, (ii) operational performance as measured through Key Performance Indicators (KPIs), (iii) identification and classification of critical non-conformities, and (iv) evaluation of the system's repeatability and potential for international scalability.

The results presented herein confirm the system's capacity to close normative gaps, institutionalise best practices, and generate measurable operational improvements in high-risk energy logistics environments. These findings validate the applicability of the proposed model and lay the groundwork for its adoption in countries with similar logistical structures and regulatory challenges.

4.1 Initial Assessment of Regulatory and Technical-Operational Compliance

The baseline assessment was conducted through structured technical audits across the 50 LPG cylinder distribution depots selected for this study. Each audit was performed using verification checklists specifically tailored to reflect the technical and procedural requirements of the applicable regulatory frameworks. The findings, summarised in Table 2, quantify the pre-

implementation level of compliance in key operational domains critical to the safety and performance of LPG distribution systems.

Table 2. Baseline Regulatory Compliance across Technical Domains

Technical Standard	Evaluated Area	Average Compliance (%)
ISO 9001	Quality management and traceability	43.2%
NFPA 58	Operational safety and hazard signage	51.4%
NTE INEN 1534	Storage	48.7%
NTE INEN 1535	Cylinder transport	45.9%
NTE INEN 1536	Plant procedures	53.6%
Occupational Safety Reg.	PPE use and working conditions	49.0%

The results reveal systemic deficiencies across all regulatory domains, most notably in the deployment of quality control mechanisms, process documentation, and safety signalling protocols.

From an international perspective, these gaps are not unique to the Ecuadorian context. Countries with decentralised energy infrastructures and reliance on LPG cylinders often experience similar regulatory fragmentation and operational inconsistency.

Consequently, the insights from this baseline diagnosis underscore the pressing need for integrated management systems anchored in globally recognised standards such as ISO 9001 and NFPA 58 to systematically address these vulnerabilities.

The shortcomings presented on Figure 3, reflect a limited institutional integration of safety and quality principles into daily operations, which in turn increases exposure to preventable incidents and operational inefficiencies.

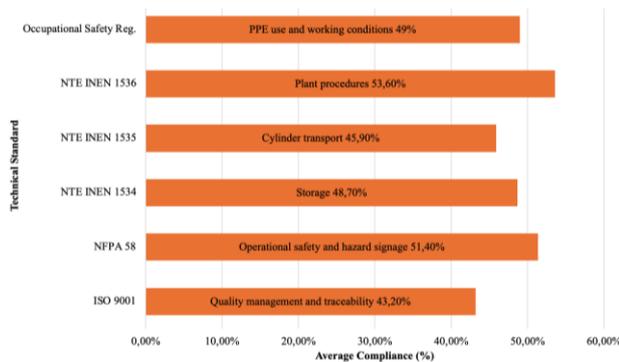


Figure 3. Regulatory Compliance

This initial assessment served as the technical foundation for the development of the dual management model, providing quantitative evidence to prioritise intervention areas and align depot operations with best practices in quality assurance and industrial safety. It further sets a comparative benchmark for evaluating the post-implementation performance and potential scalability of the system in similar regulatory environments.

4.2 Technical Risk Prioritisation Heatmap and Strategic Focal Recommendations

As part of the risk assessment methodology integrated into the dual management system, a technical heatmap was developed to visualise the prioritisation of operational vulnerabilities. This tool correlates nonconformity frequency with assessed severity, following the criteria defined in the integrated quality-and-safety framework. The resulting matrix identifies high-risk clusters within the LPG cylinder distribution process—particularly internal storage, loading/unloading activities and inter-site transport, as shown in Figure 4.

Non-Conformity Type	Frequency (%)
Absence of PPE	60%
Inadequate Safety Signage	48%
Improper Cylinder Storage	48%
Inadequate Cylinder Inspection	38%
Unprotected Transport Practices	55%
Deficient Personnel Training	60%
Incomplete Incident Records	28%
Incomplete Documentation	25%

Figure 4. Technical Risk Prioritisation Heatmap

Heat concentration in these domains reflects both recurrence and impact potential, validated through field inspections and documentation audits. The visual output supports the ranking of critical processes and directs corrective action and resource allocation with higher strategic precision.

Methodologically, the heatmap functions as a primary analytical device that consolidates operational indicators into actionable risk intelligence. Its use enables targeted audit planning, optimised inspection routes and prioritised investment in infrastructure and technical capacity. Embedded within the dual-management system, it establishes a replicable risk-visualisation practice applicable to high-risk energy logistics environments, improving traceability and decision-making while supporting scalable international deployment.

4.3 Identification of Critical Non-Conformities and Corrective Action Plans

The initial diagnostic stage revealed eight distinct categories of non-conformities, of which seven were classified as critical, based on a prioritisation matrix encompassing frequency and severity. These findings are summarised in Table 3.

The risk-based prioritisation framework allowed the targeted development of corrective actions, tailored to each depot's operational reality. All action plans were fully executed, ensuring the remediation of each identified deviation.

Table 3. Categorization of Detected Non-Conformities and Applied Corrective Measures

Non-Conformity Type	Frequency (%)	Criticality Classification	Applied Corrective Measure
Absence of PPE	60%	Critical	Mandatory training + compliance control
Inadequate Safety Signage	48%	Critical	Standardised visual communication deployment
Improper Cylinder Storage	48%	Critical	Spatial reorganisation + SOP documentation
Inadequate Cylinder Inspection	38%	Critical	Checklists + compliance tracking
Unprotected Transport Practices	55%	Critical	Vehicle retrofitting + operator training
Deficient Personnel Training	60%	Critical	Structured training plan
Incomplete Incident Records	28%	Critical	Digital traceability system implementation
Incomplete Documentation	25%	Minor	Systematic digital documentation integration

This corrective cycle confirms the model’s capacity to not only diagnose operational vulnerabilities but also to deploy technically sound, traceable, and verifiable mitigation strategies—thereby reinforcing the model’s utility as both a quality assurance mechanism and a dynamic risk governance instrument

4.4 Performance Assessment via Key Performance Indicators (KPIs)

To facilitate continuous monitoring and validate the operational effectiveness of the implemented model, a set of Key Performance Indicators (KPIs) was defined and tracked over the twelve-month post-implementation period.

Table 4. Operational Performance Indicators

KPI	Baseline Value (%)	Final Value (%)	Improvement (%)
Regulatory Compliance Rate	52%	91%	39%
Trained Personnel Rate	45%	96%	53%
Defective Cylinder Inspection Rate	44%	89%	45%
Safety Signage Implementation Rate	40%	92%	52%
Average Monthly Incident Rate	5	1	80%

These indicators presented in Table 4, were selected based on relevance to operational safety, regulatory alignment, and process reliability.

These KPIs not only validate the technical efficacy of the model but also highlight the emergence of a safety-driven operational culture. Of particular note is the drastic 80% reduction in incident frequency, affirming the model’s tangible impact on risk mitigation as is shown on Figure 5.

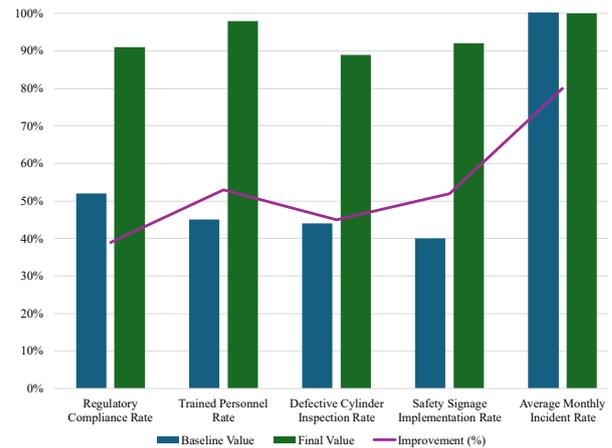


Figure 5. KPI monitoring improvement

Moreover, the integration of KPI monitoring within the quality system (in line with ISO 9001) enables evidence-based decision-making, internal audit facilitation, and structured continuous improvement—a cornerstone for long-term sustainability and replicability.

4.5 Post-Implementation Outcomes of the Integrated Management System

The comparative analysis of regulatory compliance across the 50 evaluated LPG distribution depots revealed a significant performance enhancement following the implementation of the integrated quality and safety management system.

Table 5. Comparative Compliance Levels Before and After System Implementation

Regulatory Domain	Initial Compliance (%)	Final Compliance (%)	Improvement (%)
Quality Management (ISO 9001)	43.2	89.6	+46.4
Operational Safety (NFPA 58)	51.4	93.2	+41.8
Transportation (INEN 1535)	45.9	88.1	+42.2
Storage (INEN 1534)	48.7	91.3	+42.6
Plant Procedures (INEN 1536)	53.6	92.4	+38.8
Occupational Safety (SST Regulation)	49.0	90.6	+41.6

Transforming LPG Cylinder Distribution Through Integrated Management And Compliance Systems: Validation of Operational Outcomes

As detailed in Table 5, the initial average compliance across the applicable normative frameworks (ISO 9001, NFPA 58, NTE INEN 1534, 1535, and 1536) was 48.6%, underscoring a limited institutional adoption of baseline regulatory practices.

Post-intervention, the overall compliance reached an average of 90.87%, evidencing a systemic and sustainable transformation in operational routines. As illustrated in Figure 6, the most pronounced improvements were observed in quality management (ISO 9001), cylinder storage protocols (INEN 1534), transport safety measures (INEN 1535), and infrastructure standards (NFPA 58).

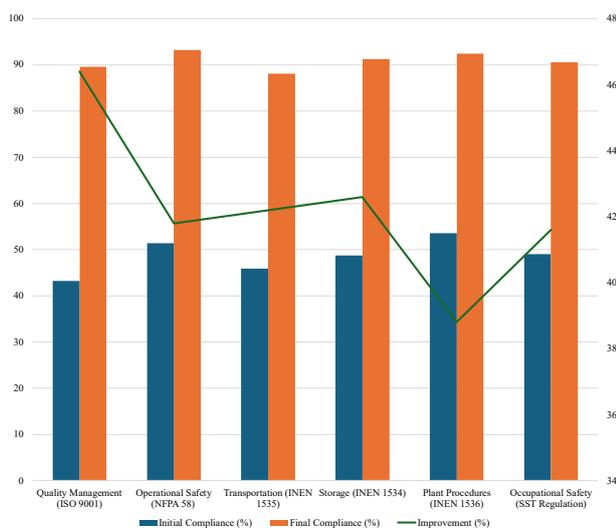


Figure 6. Improvement after system implementation

This transition was not merely procedural but structural, driven by the institutionalisation of documented operational controls, systematic training, and the deployment of standard operating procedures (SOPs). Such structural transformation demonstrates the robustness and assimilative capacity of the integrated management model.

4.6 Sensitivity Analysis of Post-Intervention Results

The sensitivity analysis assessed the response of post-intervention results to controlled variability using perturbations of $\pm 3\%$ and $\pm 5\%$, representing realistic operational and measurement uncertainty in accordance with ISO 9001:2015 and NFPA58. As shown in Figure 7, all indicators sustained positive performance gains under each scenario tested. The results consistently retained a +30% improvement over baseline.

The linear and predictable adjustment of KPIs to the applied perturbations indicates strong model stability, with no evidence of performance regression toward pre-intervention conditions. This consistency demonstrates that the intervention framework remains effective under typical uncertainty margins and maintains its functional integrity over time.

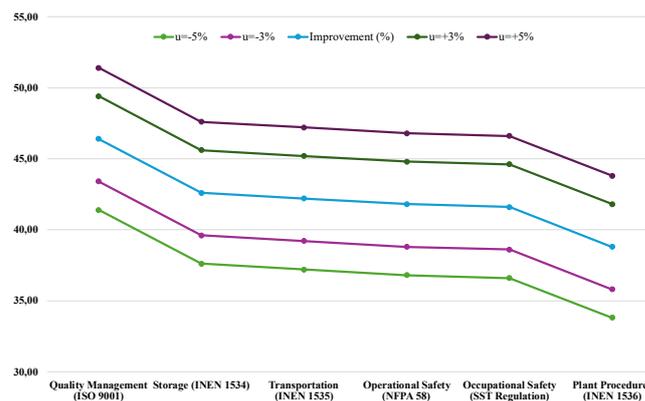


Figure 7. Improvement after system implementation

Consequently, the model exhibits clear long-term operational viability, methodological resilience, and capacity for repetition in diverse regulatory, cultural, and infrastructural environments, supporting its applicability to international LPG distribution systems.

5. DISCUSSION

5.1 Comprehensive Assessment of the Dual Quality and Safety Management System

The implementation of the dual management system, structured upon ISO 9001:2015 and NFPA 58, proved to be technically effective in addressing the structural deficiencies previously identified within the LPG cylinder distribution chain. This integrated approach enabled the establishment of a coherent operational framework where process-based quality management principles (as defined by ISO 9001) were aligned with the technical requirements for the safe handling of flammable gases (as specified by NFPA 58), thereby enhancing operational governance.

Empirical evidence demonstrated sustained improvements in regulatory compliance, enhanced process traceability, and strengthened incident response capabilities. The integration reduced normative fragmentation and fostered the institutionalisation of best practices, particularly in those facilities with a history of persistent non-compliance. Standardisation of critical processes such as: cylinder inspection, PPE usage, and risk signage protocols, was instrumental in reducing operational variability and embedding a culture of quality within the assessed depots.

5.2 Effectiveness of KPI as an Operational Monitoring Tool

The strategic design and deployment of Key Performance Indicators (KPIs) enabled the construction of a robust and quantifiable monitoring architecture aimed at continuous improvement. Metrics such as regulatory compliance rate, percentage of trained personnel, and monthly incident frequency revealed not only statistically significant enhancements but also a stabilising effect on overall operational performance.

By being integrated into the Quality Management System (QMS) structure, the KPI framework functioned as a real-time feedback mechanism, allowing for evidence-based strategic decision-making. This capability enhanced risk management efficiency and validated leadership actions in environments characterised by logistical volatility and weak enforcement mechanisms. Its proven efficacy in pre-empting critical failures justifies its permanent integration in high-risk operational settings.

5.3 Analysis and Technical Prioritisation of Non-Conformities

The identification and technical classification of eight recurring non-conformities (seven of which were deemed critical), underscored the existence of systematic operational shortcomings prior to implementation. A prioritisation matrix based on severity and frequency, complemented by a technical heatmap, facilitated a holistic risk analysis for each depot.

This methodology enabled strategic allocation of corrective resources and served as a replicable and auditable control mechanism. All 50 evaluated depots implemented specific corrective action plans, which were fully documented and validated in situ. These results underscore the system's operational feasibility and its capacity to remediate critical deficiencies in complex logistical contexts. Accordingly, the model emerges as a functional tool for technical auditing in environments with limited risk management maturity.

5.4 Replicability and International Projection of the Model

The implementation of the dual quality and safety management system across 50 Liquefied Petroleum Gas (LPG) cylinder distribution depots in Ecuador demonstrated strong technical efficacy, consistent performance, and high potential for replication in similar logistical and regulatory environments. The system was developed under ISO 9001:2015 for quality management and NFPA 58 for operational safety and strengthened through alignment with national regulations NTE INEN 1534:2015, NTE INEN 1535:1998, NTE INEN 1536:1998 and the national Occupational Health and Safety framework, resulting in a hybrid and adaptable regulatory structure.

The modular model, built on technical checklists, Key Performance Indicators (KPIs), Standard Operating Procedures (SOPs), and structured audits, ensures operational viability across diverse settings. Guided by the Plan-Do-Check-Act (PDCA) cycle, it remains transferable beyond Ecuador, particularly in regions where LPG cylinder distribution is central to domestic energy supply.

To evaluate international adaptability, an applicability matrix (Table 6) was constructed to identify markets with decentralised distribution, comparable regulatory limitations, and limited integrated management systems. This tool supports strategic assessment of the degree of customisation required for effective deployment.

Table 6. International Applicability Projection Matrix for the LPG Cylinder Management Model

Country/Region	Operational Similarities	Application Potential	Minimum Adjustments Required
Kenya	Growing LPG adoption replacing biomass fuels; rapid market expansion	Medium-High	Formalization of distribution networks + traceability systems
Peru	Decentralized network; high domestic LPG demand	High	Regulatory alignment and technical translation
Bolivia	Informal distribution; low traceability	High	Intensive technical training programmes
India	Widespread rural use; high geographic dispersion	High	Integration with national quality systems
Colombia	Strong LPG adoption in rural areas; risk exposure similar	High	Certification alignment with NTC/ISO and supplier traceability
Indonesia	High domestic consumption; high geographic dispersion	High	Gradual scalability via regional cluster rollout

As indicated by the matrix, the model's technical configuration provides a strategic advantage in regions facing infrastructure deficits, low standardisation, limited risk culture, and weak technical governance. Its adaptable structure enables phased deployment—from diagnostic assessment and training to full operational institutionalisation.

Additionally, the KPI-based quantitative component establishes an empirical basis for performance monitoring and cross-territory benchmarking. This analytical capacity strengthens its credibility before multilateral agencies, regulatory bodies, and international energy-access programmes promoting safe and sustainable LPG distribution. From a sustainable development perspective, adopting this model contributes directly to multiple Sustainable Development Goals (SDGs), including:

- SDG 7 – Affordable and Clean Energy: by enabling safer, more efficient, and traceable LPG distribution systems.
- SDG 8 – Decent Work and Economic Growth: through the promotion of formalised and safe working conditions.
- SDG 9 – Industry, Innovation and Infrastructure: by strengthening institutional capacity within decentralised energy sectors.

The successful technical validation of the model within the Ecuadorian context affirms its effectiveness. Its normative adaptability and evidence-based approach

position it as a robust and exportable management system with significant potential to improve the structural integrity of LPG distribution chains in diverse international settings.

5.5 Relevance of the sensitivity analysis

The sensitivity analysis reaffirms the robustness of the intervention under realistic operational variability. The KPIs preserved performance gains even under $\pm 3\%$ and $\pm 5\%$ perturbations, with no regression toward baseline values. This stability demonstrates that the model remains effective beyond ideal conditions and sustains improvements in quality management, safety, and operational reliability.

These findings are particularly relevant for cylinder-based LPG logistics, where fluctuations in demand, measurement uncertainty and heterogeneous compliance levels are inherent. The predictable KPI behaviour confirms the methodological reliability of the intervention and reinforces its suitability for long-term deployment. Moreover, the sustained performance under uncertainty validates the framework as a decision-support mechanism, enabling continuous monitoring and iterative improvement in alignment with ISO 9001 and NFPA 58 principles. This strengthens its applicability in operational environments that require robust governance under fluctuating risk conditions.

6. CONCLUSIONS

1. This study successfully developed, implemented, and validated an integrated dual management system for quality and operational safety, specifically tailored to the cylinder-based Liquefied Petroleum Gas (LPG) distribution chain. The model aligns the process standardisation, traceability, and continual improvement principles of ISO 9001:2015 with the technical safety guidelines of NFPA 58 and further integrates the Ecuadorian regulatory framework.
2. The technical validation conducted across a nationwide sample of 50 distribution depots revealed significant structural improvements. Average regulatory compliance rose to above 90%, operational staff training was enhanced, inspection protocols were standardised, and visual safety controls were implemented. Notably, the incidence rate of reported safety events decreased by 80%. These outcomes demonstrate the model's effectiveness in operational safety and risk governance.
3. The incorporation of Key Performance Indicators (KPIs) as continuous monitoring and control instruments, together with the application of a prioritisation matrix visualised through a heatmap, enabled the strategic identification of critical non-conformities and the prompt execution of corrective actions. This strengthened both operational traceability and real-time management oversight.
4. The sensitivity analysis confirms the operational robustness and stability of the intervention, as the

KPIs remained consistent under realistic variability conditions. This demonstrates that the model sustains performance improvements beyond controlled environments. In addition, its modular design and technical clarity support implementation in contexts with limited regulatory maturity or infrastructural constraints, where bottled LPG remains the dominant distribution method. The framework therefore offers a replicable and scalable governance solution, while integrates risk management platforms, and international standards such as ISO 9001, NFPA 58, and ISO 45001.

5. From the perspective of operational sustainability and social impact, this system offers a robust contribution to the structural enhancement of LPG supply chains. It ensures elevated safety standards for industry stakeholders, improves operational efficiency for logistics operators, and enhances reliability for end users. Its international scalability positions it as a technically sound, immediately applicable tool for advancing integrated quality and safety solutions in the global energy sector.

Abbreviations

ISO	International Organization for Standardization
INEN	Ecuadorian Institute of Standardization
SDG 7	Affordable and Clean Energy
SDG 9	Industry, Innovation and Infrastructure
SDG 13	Climate Action
LPG	Liquefied Petroleum Gas
KPI	Key Performance Indicators
NFPA	National Fire Protection Association
QMS	Quality Management System
TQM	Total Quality Management
SOP	Standard Operating Procedures
u	Uncertainty
PPE	Personal Protective Equipment

Declarations

Availability of data and materials

All data supporting the findings of this study are presented within the article and its appendixes. Additional datasets or detailed information are available from the corresponding author upon reasonable request.

Competing interests

The author declares that he has not competing interests.

Funding

The author declares that no external funding was received from any public, commercial, or not-for-profit funding agency for the development of this research.

Authors' contributions

The author is responsible for the conception, design, and execution of the study, including the development of the methodological framework, field data collection, analysis of risk and performance indicators, and

interpretation of the results. The author also drafted and critically revised all sections of the manuscript, ensured compliance with international technical standards, and prepared the final version for submission. All research activities, including the elaboration of appendices and

tables, were independently carried out by the author. The author has read and approved the final manuscript.

Acknowledgements

N/A

References:

- Ahmad, S., & Puppim de Oliveira, J. (2015). Fuel switching in slum and non-slum households in urban India. *Journal of Cleaner Production*, 94, 130-136, DOI: 10.1016/j.jclepro.2015.01.072.
- Altubaishe, B., & Desai, S. (2023). Multicriteria Decision Making in Supply Chain Management Using FMEA and Hybrid AHP-PROMETHEE Algorithms. *Sensors*, 23, 4041, DOI: 10.3390/s23084041.
- Anand, N., & Grover, N. (2015). Measuring retail supply chain performance: Theoretical model using key performance indicators (KPIs). *Benchmarking: An International Journal*, 22, 135-166, DOI: 10.1108/BIJ-05-2012-0034.
- Bakhtiar, A., Nugraha, A., Suliantoro, H., & Pujotomo, D. (2023). The effect of quality management system (ISO 9001) on operational performance of various organizations in Indonesia. *Cogent Business & Management*, 10, 2203304, DOI: 10.1080/23311975.2023.2203304.
- Camacho Vargas, M., Carranco Madrid, S., Montecé Ochoa, S., & Fonseca Peralta, C. (2025). Análisis de los sistemas de gestión riesgo laborales en las empresas. Una revisión sistemática. *RECIMUNDO*, 9(765-782), [Online]. Available: DOI: 10.26820/recimundo/9.(1).enero.2025.765-782.
- Camango, C., & Cândido, C. (2023). ISO 9001 maintenance, decertification and recertification: a systematic literature review. *Total Quality Management & Business Excellence*, 34, 1764–1796, DOI: 10.1080/14783363.2023.2203379.
- Domingues, J. P. T., Sampaio, P., & Arezes, P. M. (2015). Analysis of integrated management systems from various perspectives. *Total quality management & business excellence*, 26(11-12), 1311-1334. DOI: 10.1080/14783363.2014.931064.
- Elnajjar, E., Hamdan, M. O., & Selim, M. Y. (2013). Experimental investigation of dual engine performance using variable LPG composition fuel. *Renewable Energy*, 56, 110-116, DOI: 10.1016/j.renene.2012.09.048
- Garza-Reyes, J. A., Rocha-Lona, L., & Kumar, V. (2015). A conceptual framework for the implementation of quality management systems. *Total Quality Management & Business Excellence*, 26(11-12), 1298-1310. DOI: 10.1080/14783363.2014.929254.
- Giannakis, M., Spanaki, K., & Dubey, R. (2019). A cloud-based supply chain management system: effects on supply chain responsiveness. *Journal of Enterprise Information Management*, 32(4), 585-607. DOI: 10.1108/JEIM-05-2018-0106.
- Gould, C. F., & Urpelainen, J. (2018). LPG as a clean cooking fuel: Adoption, use, and impact in rural India. *Energy Policy*, 122, 395-408. DOI: 10.1016/j.enpol.2018.07.042.
- Gould, C. F., Schlesinger, S., Toasa, A. O., Thurber, M., Waters, W. F., Graham, J. P., & Jack, D. W. (2018). Government policy, clean fuel access, and persistent fuel stacking in Ecuador. *Energy for sustainable development*, 46, 111-122. DOI: 10.1016/j.esd.2018.05.009.
- INEN. (1998a). NTE INEN 1535:98 Prevención de incendios. Requisitos para el transporte y distribución de cilindros de gas licuado de petróleo (GLP) en vehículos automotores. Instituto ecuatoriano de normalización, 1, [Online]. Available: <https://apps.normalizacion.gob.ec/descarga/>.
- INEN. (1998b). NTE INEN 1536:98 Prevención de incendios. Requisitos de seguridad en plantas de almacenamiento y envasado de gas licuado de petróleo (GLP). Instituto Ecuatoriano de Normalización, 2, [Online]. Available: <https://apps.normalizacion.gob.ec/descarga/>.
- INEN. (2015). NTE INEN 1534:2015 Prevención de incendios. Almacenaje de cilindros para gas licuado de petróleo (GLP). Requisitos. Servicio Ecuatoriano de Normalización, 2, [Online]. Available: <https://apps.normalizacion.gob.ec/descarga/>.
- Ingason, H. T. (2015). Best project management practices in the implementation of an ISO 9001 quality management system. *Procedia-Social and Behavioral Sciences*, 194, 192-200. DOI: 10.1016/j.sbspro.2015.06.133.
- ISO. (2015). ISO 9001:2015-Quality management systems-Requirements. International Organization for Standardization, 1, Available: <https://www.iso.org/obp/ui/#iso:std:iso:9001:ed-5:v1:en>.
- Karl, A. A., Micheluzzi, J., Leite, L. R., & Pereira, C. R. (2018). Supply chain resilience and key performance indicators: a systematic literature review. *Production*, 28, e20180020. DOI: 10.1590/0103-6513.20180020.
- Kaur, M., Singh, K., & Singh, D. (2019). Synergetic success factors of total quality management (TQM) and supply chain management (SCM) A literature review. *International Journal of Quality & Reliability Management*, 36(6), 842-863. DOI: 10.1108/IJQRM-11-2017-0228.

Transforming LPG Cylinder Distribution Through Integrated Management And Compliance Systems: Validation of Operational Outcomes

- Andadari, R. K., Mulder, P., & Rietveld, P. (2014). Energy poverty reduction by fuel switching. Impact evaluation of the LPG conversion program in Indonesia. *Energy Policy*, 66, 436-449. DOI: 10.1016/j.enpol.2013.11.021.
- Lim, W. M., Ciasullo, M. V., Douglas, A., & Kumar, S. (2022). Environmental social governance (ESG) and total quality management (TQM): a multi-study meta-systematic review. *Total quality management & business excellence*, 1-23. DOI: 10.1080/14783363.2022.2048952.
- Liu, X., Zio, E., Borgonovo, E., & Plischke, E. (2024). A Systematic Approach of Global Sensitivity Analysis and Its Application to a Model for the Quantification of Resilience of Interconnected Critical Infrastructures. *Energies*, 17(8), 1823. DOI: 10.3390/en17081823.
- Hugo, M. Á., Gabriel, R. J., Rafael, V. R., & Mario, T. P. (2024). Influence of the use of ground enhancement materials on the reduction of electrical resistivity in grounding systems: a review. *Int. J. Electr. Comput. Eng. Syst*, 36, 1365-1378.
- Murshed, M. (2021). LPG consumption and environmental Kuznets curve hypothesis in South Asia: a time-series ARDL analysis with multiple structural breaks. *Environmental Science and Pollution Research*, 28(7), 8337-8372. DOI: 10.1007/s11356-020-10701-7.
- NFPA. (2023). NFPA 58: Liquefied Petroleum Gas Code. National Fire Protection Association, 1, Available: <https://www.nfpa.org/es/codes-and-standards/nfpa-58-standard-development/58>.
- Ouyang, L., Che, Y., Yan, L., & Park, C. (2022). Multiple perspectives on analyzing risk factors in FMEA. *Computers in Industry*, 141, 103712. DOI: 10.1016/j.compind.2022.103712.
- Petersen, J. A. (2019). National fire protection association standards in fire litigation. *Engineering Standards for Forensic Application*, 155-168. DOI: 10.1016/B978-0-12-813240-1.00011-X.
- Presidencia de la República del Ecuador. (2024). Decreto Ejecutivo No. 255. En Reglamento de Seguridad y Salud en el Trabajo (págs. [Online]. Available: <https://www.lexis.com.ec/noticias/reglamento-de-seguridad-y-salud-en-el-trabajo>). Quito: Ecuador.
- Psomas, E., & Antony, J. (2015). The effectiveness of the ISO 9001 quality management system and its influential critical factors in Greek manufacturing companies. *International Journal of Production Research*, 53(7), 2089-2099.), DOI: 10.1080/00207543.2014.965353.
- Raslavičius, L., Keršys, A., Mockus, S., Keršienė, N., & Starevičius, M. (2014). Liquefied petroleum gas (LPG) as a medium-term option in the transition to sustainable fuels and transport. *Renewable and Sustainable Energy Reviews*, 32, 513-525. DOI: 10.1016/j.rser.2014.01.052.
- Sfreddo, L. S., Vieira, G. B. B., Vidor, G., & Santos, C. H. S. (2021). ISO 9001 based quality management systems and organisational performance: a systematic literature review. *Total Quality Management & Business Excellence*, 32(3-4), 389-409. DOI: 10.1080/14783363.2018.1549939.
- Talha, M. (2004). Total quality management (TQM): an overview. *The bottom line*, 17(1), 15-19. DOI: 10.1108/08880450410519656.
- Troncoso, K., & da Silva, A. S. (2017). LPG fuel subsidies in Latin America and the use of solid fuels to cook. *Energy policy*, 107, 188-196. DOI: 10.1016/j.enpol.2017.04.046.
- Vásconez, D. F. V., Sarria, C. A., Ortega, S. F. C., & Hoyos, J. C. R. (2018). El riesgo en el almacenamiento de GLP en el Ecuador. *INNOVA Research Journal*, 3(1), 19-29. DOI: 10.33890/innova.v3.n1.2018.331.
- Wilson, J. P., & Campbell, L. (2020). ISO 9001: 2015: the evolution and convergence of quality management and knowledge management for competitive advantage. *Total Quality Management & Business Excellence*, 31(7-8), 761-776. DOI: 10.1080/14783363.2018.1445965.
- Wu, Z., Liu, W., & Nie, W. (2021). Literature review and prospect of the development and application of FMEA in manufacturing industry. *The International Journal of Advanced Manufacturing Technology*, 112(5), 1409-1436. DOI: 10.1007/s00170-020-06425-0.
- Zio, E. (2018). The future of risk assessment. *Reliability Engineering & System Safety*, 177, 176-190. DOI: 10.1016/j.res.2018.04.020.

Israel Alejandro Murillo-Calderón

UTE University,
Ecuador.

mcia41359@ute.edu.ec /

israel.murillo1406@gmail.com

ORCID: 0009-0008-3985-152X
