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Digital Transformation for HSEQ and Supply Chain Efficiency in Libyan Industrial Companies: A Mixed Methods Study on the Roles of RFID, IoT and ERP

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Abstract

Objective: *This study examines how RFID, IoT, and ERP enhance Health, Safety, Environment, and Quality (HSEQ) outcomes while simultaneously improving supply chain efficiency (SCE) in Libyan public industrial companies.*

Methods: *An explanatory sequential mixed methods design was used. Quantitative data were collected from 342 employees across four state owned firms (cement, steel, textiles, food). Qualitative data came from semi structured interviews with 12 HSEQ and mechanical engineering managers. Analysis included descriptive statistics, Pearson correlation, multiple regression, mediation analysis (PROCESS Model 4), and thematic analysis.*

Results: *ERP adoption was highest (mean=4.15/5), followed by RFID (3.68) and IoT (3.52). Information quality (mean=3.88) and traceability (3.68) were the strongest HSEQ related efficiency dimensions. The combined IT model explained 69.1% of SCE variance (R^2=0.691). RFID had a significant positive impact on SCE (β=0.187, $p<0.001$) and IoT a weaker but significant impact (β=0.135, p=0.009). Mediation analysis showed that traceability partially mediated the RFID HSEQ compliance relationship (indirect effect=0.24, 95% CI [0.12, 0.36]). Thematic analysis revealed three barriers: unreliable electricity, sensor calibration difficulties, and resistance to digital permits.*

Conclusion: *RFID, IoT, and ERP contribute significantly to both SCE and HSEQ in Libyan industry, with information quality and traceability as the strongest HSEQ linked benefits. A digital HSEQ framework integrating ERP for documentation, RFID for hazardous material tracking, and IoT for environmental monitoring is proposed.*

Keywords: HSEQ, RFID, IoT, ERP, supply chain efficiency, Libyan industry, environmental monitoring, traceability, ISO 45001, ISO 14001.

Introduction

Health, Safety, Environment, and Quality (HSEQ) management is critical in heavy industries to prevent accidents, reduce environmental impact, ensure product quality, and comply with regulations (ISO 45001, 2018; ISO 14001, 2015). In Libya, industrial companies face additional challenges: aging infrastructure, weak digitalization, and a post conflict regulatory environment. Emerging digital technologies such as Radio Frequency Identification (RFID), the Internet of Things (IoT), and Enterprise Resource Planning (ERP) offer new possibilities for real time HSEQ monitoring and supply chain integration.

Although extensive literature exists on ERP and RFID in supply chains (Angeles, 2005; Ben Daya et al., 2019), few studies have explicitly integrated HSEQ as a dependent variable, especially in developing and post conflict settings. Moreover, most previous research relies solely on quantitative surveys without exploring the contextual barriers that hinder technology effectiveness. This study addresses these gaps by: (1) measuring the adoption levels of RFID, IoT, and ERP in Libyan industrial companies; (2) assessing their impact on SCE dimensions directly relevant to HSEQ (information quality, traceability, responsiveness); (3) testing the mediating role of traceability in the RFID HSEQ relationship; and (4) qualitatively investigating implementation barriers.

The study is derived from a larger investigation of IT impact on supply chain efficiency but focuses specifically on how these technologies can enhance HSEQ outcomes. We propose a digital HSEQ framework aligned with ISO 14001 and ISO 45001.

Research Objectives and Hypotheses

Objectives

1. To measure the level of RFID, IoT, and ERP adoption in Libyan industrial companies.
2. To assess the impact of these technologies on supply chain efficiency dimensions relevant to HSEQ (information quality, traceability, responsiveness).
3. To evaluate specific HSEQ benefits: hazardous material tracking, emissions monitoring, safety documentation, and regulatory compliance.
4. To test whether traceability mediates the relationship between RFID and HSEQ compliance.
5. To qualitatively identify barriers to effective implementation.

Hypotheses

- **H1:** RFID has a significant positive effect on supply chain efficiency in Libyan industrial companies.
- **H2:** IoT has a significant positive effect on supply chain efficiency.
- **H3:** ERP has a significant positive effect on supply chain efficiency.
- **H4:** Traceability mediates the relationship between RFID and HSEQ compliance.

Materials and Methods

Study Design

An explanatory sequential mixed methods design (Creswell & Clark, 2017) was employed: quantitative data collection (survey) followed by qualitative data collection (semi structured interviews) to explain and contextualize the quantitative findings.

Quantitative Phase

Population and Sample

The target population comprised 4,200 employees in supply chain related roles (procurement, inventory, distribution, IT, production) across four Libyan public industrial companies:

- Food Libyan Cement Company (Benghazi)
- Libyan Iron and Steel Company (Misrata)
- Libyan Textile Company (Tripoli)
- Libyan Industries Company (Benghazi)

Using Krejcie & Morgan's (1970) table and Yamane's formula (e=0.05), a target sample of 384 was set. Stratified random sampling (proportional allocation by company size) was applied. After data cleaning, 342 valid responses were obtained (response rate 89.1%).

Instrument

A 60 item Likert scale questionnaire (1–5) was developed, covering:

- IT adoption: RFID (5 items), IoT (5 items), ERP (5 items), plus EDI and AI.
- Supply chain efficiency: cost reduction, lead time reduction, information quality, responsiveness, forecast accuracy (5 items each).
- HSEQ operationalization:

Information quality sub dimensions (accuracy, timeliness, transparency) as proxy for safety documentation.

Traceability (RFID based tracking of hazardous materials, assets, waste).
Responsiveness (ability to adapt to safety/environmental changes).
Direct HSEQ compliance (self reported adherence to ISO 45001 and 14001).

Validity and Reliability:

Face and content validity were confirmed by 7 expert judges (inter rater agreement 87.5%). Construct validity was confirmed via Pearson correlation ($r=0.45–0.82$, $p<0.01$). Reliability was excellent: Cronbach's alpha for RFID=0.83, IoT=0.87, ERP=0.88, information quality=0.84, overall=0.94.

Quantitative Data Analysis:

SPSS v26 was used for descriptive statistics, Pearson correlation, multiple linear regression (enter method), and one way ANOVA. Assumptions: normality (Kolmogorov Smirnov $p>0.05$), homoscedasticity, no multicollinearity (VIF<5). Mediation was tested using PROCESS v4.1 Model 4 with 5,000 bootstrap samples. Significance level $\alpha=0.05$.

Qualitative Phase

Participants

Twelve managers were purposively selected (3 per company): 4 HSEQ managers, 4 maintenance engineers, 2 IT managers, and 2 operations managers.

Interview Protocol

- A semi structured guide with 8 open ended questions, e.g.:
- "What are the main challenges you face when using RFID for tracking hazardous materials?"
- "How do power outages affect your IoT sensors?"
- "Describe any resistance to digital safety permits."

Data Analysis

Interviews were audio recorded, transcribed verbatim, and analyzed using thematic analysis (Braun & Clarke, 2006) with NVivo 14. Two researchers independently coded the data; inter coder reliability was 0.86.

Ethical Considerations

The study received institutional approval. All participants gave informed consent. Anonymity and confidentiality were guaranteed.

Results

Quantitative Results

Demographic Profile (n=342)

Characteristic	Category	Percentage
Gender	Male	63.7%
Age	30–40 years	42.4%
Education	Bachelor's degree	62.9%
Experience	5–15 years	65.2%
Firm size	Large (>250 employees)	85.7%
Sector	Iron & steel	47.7%
	Cement	28.7%
	Textiles	12.0%
	Food	11.7%

Adoption Levels of RFID, IoT, and ERP

Technology	Mean (1–5)	SD	Level
ERP	4.15	0.58	Very high
RFID	3.68	0.68	High
IoT	3.52	0.71	High

HSEQ related Supply Chain Efficiency Dimensions

Dimension	Mean	SD	Interpretation
Information Quality (HSEQ docs)	3.88	0.59	Good – safety data accessible
Traceability (RFID)	3.68	0.68	Moderate – hazardous tracking
Responsiveness (HSEQ flexibility)	3.75	0.65	Good – adaptive to regulations
Direct HSEQ compliance (self reported)	3.45	0.77	Moderate

Pearson Correlations (HSEQ relevant)

Pair	r	p
RFID – Information quality	0.68	<0.01
RFID – Traceability	0.72	<0.01
IoT – Responsiveness	0.62	<0.01
ERP – Information quality	0.70	<0.01
RFID – Direct HSEQ compliance	0.55	<0.01

Multiple Regression (IT dimensions → Total SCE)

IT Dimension	Std. Beta	p value	Significant
ERP	0.412	<0.001	Yes
EDI	0.298	<0.001	Yes
RFID	0.187	<0.001	Yes
IoT	0.135	0.009	Yes
AI	0.098	0.059	No

Model: $R^2 = 0.691$, Adj. $R^2 = 0.687$, $F = 150.2$, $p < 0.001$. VIF = 1.8–2.5 (no multicollinearity).

Mediation Analysis (RFID → Traceability → HSEQ compliance)

Using PROCESS Model 4:

- Total effect of RFID on HSEQ compliance: $c = 0.42$ ($p < 0.001$)
- Direct effect (c'): 0.18 ($p = 0.012$)
- Indirect effect via traceability: 0.24 (95% bootstrap CI: 0.12 to 0.36)

Proportion mediated = 0.24 / 0.42 = 57%. This indicates partial mediation: traceability explains more than half of RFID's impact on HSEQ compliance.

ANOVA Results

Factor	F	p	Significant?
Sector (cement, steel, textiles, food)	1.27	0.285	No
Firm size (large vs. medium)	2.01	0.157	No
Employee experience (years)	1.06	0.366	No

Qualitative Results

Thematic analysis revealed three main themes:

Theme 1: Unreliable electricity as the main barrier for IoT

"*We have temperature sensors in the cement kiln area, but power cuts 6 hours a day disconnect the gateway. Data is lost.*" (Maintenance Manager, Cement Co.)

All 12 interviewees mentioned electricity instability. Only two companies had backup generators for critical sensors, but fuel shortages limited their use.

Theme 2: Calibration difficulties in dusty environments

"*RFID tags on chemical drums get covered with dust within days. Readers fail, and we revert to manual barcode scanning.*"

(HSEQ Manager, Steel Co.)
Interviewees reported that passive UHF RFID tags performed poorly in high dust areas. Cleaning protocols were inconsistent, and no on site calibration equipment was available.

Theme 3: Resistance to digital safety permits

"*Senior supervisors prefer paper permits because they are used to signing physically. They see digital permits as a threat to their authority.*" (IT Manager, Food Co.)
Five of the 12 managers reported active resistance from older, experienced workers. Younger employees (under 35) were more accepting. This explains why ERP based safety documentation adoption (mean 3.88) is higher than RFID based traceability (3.68): the former is office based, the latter involves field operations.

Discussion

This study provides empirical evidence that RFID, IoT, and ERP significantly enhance both supply chain efficiency and HSEQ outcomes in Libyan industrial companies, with information quality and traceability as the strongest HSEQ linked benefits. However, the magnitude of impact varies: ERP has the strongest effect (β=0.412), followed by RFID (β=0.187) and IoT (β=0.135). The non significance of AI (p=0.059) reflects the lack of historical data and analytical infrastructure.

The mediation analysis is a novel contribution: it shows that RFID improves HSEQ compliance not directly but through improved traceability of hazardous materials and waste. This aligns with the theoretical logic of the "track and trace" paradigm (Angeles, 2005). Without traceability, RFID tags are merely inventory tools; with traceability, they become safety devices.

The qualitative findings explain the quantitative results: the moderate adoption of RFID (3.68) and IoT (3.52) is not due to lack of interest but to concrete operational barriers (dust, power, resistance). These barriers are rarely discussed in Western centric digital transformation literature but are critical for developing countries.

The uniform impact across sectors and firm sizes (ANOVA p>0.05) suggests that HSEQ benefits from digitalization are universally applicable – a finding that encourages national level digital HSEQ programs. However, the weaker performance in direct HSEQ compliance (3.45) compared to information quality (3.88) indicates that documentation has improved more than actual field safety practices. This is a common "digital illusion" where digitizing paperwork is mistaken for improving safety.

Conclusion

RFID, IoT, and ERP contribute significantly to both supply chain efficiency and HSEQ outcomes in Libyan industrial companies. Information quality and traceability are the strongest HSEQ linked benefits. Traceability partially mediates the RFID HSEQ compliance relationship. AI remains immature in this context. Qualitative barriers (electricity, dust, resistance) must be addressed before full benefits can be realized. A digital HSEQ framework should prioritize ERP for documentation, RFID for hazardous material tracking, and IoT for environmental monitoring, while investing in backup power, protective enclosures for tags, and change management.

Recommendations

For HSEQ Engineers and Managers

1. **RFID Deployment:** Tag all hazardous chemical containers, waste drums, and critical PPE. Install RFID gates at storage exits with industrial grade readers (IP67 rated). Use active RFID for outdoor areas.
2. **IoT Sensors:** Install air quality sensors (PM2.5, CO, SO_2, NO_x) near kilns and stacks, connected to a central dashboard with real time alerts. Use solar powered gateways with battery backup.
3. **ERP Integration:** Ensure all Safety Data Sheets (SDS), risk assessments, environmental permits, and inspection findings are stored and version controlled in ERP modules.
4. **Training:** Train HSEQ staff on using RFID readers, IoT dashboards, and ERP reporting tools. Include change management workshops for older supervisors.

For General Management

- Allocate budget for retrofitting sensors and tags, including backup power and dust proof enclosures.
- Link HSEQ digital KPIs (e.g., % of hazardous items tagged, emissions exceedance frequency, safety incident reporting rate) to departmental performance bonuses.

For Policymakers

- Mandate RFID based tracking for imported hazardous materials (chemicals, waste).
- Subsidize IoT air quality monitoring stations in industrial zones.
- Adopt a national digital HSEQ reporting standard based on ERP data exchange.

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