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Quantitative Risk Assessment of Fire Hazards during Fuel Unloading and Dispensing in Maiduguri Petrol Filling Stations

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ABSTRACT

Petrol filling stations (PFS) present significant fire and explosion hazards, particularly during unloading and dispensing operations. Traditional risk assessment methods often fail to integrate multi-hazard factors dimensions into a single evaluative framework. Effective risk management requires robust tools for prioritising hazards and allocating resources, especially in data-scarce environments. This study applies the Composite Risk Index (CRI) to assess and rank risks associated with unloading and dispensing operations at PFS in Northern Nigeria. A hybrid methodology was employed, combining Hazard identification and risk scoring were conducted through site inspections, staff interviews, and historical data review. A risk score matrix with Analytic Hierarchy Process (AHP) weighting was employed to compute CRI for both unloading and dispensing operations. The analysis revealed that all stations presented a 'medium' risk level during unloading operations (CRI: 0.401-0.630), driven by leakage, containment failure, and ignition hazards. Dispensing operations were predominantly 'low risk' (CRI: 0.321-0.400), with behavioural issues being the main contributors. One station (PFS-E) was ranked the highest risk for both operations, indicating systemic safety failures. The CRI method demonstrates strong potential for supporting regulatory decision-making by simplifying complex risk data into actionable rankings. It enables regulators and operators to implement a tiered, risk-informed oversight strategy, prioritising interventions for the highest risk facilities and most vulnerable operational phases, thereby enhancing the overall safety of the downstream petroleum sector.

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1.0 INTRODUCTION

A petrol filling station (PFS) is a retail facility where automotive fuels, lubricants, and related services are dispensed to consumers (De Sousa, 2015; Mäkkä et al., 2023; Ogunkan et al., 2023). The configuration, storage capacity, and operational characteristics of these facilities vary significantly based on regulatory standards, local energy demand, and safety provisions (Ogunkan et al., 2023; Taylor et al., 2016). In Nigeria, with an estimated population of 233 million (UN-DESA, 2024) and approximately 13 million vehicles (NBS, 2018), the daily consumption of petrol and diesel averaged 55.6 million and 13.5 million litres, respectively, in 2023 (NBS, 2024). To meet this demand, the Nigerian Midstream and Downstream Petroleum Regulatory Authority (NMDPRA) reported the existence of roughly 33,000 PFS facilities nationwide (Asu, 2021). While this extensive network enhances fuel accessibility, its rapid expansion has often outpaced regulatory oversight, resulting in substandard siting and operational practices that exacerbate safety risks (Mäkkä et al., 2023; Mshelia et al., 2015; Periyasamy et al., 2017).

The hazards inherent to PFS operations arise from both their physical siting and operational processes, particularly during fuel unloading from tankers and dispensing to customers (Khalid et al., 2015; Ma & Huang, 2019). Historical incidents underscore the catastrophic potential of these risks. The 2015 Accra fuel station explosion in Ghana, which resulted in over 150 fatalities, was initiated by a fuel spill and flood-driven dispersion towards multiple ignition sources (Darko, 2015; Monney et al., 2015; Obeng-Odoom, 2018). Similarly, an analysis of 41 PFS accidents in South Korea between 1992 and 2003 found that 61% involved fire or explosion (Park et al., 2006). More recent tragedies include a 2016 service station explosion in Haiti that killed at least seven people during tanker unloading (HaitiLibre, 2016; Hawkins, 2016) and a 2018 liquefied petroleum gas tanker explosion in Nigeria that caused at least 35 fatalities and hundreds of injuries (Al-Jazeera, 2018; Eboh, 2018). Consequently, the effective evaluation of fire and explosion hazards is critical for implementing targeted safety measures and minimizing accident occurrence (Ahrens, 2020).

Various approaches have been employed to assess PFS risks. Computationally intensive methods, such as Computational Fluid Dynamics (CFD) for modelling vapour dispersion and explosions (Dadashzadeh et al., 2013; Juwari et al., 2023), require precise data often unavailable

in developing regions. Bayesian Networks provide dynamic risk analysis but depend heavily on subjective probabilities due to sparse incident data (Khakzad et al., 2013; Zarei et al., 2019). Other studies, such as those by Zolfaghari et al. (2024) in Iran and Kuburi et al. (2023) in Nigeria, have utilized semi-quantitative and checklist-based methods. Recent work by Qonono (2024) in South Africa applied a mixed-method approach, while Li et al. (2024) in China combined Preliminary Hazard Analysis with Fault Tree Analysis. A persistent limitation across these studies pertains to a need for a transparent mechanism for prioritizing risks based on their relative importance (Marhavilas et al., 2019; Ramachandran & Charters, 2011).

To address these gaps, the Analytic Hierarchy Process (AHP) has been increasingly integrated into risk assessment frameworks. AHP uses structured pairwise comparisons to derive consistent, weighted criteria, reducing arbitrariness in risk prioritization (Saaty, 2003). For instance, Labib et al. (2023) used AHP to determine vulnerability weights for petrol stations in Odessa, guiding regulatory decision-making. Similarly, Marhavilas et al. (2019, 2022) demonstrated the hybridisation of AHP with HAZOP and decision-matrix risk assessment to prioritize occupational hazards in process industries. Building on these developments, this study applies a quantitative risk assessment framework, using a Risk Score Matrix with AHP weighting, to evaluate fire and explosion hazards at PFS facilities in Maiduguri, Nigeria. This integrated approach provides a structured, transparent, and defensible basis for hazard prioritization, particularly in data-scarce contexts, and aims to inform both operational safety improvements and regulatory interventions.

2. Methods

QRA is a conventional methodology globally applied for the risk assessment of potential hazards under different scenarios (Ramachandran & Charters, 2011). The method employs a systematic approach to quantitatively assess risks through hazard identification, risk evaluation, and mitigation strategies, ensuring compliance with safety standards and promoting operational safety (Mandal & Agarwal, 2024). The risk assessment study was conducted across five operational PFS facilities, confidentially tagged PFS -A, PFS-B, PFS-C, PFS-D, PFS-E, within Maiduguri metropolis in Borno state, Nigeria based on their traffic volume, urban location, and operational history. The stations were representative of common operational PFS

conditions, including facilities and associated safety infrastructure. The analysis focused primarily on fire and explosion hazards during two distinctive PFS operations: fuel unloading from tankers into underground storage tanks, and retail dispensing into customer vehicles and containers. The assessment entails hazard identification, data collection risk and risk assessment.

2.1 Hazard Identification (HAZID)

The HAZID process applied a multi-source hazard recognition framework to systematically recognise, and document fire and explosion hazards associated with fuel unloading and dispensing operations at the selected PFS. The process combined systematic on-site inspections, structured staff interviews, and examination of available historical accident and near-miss records. Incident logs were reviewed in detail to identify recurring or high-consequence hazards (Crawley, 2020; Hyatt, 2018), while compliance was verified against DPR safety requirements, including equipment standards, operational procedures, and hazardous area classification (DPR, 2007). The approach follows ISO 31000:2018 and ISO 31010:2019 guidelines for structured hazard identification and risk management (Farkas et al., 2020; Hutchins, 2018; Makajić-Nikolić, 2023), and the DPR, now Nigerian Midstream and Downstream Petroleum Regulatory Authority (NMDPRA) regulatory requirements (DPR, 2007).

2.2 Data Collection

Primary data collection was undertaken over a continuous ninety (90) day observation period, covering the daylight operational cycle of each

participating PFS. Field observations were systematically recorded by trained data collection assistants, focusing on deviations from safe operating procedures, hazardous behaviours, and unsafe conditions (Crawley, 2020). These observations were supplemented by interviews with station managers and fuel attendants to capture operational insights and undocumented hazard occurrences. Historical incident and near-miss records were retrieved from available station archives and from official DPR reports and Borno state emergency management agency data. All identified hazards were classified by type, description, and documented in a tabular format that included potential consequences and observed frequency. This structured hazard inventory served as the foundation for subsequent quantitative risk analysis.

2.3 Risk Assessment

The procedure followed to compute the risk score matrix and composite risk index, derived using AHP pairwise weighting, is presented.

2.3.1 Risk score matrix calculation

The dimensionless numerical risk score (RS) was calculated for each hazard using the 5 x 5 matrix approach and the hazard frequency ratings in Table 1 and Table 2 (Bao et al., 2022; ISO, 2019). Each hazard was first assigned a Severity (S) value based on the most credible worst-case consequence in the operational context, using descriptors in Table 2. This rating considered human safety impacts, potential for asset/property damage, and fire or explosion propagation (Brzezińska & Bryant, 2021), consistent with DPR requirements for motor fuel dispensing facilities (DPR, 2007).

Table 1: Hazard frequency rating

Rating	Likelihood	Frequency	Description
1	Rare	$\leq 10^{-4}$ per activity	Extremely unlikely within the reference timeframe
2	Unlikely	$> 10^{-4}$ up to 10^{-3}	Low probability of occurrence but plausible
3	Possible	$> 10^{-3}$ up to 10^{-2}	Occasional occurrence during normal operations
4	Likely	$> 10^{-2}$ up to 10^{-1}	Expected to occur with moderate frequency
5	Very likely	$\geq 10^{-1}$	High frequency: the event is expected in most operational cycles

Source: (Bao et al., 2022)

Table 2: Hazard severity rating

Rating	Severity	Description
1	Insignificant	No injury or damage-negligible consequence.
2	Minor	First-aid-level injury or minor property damage, easily remedied.
3	Moderate	Medical treatment injury, localised damage, or service disruption.
4	Harmful (Major)	Serious injury or a single fatality, major asset damage, or temporary facility loss.
5	Extremely harmful (Catastrophic)	Imminent danger exists; multiple fatalities, extensive property loss, long-term shutdown, or major environmental harm.

Likelihood (L) values, using Table 1 and calculated frequency using Equation 1, were determined for each station from site-specific field observations and historical occurrence data, reflecting the estimated probability of the hazard

$$\text{Frequency} = \frac{\text{Incident}}{\text{Total observed activity}} \quad 1$$

$$RS_h = S \times L \quad 2$$

2.3.2 AHP pairwise weight derivation

The precomputed risk scores, RS_h for each hazard are used for further computations. The total risk per hazard is totalled across all PFS using Equation 3 and the sum of all the hazards

$$\text{Total risk per hazard} = \sum_{PFS-A}^{PFS-E} RS_h \quad 3$$

$$\text{Sum of all the hazard risks} = \sum \text{Total risk per hazard} \quad 4$$

$$\text{Normalised score} = \frac{\text{total risk per hazard}}{\text{sum of all the hazard risks}} \quad 5$$

To account for the relative impact of each hazard, an AHP pairwise comparison matrix is constructed. Each matrix entry A_{ij} represents the importance of hazard i relative to hazard j , using Saaty's 1–9 scale where 1 denotes equal importance and 9 denotes extreme importance of one hazard over another (Leal, 2020; Saaty, 2003). The sum of each column was calculated, and each element in that column was normalised

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad 6$$

$$CR = \frac{CI}{RI} \quad 7$$

where n is the number of hazards and RI is the Random Index for the given number of hazards given as (Saaty, 2003):

$$RI = 1.45 \quad \text{for } n = 9 \quad 8$$

$$RI = 1.45 \quad \text{for } n = 9 \quad 9$$

A CR value less than 0.10 was deemed acceptable in accordance with Saaty's consistency criterion (Saaty, 2003).

2.3.3 Composite risk index calculation

The Composite Risk Index (CRI) for each station was calculated by combining the station-specific

$$cRS_h = W_h \times RS_h \quad 10$$

The CRI for a station was obtained by summing these weighted risk contributions across all

materialising within a defined operational period. For each station and hazard pair, the dimensionless numerical RS was then computed as the product (Bao et al., 2022; Brzezińska & Bryant, 2020; ISO, 2019) from Equation 2.

risk is calculated from Equation 4. A normalised score for each total risk per hazard is calculated from Equation 5 (Leal, 2020; Li et al., 2013; Saaty, 2003):

by dividing it by the column sum. The resulting normalised matrix entries were then averaged across each row to produce the priority weight vector (Wh_i), which represents the relative weight assigned to each hazard. Consistency of the judgements was tested by calculating the maximum eigenvalue λ_{max} (Leal, 2020; Saaty, 2003). The Consistency Index (CI) and Consistency Ratio were calculated from:

risk scores, from section 2.3.1 with the hazard weights obtained from section 2.3.2. For each hazard at a station, the contribution to the CRI was computed from:

hazards. This aggregation method ensures that the CRI reflects both the inherent risk of each

hazard and its relative importance in the operational context. The CRI values were then ranked and categorised into qualitative bands. The CRI bands classify risks as low (<0.4), medium ($0.4-0.6$), or high (>0.6) based on threshold values consistent with organisational risk acceptance criteria and process safety management principles (Khan & Samadder, 2015; Leal, 2020; Li et al., 2013).

3. Results and discussions

3.1 hazard observations

All PFS have cement concrete surfaces and a covered designated dispensing forecourt for petrol. The all have uncovered areas for diesel dispensing, as well as a separate fuel unloading area. PFS-A has thirteen petrol dispensing nozzles, PFS-B has eight nozzles, PFS-C has twelve nozzles, while PFS-D and PFS-E have four nozzles each. PFS-C has two diesel dispensing nozzles while all the rest have one diesel dispensing nozzle each. The diesel dispensers are typically positioned near the roadside shoulder to facilitate access for trucks and large vehicles. The HAZID process identified hazards, along with their potential consequences and field observations, that were

systematically documented. Nine distinct fire and explosion hazards were identified during fuel unloading operations as shown in Table 3, and nine hazards were also identified during fuel dispensing operations (as shown in Table 4). The data presented in Table 3 provides detailed observations of hazards and activities during fuel unloading operations across five petrol filling stations (PFS-A to PFS-E). The total observed activities for each site indicate varying operational frequencies, with PFS-A having the highest recorded number of unloading activities (16) and PFS-E the lowest (8). Severity for each hazard was determined using information in the 'Potential Consequences' column with Table 2. Each hazard likelihood for each PFS was calculated from the observation and incident data with Equation 1 and Table 1. The data presented in Table 4 outlines observed hazards and activities during fuel dispensing operations at the five petrol filling stations (PFS-A to PFS-E). Total dispensing activity counts range from 3,870 in PFS-E to 11,843 in PFS-A, highlighting differing throughput levels which have a bearing on the cumulative risk exposure.

Table 3: Fuel unloading activity and fire and explosion hazards observations

Hazard Type	Hazard Description	Potential Consequences	Total observed activity				
			PFS-A	PFS-B	PFS-C	PFS-D	PFS-E
			16	12	12	10	8
Incidents							
Fuel spillage (transfer overflow / hose rupture)	Overflow, hose/coupling failure or valve failure during tanker-to-tank transfer	Fuel spills, flammable vapour clouds and pool fires with mass-casualty and major property/environmental impacts.	-	-	-	-	1
Leaking hoses or valves (minor chronic leaks)	Worn or poorly maintained hoses, fittings or valves causing continuous/drip leakage	Fuel leak elevate vapour concentrations and produce serious fires and injuries on ignited.	10	5	9	9	8
Ignition sources (during unloading)	Running engines, welding, smoking, mobile phone use, faulty wiring, hot surfaces	Instantaneous ignition of fuel in vapour-rich zones can convert releases into large fires/explosions.	1	1	1	2	2
Human error / untrained personnel	Failure to follow standard operating procedures, mis-valving, wrong sequencing during transfer	Operational errors leading to spills and fire escalation.	-	-	-	-	1
Absence of bonding & grounding	No bonding/grounding between tanker and tank during transfer	Electrostatic discharge leading to ignition can trigger fires and explosions.	-	-	1	1	1
Incompatible equipment / wrong materials	Use of hoses/fittings incompatible with fuel type or pressure rating	Failure under pressure causes sudden and large releases of fuel.	-	-	-	-	1
Adverse weather (lightning, heat, wind, rain)	Lightning strike, high ambient temperature (high vapour pressure), strong winds dispersing vapour	Increased static buildup, high vapour generation, high temperatures elevate fire/ explosion risk.	1	1	-	-	-
Inadequate spill containment	No bunds, no absorbents, blocked drains, absent spill kits	Uncontrolled spread of fuel, fire escalation.	5	6	9	10	8
Poor housekeeping & emergency equipment maintenance	Expired/absent extinguishers, oil-contaminated surfaces, blocked drains	Increases ignition likelihood and reduces initial response effectiveness.	1	1	1	1	1

Table 4: Fuel dispensing activity and fire and explosion hazards observations

Hazard type	Hazard description	Potential consequences	Total activity				
			PFS-A	PFS-B	PFS-C	PFS-D	PFS-E
			11843	8811	10035	5281	3870
Observations							
Fuel spillage into vehicles during dispensing	Overfilling, nozzle misplacement, distraction causing product release	Uncontrolled spills, pool fire, flash fire, vapour inhalation, ground contamination	19	25	30	18	10
Use of mobile phones near pump	Electromagnetic emissions or accidental spark near vapour zone	Potential ignition of vapour cloud	1020	819	522	453	209
Children or unattended minors	Minors as customers or handling dispensed fuel containers	Spillage, accidental ignition, burns, injury	1111	214	1978	213	1212
Untrained attendants	Lack of knowledge in incident control and safety rule enforcement	Poor emergency response, escalation of incident severity	1	1	1	1	3
Inadequate fire extinguishers or safety equipment	Missing, empty, or non-functional extinguishers; compacted sand in sand bucket	Inability to suppress small fires before escalation	60	40	70	90	90
Fuel dispensed into inappropriate containers	Filling unapproved plastic jerry cans or unvented containers	Static buildup, uncontrolled spill, vapour leakage, potential ignition	2413	1544	1462	1831	2143
Congestion in dispensing forecourt	High vehicle density blocking exits and movement	Static buildup, delayed evacuation with property impact	40	32	10	11	5
Idling vehicles close to dispenser	Heat from engine, static charge from movement	Vapour ignition, localised fire outbreak	201	100	83	101	322
Faulty or leaking dispenser pump	Malfunctioning pump producing noise, vibration, overheating	Vapour release and ignition, potential pump fire	-	-	-	-	3

3.2 Risk Assessment

3.2.1 Risk score matrix

Table 5 presents the risk score matrix for fuel unloading operations across the five PFS. The scores highlight critical safety concerns associated with fuel unloading operations at PFSs. The data show that two systemic weaknesses dominate the hazard profile: persistent liquid leaks from hoses and valves, and the failure of spill containment systems. Both hazards were observed across all sites and consistently assigned maximum likelihood ratings, which, when combined with severity

scores of 4, produce uniformly high risk scores of 20.

The second major safety issue is the presence of ignition sources during unloading. Although ignition was recorded less frequently than leaks and containment failures, its severity rating of 5 ensures that even modest likelihood scores translate into high risk values of 20 at some sites. Inadequate bonding and grounding, recorded at three sites, further compound ignition risks by increasing the probability of electrostatic discharge. These practices are explicitly addressed in DPR regulations, which require grounding during tanker unloading (DPR, 2007).

Table 5: Fuel unloading risk score matrix

Hazard	Severity (S)	Likelihood (L)					Risk Score (S x L)				
		PFS-A	PFS-B	PFS-C	PFS-D	PFS-E	PFS-A	PFS-B	PFS-C	PFS-D	PFS-E
Fuel spillage (transfer overflow / hose rupture)	5	1	1	1	1	3	5	5	5	5	15
Leaking hoses or valves (minor leaks)	4	5	5	5	5	5	20	20	20	20	20
Ignition sources (during unloading)	5	3	3	3	4	4	15	15	15	20	20
Human error / untrained personnel	4	1	1	1	1	3	4	4	4	4	12
Absence of bonding & grounding	5	1	1	3	3	3	5	5	15	15	15
Incompatible equipment / wrong materials	4	1	1	1	1	3	4	4	4	4	12
Adverse weather (lightning, heat, wind, rain)	4	3	3	1	1	1	12	12	4	4	4
Inadequate spill containment	4	5	5	5	5	5	20	20	20	20	20
Poor housekeeping & emergency equipment maintenance	3	3	3	3	3	3	9	9	9	9	9

The risk matrix also highlights infrequent but severe hazards such as hose ruptures and overflows, which were observed at one site and assigned severity 5, producing elevated risk scores relative to peer locations. Human error, though less frequently recorded, was assigned severity 4 and generated a non-negligible risk score of 12 at one station, indicating that procedural non-compliance or poor training remains a credible pathway for escalation when coupled with leaks and ignition sources. Comparative analysis across the five sites shows that higher observation counts do not always correlate with higher risk; rather, sites with fewer observations but elevated likelihood ratings for

high severity hazards exhibit greater risk potential.

The risk score matrix for fuel dispensing operations is presented in Table 6. The data indicates that risk on the forecourt is dominated far more by behavioural non-compliance and weak administrative controls than by equipment failure. The most critical hazard is dispensing into inappropriate containers, which is rated with high severity and recorded likelihoods that produce the highest overall risk scores at two PFSs. The widespread use of mobile phones near dispensers further reflects systemic lapses in behavioural control, with the risk matrix

consistently assigning medium-to-high scores across all stations.
Table 6: Fuel dispensing risk score matrix

Hazard	Severity (S)	Likelihood (L)					Risk Score (S x L)				
		PFS-A	PFS-B	PFS-C	PFS-D	PFS-E	PFS-A	PFS-B	PFS-C	PFS-D	PFS-E
Fuel spillage during dispensing into vehicle	5	1	1	1	1	1	5	5	5	5	5
Use of mobile phones near pump	4	3	3	3	3	3	12	12	12	12	12
Children or unattended minors	3	3	2	4	2	5	9	6	12	6	15
Untrained attendants	4	1	1	1	1	1	4	4	4	4	4
Inadequate fire extinguishers or safety equipment	4	1	1	1	2	2	4	4	4	8	8
Fuel dispensed into inappropriate containers	4	4	4	3	5	5	16	16	15	20	20
Congestion in dispensing forecourt	3	1	1	1	1	1	3	3	3	3	3
Idling vehicles close to dispenser	4	2	2	1	2	3	8	8	4	8	8
Faulty or leaking dispenser pump	5	1	1	1	1	1	5	5	5	5	5

Similarly, the recurrent presence of children and unattended minors at dispensing areas represents a serious vulnerability, with elevated likelihood ratings at two sites and one station recording an especially high risk score. Another prominent behavioural issue is the idling of vehicles near dispensers, which was observed at four of the five sites and classified within the medium risk range. Two stations exhibited very high observation counts for absent or non-functional extinguishers and compacted sand buckets, with the risk matrix reflecting doubled risk scores at these locations compared to peers.

3.2.2 Composite risk index (CRI)

The computation of Saaty's 1–9 scale, the AHP weight matrix and the computed CRI are shown fuel unloading in Table 7, Table 8 and Table 9 respectively. The corresponding data for fuel dispensing is presented in Table 10, Table 11 and Table 12 respectively. The Composite Risk Index for unloading operations (UCRI) revealed that all five stations resided within the 'medium risk' band (0.4 – 0.6), though with significant variation in scores (0.401 – 0.630). This aligns with Dadashzadeh et al., (2013) that fuel unloading is a systemic vulnerability in the studied context, with potential for catastrophic BLEVEs (Boiling Liquid Expanding Vapor

Explosions) and large pool fires. The aggregation of risk scores pinpointed the dominant contributors to this risk profile: chronic leaks from hoses/valves and inadequate spill containment, both consistently scoring the maximum risk value of 20 across all sites. This finding aligns with global incident analyses, such as those by Park et al. (2006), which identified equipment failure and loss of containment as primary precursors to PFS accidents.

The ranking order, however, provides the necessary differentiation for targeted intervention. PFS-E's markedly high UCRI (0.630) stems from a confluence of high severity, high-likelihood failures, including transfer overflows, human error, and absent bonding/grounding. This profile is characteristic of a facility with profound systemic deficiencies in technical integrity, procedural control, and operator competence, a combination which is known to significantly elevate the probability of a major incident (Khan & Samadder, 2015). In contrast, the lower UCRI of PFS-C (0.401), while still in the medium band, suggests a comparatively more robust control environment, particularly regarding static electricity management.

Table 7: Saaty's 1–9 scale for unloading operation hazards

	Fuel spillage (transfer overflow / hose rupture)	Leaking hoses or valves (minor leaks)	Ignition sources (during unloading)	Human error / untrained personnel	Absence of bonding & grounding	Incompatible equipment / wrong materials	Adverse weather (lightning, heat, wind, rain)	Inadequate spill containment	Poor housekeeping & emergency equipment maintenance
Fuel spillage (transfer overflow / hose rupture)	1	3	2	1	2	1	1	3	1
Leaking hoses or valves (minor leaks)	0.33	1	1	0.33	0.5	0.33	0.33	1	0.5
Ignition sources (during unloading)	0.5	1	1	0.33	1	0.33	0.5	1	0.5
Human error / untrained personnel	1	3	3	1	2	1	1	4	2
Absence of bonding & grounding	0.5	2	1	0.5	1	0.5	1	2	1
Incompatible equipment / wrong materials	1	3	3	1	2	1	1	4	2
Adverse weather (lightning, heat, wind, rain)	1	3	2	1	1	1	1	3	1
Inadequate spill containment	0.33	1	1	0.25	0.5	0.25	0.33	1	0.5
Poor housekeeping & emergency equipment maintenance	1	2	2	0.5	1	0.5	1	2	1
Column Sum →	6.66	19	16	5.91	11	5.91	7.16	21	9.5
λ_{\max}	9.114888708								
CI	0.014361089								
CR	0.009904199	RI (n=5)	= 1.45						

Table 8: AHP weight matrix for unloading operation hazards

Aij Normalised Matrix									Weights (whi)
0.15015015	0.157894737	0.125	0.169204738	0.181818182	0.169204738	0.139664804	0.142857143	0.105263158	0.149006405
0.04954955	0.052631579	0.0625	0.055837563	0.045454545	0.055837563	0.046089385	0.047619048	0.052631579	0.052016757
0.075075075	0.052631579	0.0625	0.055837563	0.090909091	0.055837563	0.069832402	0.047619048	0.052631579	0.062541545
0.15015015	0.157894737	0.1875	0.169204738	0.181818182	0.169204738	0.139664804	0.19047619	0.210526316	0.172937762
0.075075075	0.105263158	0.0625	0.084602369	0.090909091	0.084602369	0.139664804	0.095238095	0.105263158	0.093679791
0.15015015	0.157894737	0.1875	0.169204738	0.181818182	0.169204738	0.139664804	0.19047619	0.210526316	0.172937762
0.15015015	0.157894737	0.125	0.169204738	0.090909091	0.169204738	0.139664804	0.142857143	0.105263158	0.138905395
0.04954955	0.052631579	0.0625	0.042301184	0.045454545	0.042301184	0.046089385	0.047619048	0.052631579	0.049008673
0.15015015	0.105263158	0.125	0.084602369	0.090909091	0.084602369	0.139664804	0.095238095	0.105263158	0.10896591

Table 9: CRI for unloading operation for PFS's

	Fuel spillage (transfer overflow / hose rupture) Normalised	Leaking hoses or valves (minor leaks) Normalised	Ignition sources (during unloading) Normalised	Human error / untrained personnel Normalised	Absence of bonding & grounding Normalised	Incompatible equipment / wrong materials Normalised	Adverse weather (lightning, heat, wind, rain) Normalised	Inadequate spill containment Normalised	Poor housekeeping & emergency equipment maintenance Normalised	CRI	Rank	Category
PFS-A	0.25	1	0.75	0.2	0.25	0.2	0.6	1	0.45	0.41016	3	Medium
PFS-B	0.25	1	0.75	0.2	0.25	0.2	0.6	1	0.45	0.41016	3	Medium
PFS-C	0.25	1	0.75	0.2	0.75	0.2	0.2	1	0.45	0.40143	5	Medium
PFS-D	0.25	1	1	0.2	0.75	0.2	0.2	1	0.45	0.41707	2	Medium
PFS-E	0.75	1	1	0.6	0.75	0.6	0.2	1	0.45	0.62992	1	Medium

Table 10: Saaty's 1–9 scale for dispensing operation hazards

	Fuel spillage during dispensing into vehicle	Use of mobile phones near pump	Children or unattended minors	Untrained attendants	Inadequate fire extinguishers or safety equipment	Fuel dispensed into inappropriate containers	Congestion in dispensing forecourt	Idling vehicles close to dispenser	Faulty or leaking dispenser pump
Fuel spillage during dispensing into vehicle	1	2	2	1	1	3	0.5	2	1
Use of mobile phones near pump	0.5	1	1	0.33	0.5	1	0.25	1	0.5
Children or unattended minors	0.5	1	1	0.5	0.33	2	0.33	0.5	0.5
Untrained attendants	1	3	2	1	1	4	1	2	1
Inadequate fire extinguishers or safety equipment	1	2	3	1	1	3	0.5	1	1
Fuel dispensed into inappropriate containers	0.33	1	0.5	0.25	0.33	1	0.16	0.5	0.33
Congestion in dispensing forecourt	2	4	3	1	2	6	1	3	2
Idling vehicles close to dispenser	0.5	1	2	0.5	1	2	0.33	1	0.5
Faulty or leaking dispenser pump	1	2	2	1	1	3	0.5	2	1
Column Sum →	7.83	17	16.5	6.58	8.16	25	4.57	13	7.83
λ_{\max}	9.146521721								
CI	0.018315215								
CR	0.012631183	RI (n=5)	= 1.45						

Table 11: AHP weight matrix for dispensing operation hazards

Aij Normalised Matrix								Weights (whi)	
0.127713921	0.117647059	0.121212121	0.151975684	0.12254902	0.12	0.10940919	0.153846154	0.127713921	0.128007452
0.06385696	0.058823529	0.060606061	0.050151976	0.06127451	0.04	0.054704595	0.076923077	0.06385696	0.058910852
0.06385696	0.058823529	0.060606061	0.075987842	0.040441176	0.08	0.072210066	0.038461538	0.06385696	0.061582681
0.127713921	0.176470588	0.121212121	0.151975684	0.12254902	0.16	0.218818381	0.153846154	0.127713921	0.151144421
0.127713921	0.117647059	0.181818182	0.151975684	0.12254902	0.12	0.10940919	0.076923077	0.127713921	0.12619445
0.042145594	0.058823529	0.03030303	0.037993921	0.040441176	0.04	0.035010941	0.038461538	0.042145594	0.040591703
0.255427842	0.235294118	0.181818182	0.151975684	0.245098039	0.24	0.218818381	0.230769231	0.255427842	0.223847702
0.06385696	0.058823529	0.121212121	0.075987842	0.12254902	0.08	0.072210066	0.076923077	0.06385696	0.081713286
0.127713921	0.117647059	0.121212121	0.151975684	0.12254902	0.12	0.10940919	0.153846154	0.127713921	0.128007452

Table 12: CRI for dispensing operation for PFS's

	Fuel spillage during dispensing into vehicle	Use of mobile phones near pump	Children or unattended minors	Untrained attendants	Inadequate fire extinguishers or safety equipment	Fuel dispensed into inappropriate containers	Congestion in dispensing forecourt	Idling vehicles close to dispenser	Faulty or leaking dispenser pump	CRI	Rank	Category
PFS-A	0.25	0.6	0.45	0.2	0.2	0.8	0.15	0.4	0.25	0.355959827	3	Low
PFS-B	0.25	0.6	0.3	0.2	0.2	0.8	0.15	0.4	0.25	0.346578595	4	Low
PFS-C	0.25	0.6	0.6	0.2	0.2	0.6	0.15	0.2	0.25	0.320951771	5	Low
PFS-D	0.25	0.6	0.3	0.2	0.4	1	0.15	0.4	0.25	0.399902105	2	Low
PFS-E	0.25	0.6	0.75	0.2	0.4	1	0.15	0.6	0.25	0.437847535	1	Medium

This does not imply acceptability but rather demonstrates that the CRI effectively discriminates between facilities facing a pervasive high risk environment and those where risk is managed to a marginally better, though still insufficient, standard (Khan & Samadder, 2015; Labib et al., 2023).

In stark contrast to unloading, the dispensing operation CRI (DCRI) values were primarily categorised as 'low risk' (<0.4), with only PFS-E (0.438) escalating to the 'medium' band. This divergence underscores a fundamental shift in the nature of the risk: from high-consequence, lower-frequency engineering and procedural failures during unloading to high frequency, lower-consequence behavioural and administrative failures during dispensing. The results indicate that forecourt risk is overwhelmingly driven by customer and attendant behaviours rather than catastrophic equipment failure. The hazards of "fuel dispensed into inappropriate containers" and "use of mobile phones near pumps" emerged as the most significant contributors to the DCRI, a finding that corroborates behavioural studies in safety literature where procedural violations are a persistent challenge (De Mattos et al, 2024). The outlier status of PFS-E is again telling; its elevation into the medium risk band was driven by compounded failures, including a high prevalence of unattended minors and idling vehicles.

The integration of UCRI and DCRI values generates a powerful, consolidated risk profile for each station, moving beyond a siloed view of operations to a broad safety posture. This dual-axis analysis is a key contribution of this study, providing a model for efficient resource allocation by regulators and site managers. For regulators, the CRI functions as a transparent, evidence-based tool for tiered compliance monitoring: PFS-E (UCRI: 0.630, DCRI: 0.438) is identified as the highest-priority site, warranting immediate enhanced oversight, conditional licensing, and mandated corrective action plans addressing both operational domains. PFS-A and PFS-B (UCRI: ~0.410, DCRI: ~0.350) present a clear case for focusing regulatory inspections specifically on unloading operations, verifying the adequacy of

spill containment, bonding, and grounding systems, as their dispensing risks are comparatively controlled. PFS-C (UCRI: 0.401, DCRI: 0.321), as the best performer, could be subject to a less frequent, verification-based audit regime, freeing regulatory resources to focus on higher-risk facilities. This targeted approach aligns with the core principles of risk-informed regulation and performance-based standards outlined in ISO 31000, ensuring that oversight intensity is directly proportional to demonstrated risk (ISO, 2018).

5. CONCLUSION

This study successfully employed a combined Risk Score Matrix, the Analytic Hierarchy Process (AHP) and Composite Risk Index (CRI) model to quantitatively assess and rank fire and explosion risks in petrol filling stations. The key finding uncovered fuel unloading presented a universally higher risk (CRI range: 0.401 - 0.630) than dispensing operations, which were generally lower risk (CRI: 0.321 - 0.438). Importantly, the analysis identified PFS-E as the highest-risk facility, with a CRI of 0.630 for unloading, a significant 57% higher than the best-performing station, and the only site with a medium-risk classification for dispensing (CRI: 0.438). This indicates profound systemic deficiencies. The primary practical implication is the provision of a transparent, evidence-based tool for regulators and operators to move from a one-size-fits-all compliance approach to a targeted, risk-informed oversight strategy that prioritises interventions based on the specific and relative vulnerabilities of each facility. It is recommended that regulatory bodies, such as the NMDPRA, adopt such a ranking system to optimise inspection schedules and licensing conditions.

6. RECOMMENDATION

- a. Research on sensitivity studies of the matrix weights will validate the robustness of rankings to changes.
- b. Future research should focus on longitudinal studies to validate the CRI's predictive capability for incident rates and expand its application to a larger, national sample of stations to identify broader regional risk trends.

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