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From Reactive to Proactive Resilience: A Lessons-Learned Framework for Latin American Oil Refineries

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Abstract*– This paper analyzes the development of organizational resilience in a major Latin American oil refinery, documenting its transition from reactive to proactive resilience strategies over a ten-year period (2014–2025). Employing a qualitative case study that includes semi-structured interviews with five senior managers and comprehensive document analysis, we identify critical disruptions incurring costs of up to US$8 million daily and establish an empirically grounded methodology for fostering proactive resilience. Our findings indicate that systematic capture and integration of lessons learned enabled an 86% reduction in recovery time between two comparable electrical substation failures (from approximately 168 hours in August 2024 to 24 hours in March 2025), yielding an estimated return on investment exceeding 85:1 under conservative assumptions. The research extends resilience theory by demonstrating how refineries operating within larger corporate structures in emerging economies can leverage organizational learning as a dynamic capability. The proposed six-stage framework provides practical guidance for practitioners seeking to enhance operational continuity in volatile environments, while contributing empirical evidence from a context underrepresented in current literature.

***Keywords*- Organizational resilience, oil refineries, lessons learned, emerging economies, proactive strategy**

I. Introduction

On August 16, 2024, a major Colombian oil refinery experienced a catastrophic electrical substation failure that triggered a complete shutdown of all 35 processing units, resulting in daily losses of US$8 million. Despite the severity of this incident, the refinery's Business Continuity Plan enabled 97% compliance with Jet A1 fuel deliveries, although emergency imports of 100,000 barrels were required to meet demand. This incident—and a subsequent electrical failure on February 14, 2025—underscored both the vulnerability of critical energy infrastructure in Latin America and the potential of systematic resilience-building efforts.

Latin American refineries face unique operational challenges. These aging facilities must process increasingly complex crude oils—typically heavier, high-sulfur varieties requiring sophisticated treatment processes—while meeting stringent environmental standards and responding to volatile market conditions [1]. Although the refining industry accounts for 17% of Colombia's gross industrial production, it exhibits significant resilience deficiencies that threaten both energy security and economic stability. The 2014–2016 oil price collapse, which saw prices fall from US$100 to US$26 per barrel, eliminated refining margins for extended periods and tested the adaptive capacity of regional facilities [2].

Organizational resilience—defined as the capacity to anticipate, respond to, and learn from disruptions [3]—has gained increasing prominence in the oil and gas sector following catastrophic events such as the Deepwater Horizon disaster and the COVID-19 pandemic [4]. However, existing resilience frameworks predominantly reflect conditions in industrialized economies characterized by abundant resources and stable institutional environments [5]. Latin American refineries face distinct challenges, including infrastructural constraints, political instability, currency fluctuations, and limited access to advanced technologies, which necessitate tailored resilience strategies [2].

Recent literature reveals a critical gap: although resilience strategies have been identified in the oil and gas sector [4], only 3–5% of publications incorporate proactive methodologies that simultaneously integrate risk management, operational resilience, and organizational learning [6], [7]. This fragmentation poses particular challenges for refineries in emerging economies, where the frequency and severity of disruptions render reactive strategies inadequate [8]. Furthermore, existing studies lack cost-benefit analyses demonstrating returns on resilience investments, making it difficult for resource-constrained organizations to justify such initiatives.

This study investigates how a Latin American refinery successfully transitioned from reactive to proactive resilience over a decade. We propose an empirically grounded framework that leverages lessons learned as a fundamental dynamic capability, enabling refineries operating within corporate groups in emerging economies to build resilience incrementally. Our contribution extends Duchek's [9] resilience capabilities model by demonstrating how systematic knowledge capture and transfer can complement the technological and financial resources typically assumed in Western contexts. The research addresses four objectives: (1) document the transition from reactive to proactive resilience strategies; (2) identify context-specific enablers and barriers to resilience development; (3) develop an empirically grounded framework for leveraging lessons learned; and (4) quantify the return on investment from resilience initiatives.

II. Theoretical Background

A. Organizational Resilience in High-Risk Industries

Organizational resilience encompasses the capabilities that enable organizations to sustain operations under adversity and emerge stronger from crises [9]. The concept has evolved from early engineering perspectives emphasizing recovery speed to more comprehensive frameworks incorporating anticipation, adaptation, and transformation [10]. In high-risk industries such as oil refining, resilience requires the integration of technical, organizational, and human factors to address both sudden disruptions (acute shocks) and persistent stressors (chronic pressures) effectively [11].

Duchek [9] identifies three sequential capabilities underpinning organizational resilience: anticipation (recognizing potential threats through environmental scanning and risk assessment), coping (managing immediate consequences through response protocols and resource mobilization), and adaptation (learning from experiences and transforming organizational practices). However, this linear model presupposes resource availability and institutional stability—conditions that may be absent in emerging economies where organizations must often develop multiple capabilities simultaneously under resource constraints.

The oil and gas industry faces distinct resilience challenges arising from operational complexity, environmental hazards, and economic volatility [12]. Refineries operate as interdependent sociotechnical systems where minor failures can cascade into major incidents, as demonstrated by the Chevron Richmond refinery fire, which caused US$2 billion in damages [13]. Process safety incidents in refineries have historically resulted from the interaction of technical failures, organizational lapses, and human factors, necessitating holistic approaches to resilience that transcend purely technical solutions.

B. Resilience Strategies in the Oil and Gas Sector

Recent systematic reviews categorize resilience strategies in the oil and gas industry into four types [14]: (1) proactive strategies, which emphasize anticipation and preparation before disruptions occur through predictive maintenance, scenario planning, and risk assessment protocols; (2) absorptive strategies, which enable organizations to withstand impacts while maintaining core functions through redundancy, buffers, and flexible resource allocation; (3) reactive strategies, which facilitate rapid response and recovery through emergency protocols and crisis management; and (4) dynamic strategies, which promote continuous adaptation and learning through knowledge management and organizational transformation.

Proactive strategies have demonstrated particular effectiveness in reducing vulnerability and improving recovery outcomes. Research indicates that preparatory measures can reduce recovery time by up to 60% and improve operational resilience by 40% [15]. These strategies encompass predictive maintenance using condition monitoring and analytics, systematic risk assessment protocols, scenario planning exercises, and comprehensive knowledge management systems [16]. Nevertheless, their adoption requires substantial upfront investment and technological expertise that may exceed the capacities of refineries in developing countries, creating an apparent paradox where the organizations most vulnerable to disruptions are least able to invest in prevention.

C. The Latin American Context

Latin American refineries operate under constraints that distinguish them from their counterparts in industrialized nations. These facilities typically process heavier, high-sulfur crude oils requiring complex hydroprocessing and conversion units, while contending with chronic underinvestment in maintenance and modernization [17]. Political instability, currency fluctuations, and fragile institutional frameworks further complicate resilience-building efforts. Supply chain vulnerabilities are amplified by geographic factors, with pipeline sabotage and port blockages representing recurring disruption sources.

Despite these constraints, Latin American refineries have demonstrated remarkable adaptability. During the 2014–2016 oil price collapse, regional refineries maintained operations despite negative margins by leveraging operational flexibility and innovative financing mechanisms [2]. This suggests that resource limitations may foster distinctive resilience approaches—characterized by organizational learning, workforce adaptability, and creative problem-solving—that are overlooked by conventional frameworks developed in resource-abundant contexts.

The intersection of organizational learning and operational resilience offers a potentially fruitful avenue for resource-constrained organizations. Knowledge management approaches that systematically capture, codify, and transfer experiential learning can substitute for capital-intensive technological solutions while building organizational capabilities that persist beyond individual tenure [18]. This paper examines how one Latin American refinery leveraged this approach to achieve significant resilience improvements with minimal capital investment.

III. Methodology

A. Research Design

We employed a single-case study design with embedded units of analysis to examine resilience evolution at a major Colombian refinery [19]. This approach enables deep contextual understanding of complex organizational phenomena while maintaining analytical rigor through systematic data collection and triangulation. The case study methodology is particularly appropriate for examining "how" and "why" questions regarding contemporary events over which researchers have limited control, as is the case with organizational resilience development.

The case was selected based on three criteria: (1) critical importance to national energy security, as the facility supplies 21% of Colombia's refined fuel products; (2) documented resilience transformation over the study period, including major disruptions and subsequent organizational changes; and (3) access to senior management and operational data enabling comprehensive analysis. The studied refinery, located in Cartagena, Colombia, processes 210,000 barrels per day through 35 integrated units following a US$8 billion expansion completed in 2015—an expansion that itself incurred US$4 billion in cost overruns and three-year delays, highlighting the operational challenges facing the facility.

B. Data Collection

Data collection occurred between February and April 2025, combining multiple sources for triangulation. Semi-structured interviews constituted the primary data source, conducted with five senior personnel whose combined experience exceeds 125 years in the refining industry. Table I presents participant profiles. Interviews followed a protocol of 12 questions addressing disruption experiences, resilience strategies, organizational learning mechanisms, and evolution of practices over time. Sessions lasted 45–90 minutes and were recorded, transcribed verbatim, and validated through member checking to ensure accuracy.

TABLE I
PARTICIPANT PROFILES

ID	Position	Experience (years)	Primary Domain
P1	Operations Department Head	39	Strategic Planning
P2	Department Manager	25	HSE & Projects
P3	Operations Supervisor	20	Maintenance
P4	Senior Refining Specialist	23	Risk Management
P5	Integrated Operations Engineer	18	Business Continuity

Documentary analysis complemented interview data. Internal documents included Health, Safety, and Environment (HSE) metrics (2020–2024), operational key performance indicators (KPIs), incident investigation reports, business continuity plans, and the Balanced Scorecard. External sources included regulatory filings, industry benchmarks, public incident reports, and ISO 45001:2018 certification documentation. Additionally, we analyzed Great Place to Work survey results, which showed an 84% improvement following resilience initiatives. All financial and operational figures cited in this study derive from internal management and operational reports of the studied refinery. These figures were not subject to independent external audit for the purposes of this research, although the parent corporate group is publicly listed and subject to standard regulatory disclosures.

C. Data Analysis

Interview transcripts and documents were analyzed using thematic analysis following Braun and Clarke's [20] six-phase approach: familiarization with data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the report. Initial coding identified 127 first-order concepts related to disruptions, responses, learning mechanisms, and organizational changes. These were consolidated into 31 second-order themes through axial coding and ultimately four aggregate dimensions aligned with Duchek's [9] resilience capabilities framework: anticipation, absorption, adaptation, and transformation.

Quantitative data from operational reports enabled calculation of recovery times, financial impacts, and return on investment metrics. We employed a mixed-methods approach wherein qualitative findings informed quantitative analysis and vice versa, enabling triangulation across data sources. Research quality was ensured through prolonged engagement with data, member checking of transcripts and interpretations, and systematic documentation of analytical decisions.

IV. RESULTS

A. Nature and Impact of Disruptions

The analysis revealed two categories of disruptions with distinct characteristics and management requirements. *Operational disruptions* stemmed from internal failures and technical issues. Electrical substation failures emerged as the most critical, with two major incidents causing complete refinery shutdowns. P5 provided detailed accounts of these events:

> *"The first incident occurred on August 16, 2024, causing a total shutdown of the process units. Thanks to the Business Continuity Plan, we achieved 97% compliance with Jet A1 deliveries, although we had to import 100,000 barrels to cover demand. The second incident on February 14, 2025 involved a failure in the main substation that temporarily halted operations. The effective response, supported by safety inventories, allowed us to reactivate half the units in less than a day without affecting supply."*

Production bottlenecks from equipment failures (pumps, compressors, turbogenerators) occurred monthly, with each incident causing average losses of US$2.3 million. Process safety incidents, while declining from 408 to 341 Level-3 events annually (16% reduction year-over-year), remained a persistent concern given their potential for catastrophic consequences. P3 noted that "electrical substation failures" represented the most critical operational risk, prompting systematic review of "all contacts in motors greater than 480V."

External disruptions originated from market, regulatory, and societal factors beyond the refinery's direct control. The COVID-19 pandemic reduced jet fuel demand by 90% and diesel demand by 40%, forcing production cuts and generating extraordinary costs of approximately COP$10,500 million (approximately US$2.7 million at then-prevailing exchange rates) during Q2 2020. P4 emphasized that "the pandemic and changes in market demand significantly impacted the refinery," requiring "rapid responses to adapt operations to the new reality." Oil price volatility, exemplified by the 2014–2016 collapse, eliminated refining margins for extended periods. Supply chain disruptions from pipeline sabotage and port blockages interrupted crude supply approximately four times annually.

B. Evolution of Resilience Approaches

The refinery's resilience journey unfolded through three distinct phases, each triggered by critical events that exposed existing vulnerabilities and catalyzed organizational transformation.

Phase 1: Reactive Approach (2014–2019). During this period, the refinery operated with traditional emergency response protocols focused on post-incident recovery. P3 observed: "We were always fighting fires, literally and figuratively. Each incident was treated as isolated, without systematic learning." Major operational incidents during this period typically required extended recovery periods, with limited documentation of root causes or preventive measures. The 2015 expansion project delays, which resulted in US$4 billion in cost overruns, epitomized this reactive stance. Risk management remained siloed, and as P3 noted, "operators did not have sufficiently broad professional knowledge regarding risk and its different components."

Phase 2: Transitional Period (2020–2023). The COVID-19 pandemic catalyzed fundamental changes in resilience thinking. The pandemic's simultaneous impact on workforce availability, demand patterns, and supply chains necessitated integrated response strategies. P4 explained that "initially, responses focused on ensuring personnel health and operational continuity through measures such as remote work, process restructuring, and business continuity plans." The refinery implemented its first formal Business Continuity Plan, established crisis management committees, and initiated systematic incident analysis.

P2 characterized this period as a shift toward "hybrid models that combine immediate containment with strategic adaptability." Recovery times decreased to an average of three days (72 hours), representing a 57% improvement. The refinery began adopting ISO 45001:2018 standards and implementing systematic HSE (Health, Safety, Environment) conversations. P1 highlighted the creation of an "Integrated Risk Management department integrated across the entire management control structure at strategic, tactical, and operational levels."

Phase 3: Proactive Resilience (2024–present). The August 2024 electrical failure marked a turning point, triggering comprehensive resilience transformation despite the operational crisis it caused. The refinery now employs predictive analytics for equipment health monitoring, maintains strategic inventories based on probabilistic risk assessment, and operates a formal lessons-learned platform. P5 described the implementation of a mitigation plan since October 2024 "focused on improving electrical stability, including maintenance and corrective actions scheduled through the second half of 2025."

The March 2025 electrical incident—similar in nature to that of August 2024 (which had required approximately one week to resolve)—was contained within 24 hours due to pre-positioned spare parts and cross-trained response teams, representing an 86% reduction in recovery time between two comparable substation failures occurring eight months apart. P2 articulated the transformation: "These practices enable transitioning from reactive resilience to proactive and strategic resilience." The refinery has also formulated a 2023–2040 business plan centered on sustainability and energy transition, including green hydrogen production and biofuel development.

C. Lessons-Learned Framework

Central to the refinery's resilience transformation was the development of a systematic approach to capturing, analyzing, and applying lessons from disruptions. This framework, which emerged iteratively from operational experiences, operates through six integrated stages:

Stage 1: Immediate Documentation. Promptly after any incident, operators complete standardized templates capturing initial conditions, immediate responses, and preliminary observations. P5 explained that "post-event evaluation reviews response performance, identifies failures, and documents learnings obtained." Digital tools enable real-time data collection even during emergency conditions.

Stage 2: Root Cause Analysis. Cross-functional teams conduct systematic investigations using multiple methodologies (5-Why, Fishbone, FMEA) in the days following the incident. P1 noted that "lessons-learned workshops are incorporated into the execution of root cause analysis in disruption investigations." External experts participate in Level-1 and Level-2 incidents to ensure objectivity.

Stage 3: Lesson Extraction and Categorization. Identified lessons are categorized by applicability (unit-specific, refinery-wide, or industry-relevant) and prioritized based on recurrence probability and potential impact. P5 described how "results are systematized and stored in organized databases through a knowledge management platform that centralizes manuals, reports, and case studies accessible to all workers."

Stage 4: Integration into Standard Operating Procedures. Critical lessons trigger immediate SOP updates, with version control ensuring traceability. P3 emphasized that "there are lessons-learned banks and reviewing them is mandatory before critical activities." Changes undergo risk assessment before implementation to prevent unintended consequences.

Stage 5: Training and Dissemination. Customized training modules targeting different organizational levels ensure effective knowledge transfer. P4 described how "the refinery uses methodologies such as training guides, simulations, and communities of practice to evaluate performance in critical situations." Monthly "HSE Conversations" share recent lessons across departments, while the corporate digital platform (Portal Delta) enables enterprise-wide access.

Stage 6: Performance Monitoring and Feedback. Key performance indicators track lesson implementation and effectiveness, with quarterly reviews assessing whether incorporated lessons prevent incident recurrence. P5 noted that "performance metrics are implemented to evaluate the effectiveness of disruption responses, including recovery times and associated costs." Ineffective lessons undergo re-analysis to identify implementation barriers.

Figure 1 illustrates the six-stage framework and its continuous improvement cycle.

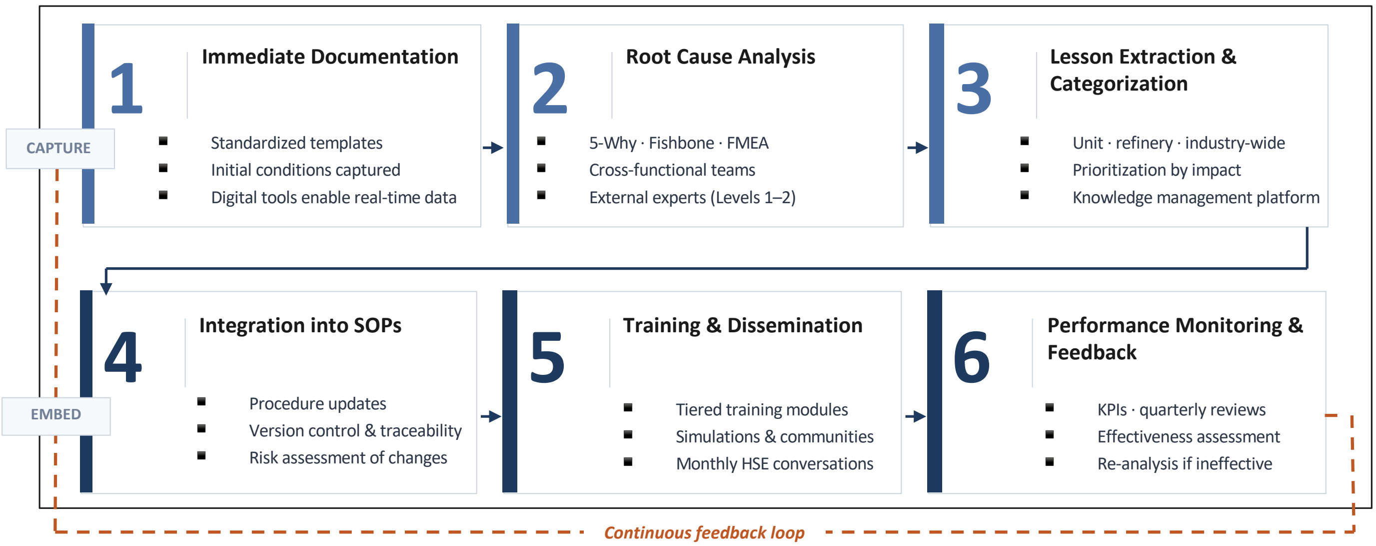

Fig. 1 Six-Stage Lessons-Learned Framework for Proactive Resilience

Note: The framework operates as a continuous cycle in which Stage 6 (Performance Monitoring) feeds back into Stage 1 through the identification of new improvement opportunities. Solid arrows indicate forward sequence; the dashed path indicates feedback. Stages 1 – 3 (Capture) structure knowledge from disruptive events; Stages 4 – 6 (Embed) institutionalize that knowledge in operational practice. The framework was developed empirically from the studied refinery's transformation (2014 – 2025).

D. Knowledge Transfer and Intergenerational Learning

A critical component of the resilience framework involves systematic transfer of experiential knowledge from senior personnel approaching retirement to newer staff. P1 explained that "senior personnel have been assigned to serve as dedicated tutors who guide new generations to do things right the first time." This mentoring program pairs experienced engineers with newer employees on real projects, facilitating contextual and practical learning.

P5 elaborated on the comprehensive approach: "The refinery has systematically documented the best practices of senior personnel in manuals and guides accessible to all workers, including procedures for both normal conditions and emergency situations." Additionally, internal case studies illustrate how real problems have been resolved, providing new workers with clear understanding of critical contexts and effective responses. P2 emphasized the integration of "tacit knowledge into new technological systems and documentary processes, such as the hyperautomation factory or the Delta portal."

P3 highlighted a cultural dimension: "The advantage of being multicultural is a strength—there are cultures more resilient than others." This diversity of perspectives, combined with formal knowledge transfer mechanisms, creates organizational memory that transcends individual departures. P5 summarized: "This culture not only enables effective knowledge transfer but also strengthens the organization's capacity to face future crises with a solid foundation of experience."

E. Measurable Outcomes

Financial analysis revealed exceptional returns on resilience investments. The proposed proactive resilience strategy, estimated at US\$2,723 in incremental cost using internal personnel and existing corporate platforms (with phase-level cost allocations detailed in Section IV.E.1), is projected to prevent at least one major incident annually, saving US\$2.34 million per avoided event—representing an estimated 859:1 return on investment under upper-bound assumptions; sensitivity analysis (Section IV.E.1) indicates the figure ranges between approximately 85:1 and 430:1 under more conservative assumptions. Predictive monitoring systems (US\$10,000 investment) enabled early detection of degradation in critical pumps, preventing an estimated US\$8 million in daily losses from unplanned shutdowns. P5 noted that the refinery achieved "a positive EBITDA of US$6.5 million in a context where a significant negative result was anticipated" through cost optimization and operational efficiency initiatives.

Implementation of proactive resilience strategies yielded measurable improvements across multiple dimensions, summarized in Table II.

TABLE II
PERFORMANCE IMPROVEMENTS FOLLOWING RESILIENCE FRAMEWORK IMPLEMENTATION

Metric	Before (2014-2019)	After (2024-2025)	Improvement
Recovery time for comparable electrical substation failures (Aug 2024 vs Mar 2025)	168 hours	24 hours	86%
Unplanned downtime (year-over-year)	Baseline	Reduced	60%
Process safety incidents (Level-3)	408//year	341/year	16%
Lost-time injury frequency (per million hours)	0.32	0.18	44%
Near-miss reporting	Baseline	Increased	200%
Delivery compliance during crises	Variable	97%	N/A
Cross-training coverage for critical roles	Partial	100%	Full coverage

E. Cost-Benefit Estimation Methodology

The cost-benefit calculation supporting the strategy follows three estimation steps. First, the strategy implementation cost (US$2,723) was derived from internal time-and-resource estimates across the four management phases of the proactive resilience strategy: scenario identification (US$805), lessons capture (US$426), integration into procedures (US$827), and dissemination/standardization (US$665). This cost reflects incremental personnel time using existing corporate platforms (Portal Delta, integrated risk management infrastructure) and excludes embedded organizational costs such as senior mentoring time, cross-functional team participation, and quarterly review cycles, which are absorbed within standard operational responsibilities.

Second, the per-event avoided-loss figure (US$2.34 million) is derived from the documented operational impact of a single-day unplanned shutdown of one critical processing unit (hydrogen generation), calculated as 195,000 BPD × US$12 net margin per barrel ≈ US$2.34M. This represents the lower bound of operational disruption cost; broader refinery-wide shutdowns (such as the August 2024 event) would yield substantially higher figures.

Third, the assumption of "at least one major incident prevented annually" reflects expert judgment from the senior management team based on the observed reduction in recovery times between the August 2024 and March 2025 incidents, rather than a counterfactual evaluation of unobserved events. Sensitivity analysis under more conservative assumptions—e.g., 0.5 incidents prevented per year, or implementation costs scaled 5× to incorporate full personnel and overhead allocation—yields ROI estimates ranging from approximately 85:1 to 430:1, all of which remain economically substantial. The reported headline figure should therefore be interpreted as the upper bound of an estimation range, not as an audited financial outcome.

V. DISCUSSION

A. Theoretical Contributions

Our findings extend organizational resilience theory in three significant ways. First, we demonstrate that resource constraints in emerging economies can foster innovative resilience approaches not captured by existing frameworks developed in resource-abundant contexts. Duchek [9] posits sequential capability development proceeding from anticipation through coping to adaptation; however, our case reveals simultaneous, iterative processes wherein learning from minor incidents enhances capacity to manage major disruptions. This "learning-by-doing" approach, characterized by P5's observation that "reactive actions transformed into learning opportunities that drove deeper structural change," may prove particularly valuable for organizations unable to afford comprehensive preparedness infrastructure investments.

Second, we conceptualize lessons learned as a dynamic capability that can substitute for technological and financial resources typically required for proactive resilience. By systematically converting tacit knowledge into documented procedures—what P2 described as "incorporating tacit knowledge into new technological systems and documentary processes"—the refinery built organizational memory that persists beyond individual departures and equipment failures. This finding challenges the assumption that proactive resilience necessitates substantial capital investment, suggesting that knowledge management can provide a more accessible pathway for refineries operating within corporate structures in emerging economies. The estimated ROI achieved through a US$2,723 strategy investment (with sensitivity range detailed in Section IV.E.1) exemplifies this potential.

Third, our framework bridges operational resilience research with organizational learning literature. Prior studies have treated these as separate domains [4]; however, we demonstrate how operational incidents become learning opportunities that enhance anticipatory capabilities. P4's description of how "lessons learned from past experiences are actively used to adjust resilience strategies" illustrates this integration. This perspective aligns with recent calls for holistic approaches to resilience in complex sociotechnical systems [21] and extends them by providing empirical evidence of implementation mechanisms.

Table III compares this study with previous organizational resilience research in the oil and gas sector, highlighting the unique contributions of the current work.

TABLE III
Comparison with previous organizational resilience studies in the oil and gas sector

Study	Context	Method	Lessons Learned	ROI	Frame work	Em. Econ.
[4]	Global O&G	Review	Partial	No	No	Limited
[2]	Americas	Quantitative	No	Partial	No	Yes
[9]	Cross-industry	Conceptual	No	No	Yes	No
[22]	Greece refinery	Action research	No	No	Yes	No
[15]	Upstream O&G	Modeling	No	Partial	Yes	No
[6]	O&G infrastructure	Review	No	No	Partial	No
[8]	Refinery operations	Modeling	No	No	Yes	No
[23]	Norwegian O&G	Case study	Yes	No	No	No
This study	**Colombian refinery**	**Qual. case study**	**Yes**	**Yes**	**Yes**	**Yes**

B. Practical Implications

Our study provides practitioners with actionable guidance for enhancing resilience under resource constraints. The six-stage lessons-learned framework offers a structured approach achievable with existing personnel and systems—requiring minimal upfront investment while generating substantial returns. As P3 emphasized, "there are lessons-learned banks, and reviewing them is mandatory before critical activities." This institutionalization of learning creates systematic resilience improvement without significant capital expenditure.

The phased evolution model enables managers to assess their organization's resilience maturity and identify appropriate next steps. Organizations in reactive phases should prioritize basic incident documentation and analysis capabilities before pursuing predictive analytics or scenario planning. P5's account of the refinery's use of "organizational maturity models and financial tools such as the Altman Z-Score" demonstrates how relatively accessible analytical approaches can enhance anticipatory capacity. Those in transitional phases can focus on institutionalizing learning systems and cross-functional integration, as exemplified by the refinery's establishment of an Integrated Risk Management department.

For policymakers, our findings highlight the vulnerability of critical energy infrastructure in emerging economies and suggest that regulatory frameworks could incentivize resilience enhancement. Mandating minimum strategic reserves—as the studied refinery implemented following the August 2024 incident—standardizing incident reporting and facilitating inter-organizational learning could strengthen sector-wide resilience without requiring direct public investment. The refinery's adoption of ISO 45001:2018 and its participation in the Ecopetrol Group's governance structures illustrate how regulatory alignment can catalyze resilience improvements.

C. Role of Corporate Backing and Scalability Considerations

The framework's effectiveness in the studied case was enabled by several corporate-level resources that should not be assumed transferable to independent refineries. These enablers include access to a corporate digital knowledge platform (Portal Delta), an Integrated Risk Management department operating across strategic, tactical, and operational levels, group-wide ISO 45001:2018 implementation, formalized senior-junior mentoring programs, and corporate governance structures providing oversight and resource allocation. Refineries operating without such corporate infrastructure would require alternative substitutes: sectoral consortia (e.g., regional oil and gas associations such as ARPEL in Latin America), inter-organizational learning platforms, shared certification schemes, or formalized cross-firm mentoring arrangements. The framework as presented should therefore be understood as applicable to similarly structured refineries within corporate groups; adaptation to independent or smaller-scale facilities is a question for future research.

D. Barriers and Enablers

Participants identified several barriers to resilience development that may apply broadly to emerging economy contexts. P1 noted "competition between departments for resources when scarce and the need to frequently obtain budget approvals from entities above the General Management, which can slow timely response to disruptions." P5 identified "resistance to change, primarily toward the use of new technologies and operational approaches" as a significant barrier, addressed through "training programs to build worker capabilities and demonstrate benefits of proposed changes."

Communication challenges also emerged prominently. P5 described "deficient communication and knowledge gaps regarding new organizational goals" requiring "clearer and more accessible communication channels to inform all levels of the company about changes and expectations." P4 identified the initial "lack of synergies between operational and technical areas" as generating obstacles, overcome by "integrating teams and establishing clear structures for communication and leadership."

Key enablers included strong organizational values—P1 highlighted "organizational values deeply rooted in the operational and maintenance workforce with a marked commitment to life and passion for excellence"—and structural flexibility. P4 described the organization as "flexible, capable of rapidly reconfiguring teams and resources according to needs, which facilitates timely response to unforeseen events." Cultural factors also contributed; P3 observed that "being multicultural is a strength—there are cultures more resilient than others."

E. Limitations and Future Research

Several limitations constrain the generalizability and interpretation of our findings. The single-case design enables deep contextual understanding but limits transferability to other settings. The Colombian refinery's recent modernization and corporate backing from Ecopetrol may not typify Latin American facilities, many of which operate with older infrastructure and less institutional support. Three sources of informant-related bias warrant explicit acknowledgment. First, all five interviewees occupy senior positions and were direct participants in the resilience transformation under study; their accounts are likely to frame the trajectory as more coherent and successful than alternative perspectives might. Second, the sample excludes operational personnel (shift operators, technicians, contractors), labor representatives, and external stakeholders (downstream clients, regulators), whose perspectives could introduce divergent assessments of the framework's effectiveness. Third, member checking of transcripts validates narrative coherence but does not neutralize systematic positivity in framing. Future research should triangulate these accounts with operator-level interviews, contractor perspectives, and regulator viewpoints. Reliance on retrospective accounts also introduces potential recall bias regarding incident timelines and decision sequences. Quantitative figures, including recovery times, financial impacts, and ROI estimates, are based on internal reports and have not been independently verified or audited as part of this research.

Future research should validate the framework across multiple refineries with varying characteristics—including older infrastructure, different ownership structures, and alternative crude supplies. Longitudinal studies tracking resilience evolution prospectively could establish causal pathways more precisely than our retrospective approach permits. Quantitative studies comparing resilience metrics across facilities would enable benchmarking and identification of best practices. Finally, investigation of resilience interdependencies among supply chain partners could reveal system-level vulnerabilities and collaborative mitigation opportunities not visible at the organizational level.

VI. CONCLUSIONS

This paper documents a Latin American oil refinery's successful transition from reactive to proactive resilience, achieving an 86% reduction in recovery time between two comparable electrical substation incidents and an estimated return on investment exceeding 85:1 under conservative assumptions through systematic organizational learning. Our empirically grounded six-stage framework demonstrates how refineries operating within corporate groups in emerging economies can progressively enhance resilience by transforming operational experiences into institutional knowledge.

The research makes three primary contributions: (1) it extends resilience theory to corporate-backed refineries in emerging economies, where systematic organizational learning supplements (rather than replaces) capital investment; (2) it provides practitioners with a practical framework requiring minimal incremental investment, demonstrated through the US$2,723 proactive resilience strategy that generated estimated annual savings of US$2.34 million; and (3) it quantifies resilience returns to justify organizational commitment, addressing a critical gap in the literature regarding cost-benefit analysis of resilience initiatives in emerging economies.

As the energy sector faces mounting pressures from climate change, market volatility, and technological disruption, building proactive resilience becomes not merely a strategic advantage but an operational imperative. The studied refinery's evolution from reactive firefighting to proactive preparation—exemplified by its ability to resolve the March 2025 electrical incident within 24 hours compared to seven days for a similar incident eight months earlier—offers evidence that even complex, hazardous operations in challenging environments can achieve resilience through systematic learning rather than capital-intensive technological solutions.

By treating lessons learned as strategic assets rather than compliance obligations, organizations can transform every incident—large or small—into an opportunity for learning and enhanced capability to face future uncertainties. As one participant summarized: "These practices enable transitioning from reactive resilience to proactive and strategic resilience." This transformation, achievable through systematic knowledge management complemented by capital investment, offers a pathway for similarly structured refineries in emerging economies to enhance their resilience in an increasingly volatile operating environment.

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