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A Proactive Contingency Framework for Bacon-Manito Geothermal Project (BMGP) Forced Outage Management

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ABSTRACT

The global energy transition relies heavily on sustainable baseload generation, a role uniquely fulfilled by geothermal energy. In the Philippines, the Bacon-Manito Geothermal Project (BMGP) is a critical asset for grid stability; however, the complex operational environment of geothermal extraction makes the facility inherently vulnerable to material degradation and forced outages. Currently, BMGP's outage management is dominated by a reactive restoration culture rather than strategic anticipation, creating an un-operationalized gap between abstract organizational resilience theory and complex engineering realities. This study aims to address this operational void by developing a Proactive Contingency Framework for BMGP Forced Outage Management to enhance operational continuity and systemic resilience. A three-phase mixed-method research design was employed, utilizing semi-structured interviews, systematic data abstraction from archival outage reports, and comprehensive document reviews to assess current resilience capabilities, identify specific systemic challenges, and construct the framework. The findings reveal that while BMGP exhibits high technical proficiency in post-incident recovery, proactive continuity is severely constrained by systemic frictions. Technically, the plant relies on reactive threshold triggers and struggles with recurring failure modes (e.g., in the Circulating Water System), creating a continuous "maintenance backlog ripple effect". Financially, rigid "zero-sum" budgeting, tedious stage-gating, and strict purchase request deadlines act as a "fiscal cliff" that delays proactive resilience projects and emergency spending. Organizationally, site-level risk management is structurally siloed, and post-outage evaluations focus almost entirely on mechanical fixes, consistently overlooking systemic organizational precursors like procurement delays and staffing gaps. The study concludes that transitioning BMGP toward sustained strategic resilience requires shifting from reactive maintenance to condition-based predictive operations. It is highly recommended that management implement the proposed Proactive Contingency Framework, which integrates specialized technical risk management, resource specificity, and adaptive governance. By establishing a Condition-Based Operational Baseline, a Pre-Positioned Resilience Fund, Green-Lane procurement, and an Adaptive Governance Structure, BMGP can reduce unscheduled downtime, secure long-term plant integrity, and bolster the energy security of the Philippine grid.

Keywords: *Geothermal Energy; Forced Outage Management; Proactive Contingency Framework; Strategic Resilience; Condition-Based Maintenance; Bacon-Manito Geothermal Project*

INTRODUCTION

The global energy landscape is currently navigating a period of unprecedented volatility. Escalating geopolitical tensions particularly the ongoing conflicts involving Iran, Israel, and the United States have severely disrupted global energy markets and international supply chains. This global instability dramatically underscores a fundamental reality: electricity is the indispensable lifeblood of modern society, powering everything from basic human needs to national economies and critical infrastructure. Relying heavily on vulnerable, imported energy sources in such a volatile climate poses a massive risk to national stability. Consequently, there is a dual imperative for nations to not only pursue sustainable development and climate change mitigation but also to achieve strict energy independence.

Central to this transition is the reliable integration of indigenous renewable energy sources, which must displace fossil fuels while guaranteeing the baseload stability previously associated with conventional power generation (Biserčić & Bugarić, 2021). Among these options, geothermal energy holds a unique and critical position. Unlike intermittent sources such as solar and wind, geothermal power plants operate on the steady heat flux of the Earth's interior, providing a high-capacity factor and reliable baseload generation. This makes them essential for grid security and national stability, particularly in tectonically active nations like the Philippines (Koons, 2024).

The Bacon-Manito Geothermal Project (BMGP), situated in the provinces of Albay and Sorsogon, stands as a cornerstone of the Philippine energy matrix, contributing significantly to the nation's supply of clean, reliable electricity. However, the operational complexity inherent in geothermal resource utilization involving high-pressure steam handling, highly corrosive fluid management, and deep-earth resource extraction renders these facilities inherently susceptible to material degradation and system failures (Nogara & Zarrouk, 2017). Within such critical infrastructure, forced outages—the unplanned shutdowns of generating units represent not merely technical interruptions but profound threats to national grid stability, financial viability, and stakeholder confidence. Because uninterrupted electricity is so vital, lessening the frequency and duration of these forced outages is a critical national imperative; every hour of downtime exacerbates the vulnerability of the grid to external shocks.

Historically, the necessity of managing these interruptions has been dominated by a reactive restoration culture rather than strategic anticipation. Indeed, prior scholarship, including the author's Master of Science in Management Engineering thesis, focused extensively on the "Assessment of the Implementation of Restoration Response during Forced Outages in Bacon-Manito Geothermal Project (BMGP)." That study provided an empirical evaluation of the technical and logistical efficacy of the post-incident recovery protocols. While establishing a baseline understanding of the project's high technical proficiency in post-incident recovery, it highlighted a significant operational gap: the deeply entrenched reactive nature of recovery efforts. Simply repairing a machine after it fails is insufficient to guarantee long-term system integrity and continuity in today's unpredictable world.

Given the high-stakes environment of global energy instability, there is an absolute, critical urgency to be proactive. This present study, "A Proactive Contingency Framework for Bacon-Manito Geothermal Project (BMGP) Forced Outage Management," shifts the focus from merely reacting to outages to proactively embedding strategic resilience within the plant's operational DNA. Strategic resilience goes beyond technical restoration; it encompasses the organizational, structural, and procedural capacity to anticipate, absorb, adapt to, and rapidly recover from high-impact disruptions while maintaining core functions (Tengblad & Oudhuis, 2018). This requires developing a formalized Contingency Framework, a structured mechanism that integrates specialized technical risk management, resource pre-positioning, and adaptive decision-making protocols tailored specifically to the dynamic environmental threats of a major geothermal facility. The development of this framework is essential to successfully transitioning BMGP from a reactive culture to one of sustained strategic resilience, protecting its operational future and, by extension, ensuring the continuous, proactive defense of the clean electricity it provides to the nation.

Literature Review

The Scholarly and Operational Gaps

This doctoral research is fundamentally necessitated by the findings of the author's preceding Master of Science in Management Engineering thesis, entitled: *Assessment of the Implementation of Restoration Response during Forced Outages in Bacon-Manito Geothermal Project (BMGP)*. While that study affirmed the project's technical competence in executing post-incident recovery protocols, it empirically demonstrated a critical systemic deficiency: the predominant reliance on a reactive restoration culture.

Current outage management protocols at BMGP, designed to react to failure and restore operational status, often rely on resource-intensive, ad-hoc decision-making under high-stress conditions. This inherently reactive paradigm is inadequate for mitigating recurrent and systemic vulnerabilities that permit frequent or prolonged downtime. The MSME thesis specifically highlighted the absence of a comprehensive, proactive strategy for Operational Continuity that effectively integrates resource pre-positioning, organizational learning, and adaptive governance mechanisms prior to disruption (Baliza MSME Thesis, 2024).

Scholarly literature on critical infrastructure reliability and geothermal engineering predominantly focuses on technical fault identification and component mitigation (e.g., condition monitoring, failure analysis). A significant, unaddressed gap persists in the development, formalization, and validation of a holistic Contingency Framework that systematically bridges organizational resilience theory with complex engineering realities to achieve sustained operational permanence.

Practical and National Significance

The development of the Strategic Resilience in Geothermal Operations Contingency Framework offers substantial contributions at both the institutional and national levels:

- Institutional Impact (BMGP): The Framework will furnish a structured and predictive mechanism for managing high-impact disruptions. It moves the operational focus beyond the Mean Time To Repair (MTTR) metric toward advanced resilience metrics, promising reduced unscheduled downtime, minimized financial losses, and demonstrably enhanced plant safety and integrity.
- National Energy Security: As a principal provider of baseload renewable power, the reliability of BMGP is intrinsically linked to the stability of the entire Philippine Luzon grid. By substantially increasing operational continuity at this key facility, the research directly supports national objectives concerning energy self-sufficiency, security, and stable power delivery to millions of industrial and residential users.
- Sectoral Applicability: The resulting Framework will be inherently scalable and transferable, serving as a best-practice blueprint for other high-value, high-complexity renewable energy installations across the Philippines and the wider Asia-Pacific region, thereby raising the standard for infrastructure resilience planning.

Originality and Contribution to Knowledge

This study represents an original and timely academic contribution, distinguished by its multi-disciplinary focus:

Theory-Practice Synthesis: It achieves a novel synthesis by applying established theoretical models of organizational resilience (Tengblad & Oudhuis, 2019) to the highly specific, high-risk engineering environment of a working geothermal power plant (Nogara & Zarrouk, 2017).

Framework Development: The research is developmental, not merely descriptive, proposing and designing a novel, formalized Contingency Framework specifically tailored to the unique operational and environmental hazards of the BMGP context.

Advancing Continuity Science: By defining and operationalizing Operational Continuity—the capacity to maintain essential utility functions during and immediately after a disruption—the study significantly advances the theoretical and applied discourse beyond mere mechanical restoration.

In summation, this research addresses a critical void identified in both the academic literature and in the operational practice of Philippine critical infrastructure, providing a decisive pathway toward securing the long-term viability and strategic resilience of the Bacon-Manito Geothermal Project.

The body of knowledge relevant to this dissertation, A Proactive Contingency Framework for Bacon-Manito Geothermal Project (BMGP) Forced Outage Management, can be segmented into three primaries, yet insufficiently integrated, streams of scholarly inquiry. This review establishes the foundation upon which the proposed Contingency Framework will be built, while simultaneously demarcating the specific scholarly void the study intends to occupy.

Technical Reliability and Restoration in Geothermal Operations

The dominant stream of research concerning geothermal power focuses heavily on technical reliability, component integrity, and post-incident restoration efficacy. Studies in this area are typically rooted in engineering science, concentrating on:

Failure Analysis and Mitigation: Extensive work addresses the causes and material impacts of forced outages, particularly those driven by geo-fluid chemistry, such as scaling and corrosion (Nogara & Zarrouk, 2017). Research in this area provides the empirical basis for understanding what fails and why.

Maintenance and Diagnostics: A substantial body of literature outlines protocols for predictive maintenance, condition monitoring, and Mean Time To Repair (MTTR) minimization (Technical Journal, 2021). These studies are prescriptive regarding technical fixes and immediate recovery actions.

Reactive Restoration Assessment: As demonstrated by the author’s MSME thesis, Assessment of the Implementation of Restoration Response during Forced Outages in Bacon-Manito Geothermal Project (BMGP), previous site-specific studies often assess the logistical execution of existing recovery procedures. The limitation of this research stream, however, is its fundamental reliance on a reactive paradigm—it assesses reaction rather than designing for proaction and prevention on a strategic level.

Organizational and Strategic Resilience Theory

A second, more conceptual body of work derives from organizational theory and resilience engineering. This stream represents a crucial shift from simply recovering from failure (recovery focus) to proactively maintaining function during and immediately after disruption (resilience focus).

Defining Resilience: Foundational scholars define strategic resilience as the organizational capacity to anticipate, absorb, adapt to, and rapidly recover from high-impact disruptions while maintaining core functions (Tengblad & Oudhuis, 2019).

Frameworks for Critical Systems: Research in this area establishes high-level frameworks for business continuity and disaster recovery, particularly for critical infrastructure sectors. These studies emphasize organizational learning, adaptive decision-making, and robust resource management.

Crucially, while these theories provide the "what" (resilience is the goal) and the "why" (it ensures long-term viability), they generally lack the necessary "how"—the empirical validation and practical tailoring required to translate abstract resilience principles into a highly specific, operational framework suitable for the complex engineering environment of a geothermal power plant.

Contingency and Continuity Framework Development

Teachers play a central role in making story-based English exposure effective. The impact of stories depends not only on the text itself but also on how the teacher introduces, reads, explains, questions, and extends the story. A teacher may use pre-reading questions, vocabulary previews, expressive reading, guided discussion, group retelling, drawing, role play, and reflection to deepen learners’ understanding. Carter (2024) emphasized in a systematic review that reading comprehension interventions in multilingual contexts require structured and responsive teaching practices. This implies that story-based exposure should not be treated as simple entertainment. It should be planned as a purposeful reading experience that supports comprehension, participation, and motivation.

Story-Based Exposure in the Context of Grade 5 Learners

Grade 5 learners are at a essential stage in reading development because they are expected to move from basic decoding toward more independent comprehension, interpretation, and subject-based reading. At this level, learners may already recognize many English words, but they may still struggle with sustained attention, confidence, vocabulary, and deeper understanding. Story-based English exposure may address these concerns by offering texts that are manageable, interesting, and emotionally engaging. Pelletier et al. (2025) noted that teacher support and reading frequency are connected with reading motivation and engagement from the upper elementary years onward. This supports the idea that regular exposure to stories may help Grade 5 learners build more positive reading habits.

Technical Reliability and Failure Analysis in Geothermal Systems

Research in this field is primarily rooted in materials science, mechanical engineering, and geo-science, seeking to identify, predict, and mitigate the physical causes of forced outages in high-enthalpy systems.

A. Corrosion, Scaling, and Component Integrity

The operational environment of geothermal power generation presents unique engineering challenges that differentiate it from conventional thermal power. High-pressure, high-temperature brine often contains high concentrations of non-condensable gases (e.g., CO2 and H2S) and dissolved solids, which are highly corrosive and scale-forming. Nogara and Zarrouk (2017) provided foundational insights into the mechanisms of corrosion in geothermal environments, emphasizing that fluid composition is the primary determinant of system integrity and subsequent failure risk. This work underscores the inherent susceptibility of facilities like the Bacon-Manito Geothermal Project (BMGP) to material degradation, which serves as the physical precursor to forced outages.

Building upon this foundation, newer research expands on how specific chemical interactions create these physical precursors. Kermani, M. (2019) indicates that even in high-temperature environments, the presence of chlorides and sulfides accelerates localized pitting and Stress Corrosion Cracking (SCC), which are identified as leading causes of sudden heat exchanger and well casing failures. Consequently, material selection paradigms have shifted; Penot, C., Martelo, D., & Paul, S. (2023) suggests that the transition from standard Carbon Steel to Corrosion-Resistant Alloys (CRAs), such as Titanium or super-austenitic stainless steels, is no longer optional for high-salinity brine environments to maintain long-term integrity. This is further complicated by Erosion-Corrosion synergy, where a case study Obiko, J., Ndeto, M., Mutua, J., Shongwe, B., Malatji, N., Bodunrin, M., & Klenam, D. (2020) from the University of Iceland on API 5L grade B steel pipelines shows that wall thinning is a mechanical-chemical hybrid; high-velocity steam at elbows and drain ports exacerbates material loss, creating a "known-known" failure mode that mirrors the recurring issues seen at BMGP.

Beyond corrosion, scaling acts as a silent precursor to forced outages by gradually "choking" the system's thermal capacity. An economic analysis by Shannon, D.W (1975) notes that silica solubility is highly sensitive to temperature drops, with some plants processing over 30,000 tons of scale annually. This can lead to a 10% reduction in overall efficiency long before a total shutdown occurs, particularly if chemical inhibitors like Diethylene Triamine Penta are not optimized. In the context of BMGP, scaling in the Circulating Water System (CWS) is often addressed through reactive cleaning. Literature suggests that this reactive approach frequently triggers a "Maintenance Backlog Ripple Effect," where vital preventive tasks are sacrificed to handle emergency scale removals.

Ultimately, integrating component integrity into a Proactive Contingency Framework requires understanding the economic and statistical risks of failure. Research into geothermal life cycles by Shannon, D.W (1975) and Kermani, M. (2019) suggests that failures in critical components like master valves or turbines due to corrosion fatigue do not just stop a machine; they cause "financial bleeding" and massive Equivalent Generation Loss (EGL). To mitigate this, a Stanford University study on Enhanced Geothermal Systems (EGS) Fichter, C., Falcone, G., Reinicke, K. M., & Teodoriu, C. (2011) advocates for moving away from simple "mechanical fixes" toward probabilistic failure modeling, recognizing that technical failures are often symptoms of missing systemic capabilities. By aligning technical triggers with proactive procurement and specialized reliability teams, BMGP can evolve its systemic resilience and protect its operational continuity against these inherent geothermal threats.

Maintenance Philosophy and Reactive Assessment

Related studies focus on optimizing maintenance strategies. Literature outlines prescriptive protocols for predictive maintenance (PdM) and condition-based monitoring, aiming to reduce the Mean Time Between Failures (MTBF) and minimize the Mean Time to Repair (MTTR).

The author’s prior MSME thesis, Assessment of the Implementation of Restoration Response during Forced Outages in Bacon-Manito Geothermal Project (BMGP), critically examined the execution of these reactive protocols at the project level. While confirming the efficacy of rapid technical restoration, the thesis identified that the underlying management structure was optimized for reaction rather than strategic anticipation. This suggests that while engineers excel at fixing the effects of failure, a strategic framework is missing to manage the systemic context of failure.

Dynamic Capabilities and Resilience in High-Uncertainty Energy Sectors

In today’s landscape of escalating volatility and change, learning how to adapt and navigate an increasingly uncertain "new normal" has become a primary objective for organizations across all industries. In management literature, the capacity to survive and thrive in such unpredictable environments requires specific organizational competencies known as Dynamic Capabilities (DCs), which encompass an organization’s ability to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments. A recent study utilizing the DCs framework provides profound insights into how developing these superior capabilities helps energy organizations endure and recover during periods of deep uncertainty (Norouzi Tioola, Kourosh (2022).

Employing an embedded case study design focused on Iran’s oil industry, an environment complicated by unique governing structures and prolonged external crises, such as severe sanctions—the research examined how capabilities are initiated, developed, and deployed under extreme conditions. The empirical findings demonstrated that highly uncertain, dynamic, and resource-constrained environments exponentially increase the need for organizations to practice DCs. Specifically, the study identified three distinct forms of dynamic capabilities: adaptive, absorptive, and innovative capabilities. Collectively, these competencies allow businesses to not merely survive extreme contexts, but to adapt and achieve sustainable growth.

This perspective on Dynamic Capabilities shares a profound theoretical alignment with the principles of Organizational Resilience and High-Reliability Organization theory that anchor the operational continuity of the Bacon-Manito Geothermal Project (BMGP). Much like the extreme, resource-constrained circumstances evaluated in the aforementioned study, geothermal resource utilization operates within a highly complex and volatile environment—managing high-pressure steam, highly corrosive fluids, and dynamic sub-surface threats. The adaptive, absorptive, and innovative capabilities identified in the DC framework directly parallel BMGP’s need to build the capacity to "anticipate, absorb, adapt, and learn" from forced outages.

Furthermore, the study offers a critical insight into the structural governance required to execute these capabilities. Unlike previous literature that often-framed DCs purely as a localized, firm-level management task, the findings illustrated that in non-market or highly complex political economies, the development of these capabilities requires collaborative stewardship. Because of their strategic nature, these capabilities are often initiated through top-down, state-driven guidance, but they are only operationalized successfully through the collective, bottom-up efforts of various operational actors.

This finding is highly relevant to the operational gaps identified at BMGP. Currently, BMGP's resilience is constrained by organizational silos and administrative centralization, where proactive responses are delayed by "zero-sum" budgeting and strict stage-gating. The dynamic capabilities study reinforces the premise that true adaptability under adverse conditions cannot be achieved through isolated, reactive technical fixes. Instead, as proposed in BMGP's Proactive Contingency Framework, it requires an "Adaptive Governance Structure". Just as the successful deployment of DCs in the oil industry required a synergy between macro-level strategy and ground-level execution, BMGP must combine top-down strategic support—such as Pre-Positioned Resilience Funds and Green-Lane Procurement—with bottom-up operational vigilance, such as the Chronic Unease Protocol executed by the site's maintenance teams. Ultimately, this literature reinforces the core argument of this dissertation: that surviving and thriving amidst disruptions requires bridging the gap between high-level administrative strategies and complex engineering realities.

Organizational and Strategic Resilience Theory

This stream provides the theoretical foundation for moving beyond technical restoration toward systemic continuity. Strategic resilience is a management capability that transcends simple failure recovery.

Foundational Resilience Concepts

Tengblad and Oudhuis (2019) defined organizational resilience not as the capacity to "bounce back," but as the organizational capacity to anticipate, absorb, adapt to, and rapidly recover from high-impact disruptions. This capability is fundamentally rooted in organizational structure, culture, and governance, rather than solely on technical safeguards.

Research further delineates the four core resilience capabilities (Hollnagel, 2014): (1) Anticipating: Knowing what to expect and preparing for it (e.g., risk assessment, scenario planning), (2) Monitoring: Knowing what is happening (e.g., systemic monitoring, weak signal detection) (3) Responding: Knowing what to do (e.g., effective, non-scripted intervention) and (4) Learning: Knowing what has happened (e.g., embedding lessons into future operations).

The literature confirms that high-reliability organizations (HROs) maintain continuity by prioritizing these adaptive capabilities over strict adherence to rigid pre-planned responses (Weick & Sutcliffe, 2015). This theoretical perspective highlights the need for BMGP to shift its focus from adherence to restoration procedures (reactive) to the institutionalization of adaptive capabilities (proactive and strategic).

Bridging Engineering and Management

While resilience literature is robust, a clear scholarly gap remains in its application to highly specialized, high-consequence engineering contexts like geothermal power. The concepts of anticipation and adaptation often remain abstract and untranslated into measurable, actionable frameworks for plant operators and mechanical engineering management, creating the theory-practice gap that this dissertation intends to close.

Applied Contingency Planning and Business Continuity Frameworks

This stream reviews existing models for formalized planning, examining how organizations structure their response to crises.

General Business Continuity Planning (BCP) and Disaster Recovery (DR) models emphasize identifying mission-critical functions, defining Recovery Time Objectives (RTOs), and creating hierarchical command structures for managing incidents (Contingency Planning Authority, 2018). These models are robust for corporate operations (e.g., IT, supply chain logistics) and often rely on standardized templates.

The integration of financial dimensions into traditional operational frameworks is a critical evolution in modern business continuity planning. This is effectively demonstrated in the study *"Developing a Comprehensive Risk Management Model for Integrated Electricity Providers: Insights from ISO 22301-Based Financial Impact Analysis."* Sutarmin, S., & Fitriani, L. . (2026). The research explores financial resilience strategies for integrated electricity service providers navigating global turbulence, supply chain disruptions, exchange rate volatility, and cyber threats. By extending the Business Impact Analysis (BIA) and Risk Maturity Index (RMI) of ISO 22301 standards which are traditionally applied strictly to operational aspects into the financial domain, the study provides a clearer risk landscape. Utilizing a mixed-method approach that includes risk heat mapping, stress testing, and scenario sensitivity testing, the findings revealed that electricity providers often operate at a low level of risk maturity (RMI 2.4 – developing phase) and face significant strategic risks regarding liquidity, tariff setting, infrastructure reliability, and cybersecurity. To enhance business continuity, the study emphasizes the need to identify specific crisis triggers and recommends strengthening asset management, improving human resource capacity, and exploring dedicated financial instruments for risk mitigation.

This perspective on financial resilience is highly applicable to the operational continuity challenges identified at the Bacon-Manito Geothermal Project (BMGP). As highlighted in the assessment of BMGP, traditional, generic Business Continuity Planning (BCP) models often fail because they do not account for the resource specificity and long lead-time components unique to geothermal operations. However, the ISO 22301-based study validates that true business continuity must explicitly map and resolve financial and liquidity bottlenecks. Similar to the integrated electricity providers facing strategic liquidity risks, BMGP's operational continuity is severely constrained by a rigid financial bureaucracy. The facility's reliance on a reactive "zero-sum" budgeting approach and tedious stage-gating acts as a massive bottleneck, forcing proactive resilience measures to compete with daily operational funds and "starving" other critical departments during sudden emergencies. Furthermore, strict deadlines for Purchase Requests on long-lead items create a dangerous "fiscal cliff," severely delaying critical emergency spending when infrastructure reliability is threatened.

The external study's recommendation to explicitly identify "crisis triggers" and utilize financial instruments for risk mitigation provides strong theoretical support for the financial interventions proposed in BMGP's Proactive Contingency Framework. To elevate BMGP from a reactive, low-maturity phase to a state of sustained strategic resilience, Phase 2 (Financial Process Flow) of the framework targets the exact financial vulnerabilities highlighted in the literature. Specifically, the recommendation to explore financial instruments perfectly aligns with the framework's establishment of a Pre-Positioned Resilience Fund (to decouple infrastructure hardening from standard budgets) and Emergency Financial Tiering (granting decentralized spending authority directly to Incident Commanders). Furthermore, the study's call to strengthen asset management mirrors the framework's technical requirement to execute a Core Technical Reclassification, ensuring BMGP's lifecycle planning (CARR-LTAP) is prioritized rather than treated as a secondary task.

Ultimately, integrating this financial impact analysis into the literature reinforces a core argument of the dissertation: BMGP cannot achieve true operational continuity through mechanical engineering alone. It requires an adaptive financial architecture capable of rapid, unhindered procurement during high-stakes disruptions

Strategic Resilience in Practice: The Tata Power Case

A highly relevant case study demonstrating the principles of Strategic Resilience and its application in managing widespread forced outages comes from the efforts of Tata Power in India to cope with severe climate events, which serve as an external shock analogous to a major, unplanned operational disruption.

This study details a holistic, risk-based approach to managing external threats, thereby informing the development of a robust contingency framework for the Bacon-Manito Geothermal Project (BMGP).

The core problem addressed by Tata Power was the recurring, severe risk posed by monsoons and cyclones, which routinely caused major, widespread forced outages across their network. Their response involved a multi-faceted Strategic Resilience program focusing on anticipatory and adaptive measures:

- Infrastructure Hardening and Mitigation: A significant portion of the strategy involved Grid Hardening, which served as a primary prevention and mitigation measure against physical damage. This included reinforcing poles and towers, upgrading foundations, and utilizing corrosion-resistant materials. Furthermore, the utility adopted Selective Underground Cabling in the most cyclone-prone areas to substantially reduce the frequency of outages and accelerate restoration time, mitigating the severity of the initial shock.
- Localized Resilience through Decentralization: Crucially, Tata Power implemented a strategy of localized resilience by piloting Solar + Battery microgrids and other Decentralized Backup solutions in remote regions. This strategic shift is directly relevant to BMGP, illustrating how a standalone power generator can develop the capability to maintain station service or critical loads during an external grid disturbance or a prolonged internal forced outage, thereby enhancing overall operational continuity.
- Emergency Preparedness and Contingency Response: The response framework was bolstered by rigorous Emergency Preparedness. This involved comprehensive annual mock drills, stockpiling essential restoration materials, and the strategic pre-deployment of approximately 15,000 personnel in advance of the monsoon seasons. This represents the practical implementation of a robust contingency response plan designed for immediate and effective execution.

The success of this comprehensive strategy was evidenced by the utility's performance following Cyclone Yaas in 2021. The rapid response and inherent resilience of the hardened system allowed for a significantly accelerated recovery, with supply being restored within just 48 hours in many affected areas, a result that demonstrates a high capacity for operational resilience and a reduction in the duration and impact of the forced outage event. This case study provides a strong model for how a utility can translate a strategic commitment to resilience into measurable improvements in forced outage management through disciplined risk-based planning and investment.

The theoretical underpinnings of Strategic Resilience and its subsequent quantification within a Contingency Framework are strongly supported by case studies from major utilities and academic work on smart grid technology. These examples demonstrate the efficacy of long-term risk mitigation investments and advanced deployment planning, which is highly relevant to establishing an effective forced outage management system at the Bacon-Manito Geothermal Project (BMGP).

Quantifying Resilience through System Hardening: The Florida Power & Light (FPL) Experience

The experience of Florida Power & Light (FPL) in the United States offers a clear, measurable example of how long-term infrastructure investment serves as a core resilience strategy against high-impact, low-probability risks. The primary challenge FPL faced was the severe and frequent damage caused by hurricanes, which historically resulted in multi-week-long power outages.

FPL's contingency strategy centered on Infrastructure Hardening, including key mitigation efforts such as replacing traditional wooden poles with steel and implementing various other system upgrades (Source 1.5). The tangible result of this long-term, risk-informed investment was most clearly observed when comparing the restoration efforts following two major storms: After the hardening efforts were substantially implemented post-Hurricane Wilma (2005), the impact of the equally powerful Hurricane Irma in 2018 saw power restored in the same affected areas in a matter of several days, a dramatic improvement over the several weeks required in the previous major event.

This FPL case study provides a practical, quantifiable metric for the proposed BMGP framework: the direct reduction in Mean Time to Restoration (MTTR) from a catastrophic forced outage. It validates the strategic principle that investment in resilient infrastructure directly lowers the duration and severity of disruption.

Integrating Advanced Technology into Contingency Planning

Complementing the infrastructure focus of the FPL case, academic research on Smart Grid technology and Mobile Emergency Resources provides a necessary technical framework for the active management and recovery phases of a contingency plan. This work addresses the risk of disruptions in distribution systems (DSs), which require maximum system resilience.

The key contingency and resilience strategies proposed in this academic literature include:

- Automated Fault Isolation: Utilizing smart grid technology for Network Reconfiguration to automatically reroute power and isolate faults. This ensures that a localized failure does not cascade into a widespread forced outage (Source 2.4).
- Optimal Resource Deployment: Developing a strategy for the optimal number and capacity of Mobile Emergency Generators (MEGs) and prioritizing their deployment to critical loads (Source 2.2).

The integration of these concepts directly informs the development of the BMGP Contingency Framework by establishing a crucial operational process. This involves: prioritizing critical loads (essential for plant self-sustainment or black start capabilities), optimizing the deployment of mobile/backup resources (such as portable welders, mobile substations, or rental generators), and embedding Resilience Metrics to consistently quantify and enhance system performance during and after a forced outage event.

Taken together, these two studies provide a robust template, linking strategic investment (FPL) with technical execution and quantification (Academic) to build a truly resilient forced outage management framework for a specialized facility like BMGP.

Theoretical Framework

This study was fundamentally rooted in Resilience Engineering (RE), which provides the necessary strategic perspective to move beyond reactive safety models. RE posits that safety and continuity are achieved not by preventing all failures, but by building the capacity to anticipate, absorb, adapt, and learn from disruptions. HRO theory emphasizes mindfulness, chronic unease, and a commitment to resilience, showing how organizations can manage complex, high-consequence environments (like geothermal plants) by prioritizing adaptive capabilities over rigid protocols. RE shifts the focus from "fixing the failure" (reactive) to "managing the systemic context of failure" (proactive). This directly supports your argument that BMGP needs to move beyond technical restoration toward strategic continuity.

Conceptual Framework

The conceptual framework is composed of three phases. Phase 1 supports the research foundation and problem. Through Strategic Resilience Theory, Technical Failure Analysis Literature, Generic BCP Models, Diagnostic Assessment of BMGP's Current Reactive Practices, research gaps will be identified. This is the disconnect between abstract RE principles and geothermal-specific technical management. The phase 2 is about the operationalizing resilience. This is the Developmental Phase where the core RE principles is translated into the Contingency Framework Components (Anticipating, Monitoring, Responding, Learning). A structured model with protocols tailored for geothermal resource specificity and dynamic threats through a draft Strategic Contingency Framework is expected to be done. The phase 3 focused on the solution of the problem. Expert Validation Data (from Delphi/SME Review) on Relevance, Feasibility, and Completeness is facilitated to validate the Geothermal-Specific Contingency Framework. This is the concrete solution ready for recommendation to management to ensure operational continuity.

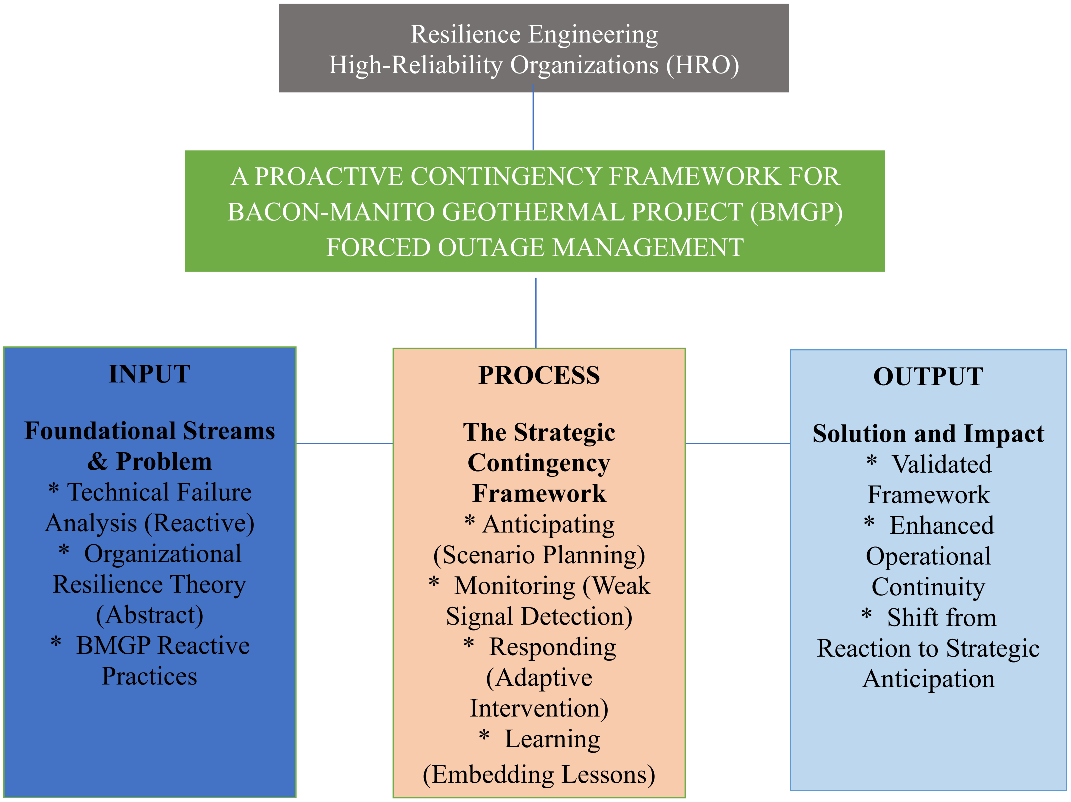


Fig. 1 *Theoretical and Conceptual Framework*

The review of related literature and studies reveals three distinct, yet currently disconnected, streams of inquiry relevant to operational continuity in the geothermal sector. The synthesis of these streams—Technical Reliability, Organizational Resilience, and Applied Contingency Planning—establishes the scholarly gap this dissertation intends to address.

The literature on Technical Reliability and Failure Analysis (Nogara & Zarrouk, 2017; *Technical Journal*, 2021) is robust in diagnosing the physical causes of failure (corrosion, scaling) and optimizing reactive maintenance protocols (PdM, MTBF/MTTR). This stream is highly effective at ensuring technical restoration, as evidenced by the author's prior MSME thesis on the Bacon-Manito Geothermal Project (BMGP). However, this focus is ultimately **reactive**, managing the effects of failure without addressing the systemic context of the operation.

The body of work on Organizational and Strategic Resilience Theory (Tengblad & Oudhuis, 2019; Hollnagel, 2014; Weick & Sutcliffe, 2015) offers the necessary proactive and strategic perspective. It defines resilience as the adaptive capability to anticipate, monitor, respond, and learn, establishing the theoretical foundation for high-reliability organizations (HROs). The key scholarly gap lies here: this theory often remains abstract and untranslated into measurable, actionable management and engineering frameworks specifically tailored for the high-consequence, specialized environment of geothermal power.

Finally, Applied Contingency Planning and Business Continuity Frameworks (Contingency Planning Authority, 2018) provide standardized structures for crisis management. While useful for general corporate functions, they prove insufficient for critical infrastructure like BMGP. They lack the necessary resource specificity (e.g., long lead-time components) and fail to account for the environmental dynamics (constant geological and chemical threats) unique to geothermal operations, requiring continuous adaptation beyond simple restoration.

The critical theory-practice gap is thus defined by the chasm between abstract strategic resilience principles and highly specialized engineering management practices. Current approaches are either excellent at fixing the problem (technical), excellent at defining an adaptive mindset (organizational), or excellent at generic process planning (BCP), but none successfully integrate all three into an actionable framework for the geothermal sector.

This dissertation addresses this gap by developing a Contingency Framework that (a) Bridges Engineering and Management that operationalizes the adaptive capabilities of resilience theory (Anticipating, Monitoring, Responding, Learning) into measurable, plant-level protocols, (b) Integrates Specificity that grounds the framework in the high-consequence technical realities of corrosion, scaling, and specialized resource needs unique to BMGP and (c) Shifts Focus from Reaction to Anticipation that moves beyond optimization for rapid restoration to the institutionalization of capabilities for strategic anticipation and adaptation.

In summary, the literature confirms the need to shift BMGP's management focus from rigid adherence to reactive restoration procedures toward the institutionalization of adaptive, strategic capabilities necessary for systemic operational continuity. This Contingency Framework is the mechanism to achieve that transition.

The core problem in the geothermal sector, particularly at facilities like the Bacon-Manito Geothermal Project (BMGP), is the strategic and organizational inadequacy in managing operational continuity despite high technical proficiency in failure restoration.

This problem can be delineated through the following key points, which establish a critical gap between theory, technical capability, and practice:

Reactive Management Predominance over Strategic Anticipation

Existing management structures are optimized for reactive restoration, excelling at mitigating the effects of forced outages (e.g., minimizing MTTR and maximizing technical repair speed, as discussed in the MSME thesis). However, this structure lacks institutionalized capabilities for strategic anticipation and systemic management of failure precursors (Hollnagel, 2014), leading to a continuous cycle of high-impact technical fixes rather than proactive risk elimination and adaptation.

The Un-Operationalized Theory-Practice Gap

While the theoretical foundation for Strategic Resilience exists (Tengblad & Oudhuis, 2019; Weick & Sutcliffe, 2015), providing a model for anticipating and adapting to high-impact disruptions, this concept remains abstract and untranslated into measurable, actionable management and engineering frameworks for specialized, high-consequence environments like geothermal power.

There is a clear scholarly and practical void in bridging the language and principles of organizational adaptability with the rigorous, technical requirements of mechanical engineering and plant operation.

Inapplicability of Generic Contingency Models

Standard Business Continuity Planning (BCP) and Disaster Recovery (DR) models are insufficient for the critical infrastructure context of geothermal energy because they are generic. They fail to account for the integrated nature of highly specialized technical systems, resource specificity (e.g., procurement of long lead-time components), and the need for continuous adaptation to dynamic geological and chemical threats that fundamentally change the operational baseline.

In essence, the field is characterized by a high-reliability technical operation embedded within a management paradigm that is structurally optimized for reaction, leading to a persistent vulnerability to systemic, high-consequence failures that could be strategically anticipated and mitigated.

This dissertation seeks to resolve this problem by developing and validating a Contingency Framework that operationalizes strategic resilience principles, thus shifting the focus from simply fixing failures to managing the systemic context of operational continuity in the geothermal sector.

The current body of knowledge and professional practice exhibits a significant theory-practice gap in ensuring operational continuity within highly specialized critical infrastructure, particularly the geothermal energy sector.

One of the gaps of the study is that there is a lack of empirical research and practical frameworks that successfully translate the principles of organizational resilience (Anticipating, Monitoring, Responding, Learning) into measurable, actionable management and engineering protocols specifically designed for the unique, integrated, high-consequence technical environment of geothermal power generation.

Another gap is maintaining the status quo in one organization. Operations like BMGP are currently managed by a paradigm that is heavily reactive—optimized for technical restoration—rather than proactive—optimized for strategic anticipation. No established framework exists that serves as a strategic bridging mechanism to harmonize the need for highly specialized technical response with the need for systemic, adaptive organizational management. This absence perpetuates a continuous cycle where management is forced to react to predictable technical failures rather than structurally mitigating the systemic context of those failures.

In summary, the research gap is the absence of a validated, Geothermal-Specific Contingency Framework that operationalizes strategic organizational resilience principles to manage technical-systemic risks, thereby shifting the industry's focus from rapid failure restoration to proactive operational continuity.

Objectives of the Study

The main objective of this dissertation is to develop and validate a Strategic Contingency Framework designed to enhance operational continuity and systemic resilience within the high-consequence environment of the geothermal energy sector, using the Bacon-Manito Geothermal Project (BMGP) as a primary case study.

Specifically, this study aims to achieve the following:

1. To assess the current state of strategic resilience capabilities at the Bacon-Manito Geothermal Project (BMGP) in managing forced outages, specifically evaluating the degree to which current management structures and operational protocols align with the core components of organizational resilience (Anticipating, Monitoring, Responding, and Learning).
2. To identify the challenges in BMGP that hinder the effective forced outage management (technical, financial and organizational).
3. To develop a comprehensive Strategic Contingency Framework that operationalizes the principles of organizational resilience by integrating:
   a. Specialized Technical Risk Management: Detailed protocols for anticipating and mitigating component integrity failures.
   b. Resource Specificity: Mechanisms for the rapid and pre-positioned procurement of long lead-time, specialized geothermal components.
   c. Adaptive Governance: A flexible command and control structure that facilitates non-scripted, adaptive intervention over rigid, pre-planned responses.
4. To validate the proposed framework with a panel of experts to evaluate its relevance, feasibility, and completeness.

METHODS

Research Design

To develop and validate a strategic contingency framework, the research design used primarily follow a Mixed-Methods design. The study employed a Descriptive, Developmental, and Evaluative research design to systematically address the research gap by moving from assessment to framework creation and, finally, to validation. The initial phase described and diagnosed the current state of practice at BMGP to ground the framework in empirical reality. The goal is to assess the gap between current reactive practices and desired strategic resilience capabilities. For the core phase which is the development and framework construction, the goal is to construct the Strategic Contingency Framework by integrating organizational resilience principles with geothermal-specific technical requirements. The final phase evaluated and validated the proposed framework for relevance, feasibility, and completeness to establish the viability and potential utility of the developed framework before recommending implementation.

Sources of Data

The primary data used for this research were gathered from the responses collected from the questionnaire including the result of FGD and interviews. The exported BAC-MAN Outage and Deration Monitoring Database of BMGP from 2022-2024, LTAP database, Maximo database, Budget Revision Request manual, Post Outage Meeting Minutes and Table of Organization were used as secondary data.

Study Population

The study population is provided in Table 1.

Table 1

Study Population

Respondents	Number
People’s Manager	8
Supervisor	2
Professional/Technical	10
Total	20

Note: Data included the total enumeration of respondents with 100% retrieval rate.

The respondents of this study were those involved in Facility Operations and Maintenance group in the restoration of BMGP during outages. The highest number of respondents came from the Maintenance department

Research Instrument

The core instrument used is the Semi-Structured Interview Protocol. This isn't just a casual chat; it’s a detailed, qualitative tool designed to probe the perceptions of key personnel from field operators up to senior management. The purpose here is crucial: to move beyond technical reports and understand the organizational capabilities for resilience. The researcher asked about their capacity to Anticipate future failures, monitor warning signs, respond effectively, and, critically, Learn from past incidents. This gave the human and cultural context of the problem. The second tool for the Diagnostic Phase is the Data Abstraction Form. This is a systematic, quantitative instrument used for Content Analysis of archival data—specifically, years of Forced Outage Reports and work order reports. This was used to quantify the data: to count the frequency of failure modes and establish verifiable patterns of reactive behavior. By combining the interview (why things happen) and the abstraction form (what actually happened), we get a complete diagnostic picture. Finally, in Phase 3, the Proactive Contingency Framework was made considering the results gathered in Phase 1 and Phase 2. A Validation Questionnaire (using a Likert scale) and open-ended questions designed to solicit quantitative ratings and qualitative feedback on the framework's components was used in this study.

Data Gathering Procedure and Data Analysis

For Phase 1, descriptive design was used to evaluate the current state of resilience capabilities at BMGP to ground the framework in empirical reality. This was conducted through a content analysis of outage reports and technical logs, different database and manuals supplemented by in-depth, semi-structured interviews with engineers, operators, and senior management.

In the Phase 2, the specific technical, financial, and organizational challenges that hinder effective outage management were identified. This was done through BMGP documents review such as the 2022 - 2024 BACMAN Outage Monitoring Database, BacMan Work Management System, Budget Revision Request Process, Post Outage Meeting Minutes and review of Table of Organization.

Finally in the Phase 3, data gathered from Phase 1 and 2 were synthesized to developed the Proactive Contingency Framework. A Rapid Delphi Technique was conducted. Researcher sent an email to expert reviewers containing 3 questions under Round 1. After collating the answers in Round 1, another email was sent to the expert containing 3 questions to conclude the review. The researcher used statistical measures like Frequency and Ranking, Mean, Mode and Range to assess consensus among experts and qualitative analysis to refine the framework based on expert recommendations. A validated and refined Strategic Contingency Framework ready for real-world pilot or implementation recommendation is the final output of this study.

Ethical considerations

The ethical considerations for this study center on the protection and professional respect of the human participants, particularly the Subject Matter Experts (SMEs) and BMGP personnel involved in interviews and framework validation.

Initially, a letter of request from the Facility Head was secured by the researcher. Since Informed Consent is mandatory in this type of research, all participants were fully informed about the study's purpose, procedures, and how their data will be used before they agree to participate.

The confidentiality and anonymity are paramount, especially given the sensitive nature of operational risk and proprietary knowledge in critical infrastructure. While the project (BMGP) is named as a case study, individual names, positions, or specific quotes that could lead to the identification of participants were anonymized and protected in all data handling and reporting. Data were aggregated, especially in the expert validation phase, to ensure no single expert's views are isolated or attributed.

The research maintained Scientific Integrity by reporting findings honestly, accurately representing expert consensus, and ensuring the framework validation process is unbiased. There was no coercion or undue influence to sway experts' validation of the proposed Contingency Framework.

Finally, the study recognized a duty of care toward the organization. The research findings, particularly the diagnostic assessment of BMGP's current protocols, will be communicated responsibly to management, focusing on areas for strategic improvement rather than assigning blame, thus ensuring the research is beneficial and non-harmful to the institution.

RESULTS AND DISCUSSION

Analysis of Resilience Capabilities at BMGP

The assessment of the Bacon-Manito Geothermal Project reveals a facility in a state of transition, moving away from reactive maintenance toward a framework of organizational resilience. When examining the first pillar of resilience, Anticipation, the findings suggest a strong foundation in asset-level management that is occasionally hindered by fiscal rigidity. This was supported by the results from the respondents using the Semi Structured Interview Protocol and the careful examination of BMGP's internal policies and existing processes. During the interview, it was found out that BacMan has implemented the so-called Reliability Centered Maintenance (RCM). This process identifies the criticality of equipment in the plant and facilitate task selection review. The Subject Matter Experts (SME`s) identified the list of critical equipment and shall collaborate with SKF (third party) to discuss all identified critical assets on its equipment failure modes, effects and criticality analysis including task selection.

Another asset-level resiliency program in BMGP is the Critical Asset Risk Registry-Long Term Asset Planning (CARR-LTAP). Long Term Asset Plan (LTAP) also called Lifetime Asset Plan or Asset Lifecycle Plan encompasses all stages of the asset lifecycle to ensure compliance, maximize value, minimize costs, and manage risks effectively. The primary goal is to ensure that assets are available, reliable, and performing optimally throughout their entire useful life. At its core, LTAP is about moving away from "firefighting" (reactive maintenance) and toward sustainable stewardship. While most business plans look 1–3 years ahead, an LTAP typically spans 10 to 30 years. The ultimate goal is to ensure that an organization can deliver its required level of service at the lowest possible cost over the entire lifecycle of its assets, while managing acceptable levels of risk.

The LTAP is updated semi-annually during the annual budget cycle (as part of capital allocation exercise) and at the end/start of the year (as part of year-end review and/or strategic planning). Based on the data, there are six (6) expected insights that can be drawn from the LTAP such as Repair vs Replace decisions, Optimal Maintenance Strategies, Future Investment and Budgeting, Resource Allocation, Performance and Efficiency Optimization and Risk Mitigation and Compliance. The implementation of Reliability Centered Maintenance (RCM) and use of Critical Asset Risk Registry-Long Term Asset Planning (CARR-LTAP) to categorize over 2,000 pieces of equipment demonstrate a sophisticated approach to identifying criticality. However, a divergence exists between new and legacy units; while older units benefit from decades of historical data, newer units remain tethered to Original Equipment Manufacturer (OEM) predictions.

The overall process is simplified in Fig. 2 Asset Lifecycle Management below.

Fig. 2 *Asset Lifecycle Management Process Flow*

Another significant finding in this area is the "Stage Gating" process for procurement. According to the interview, while this ensures financial oversight, it creates a strategic tension during the pre-positioning of long lead-time components. Because infrastructure hardening is often viewed through the lens of "cost per kWh" rather than a dedicated resilience budget, the project's ability to proactively harden against systemic shocks remains dependent on immediate economic rationalization rather than long-term risk mitigation. The Stage Gating is part of the project management guiding the project work to deliver the intended outcome. The Stage-Gate process aims to maximize the value realized from all of the company's projects. Through the 5 stage-gate approach, the key issues to strengthen the project delivery is addressed. Depending on the cost and complexity, projects are gated at the vertical and enterprise level. The overview of the process is projected in Fig. 3 Stage Gating Process.

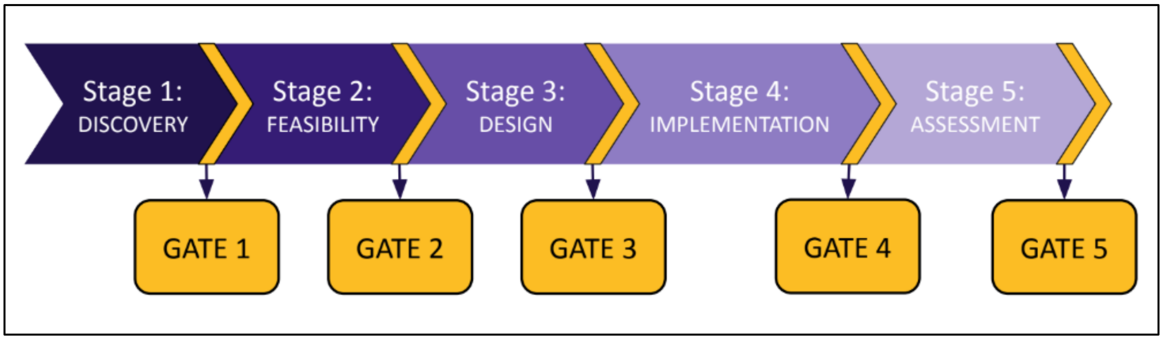


Fig. 3 *Stage Gating Process*

Monitoring pillar, or Weak Signal Detection, BMGP exhibits a high degree of technical competence that has not yet fully matured into a cultural "chronic unease." This was based on the interview result where data confirms that vibration analysis and ultrasonic gauging are standard practices used to establish equipment health. However, these tools are primarily utilized as threshold triggers—signaling a need for repair once a parameter is breached—rather than as a holistic "condition-based operational baseline" that informs total system health. There is also a notable stratification in how signals are processed. High-risk, non-redundant assets receive daily scrutiny, while non-critical assets are monitored monthly as mentioned by one of the interviewed personnel. This hierarchy, while practical for resource allocation, leaves the project vulnerable to the normalization of deviance, where subtle anomalies in secondary systems might be dismissed until they escalate into a forced outage.

Response pillar at BMGP showcases a robust technical flexibility supported by the established Management of Change (MOC) protocol. As per interview to one of the people managers, he acknowledged the importance of MOC in adaptive decision making. MOC is a systematic approach to manage risks ensuring delivery of desired outcomes while safeguarding operations, employees and assets. Facility Operations and Maintenance (FOM) MOC process covers permanent and emergency changes affecting health, safety and environment (HSE), infrastructure, process controls, procedures and software. This MOC framework in Figure 4 allows people managers and engineers to implement non-scripted interventions and quick fixes to shorten outage durations, effectively bypassing the limitations of rigid restoration scripts.

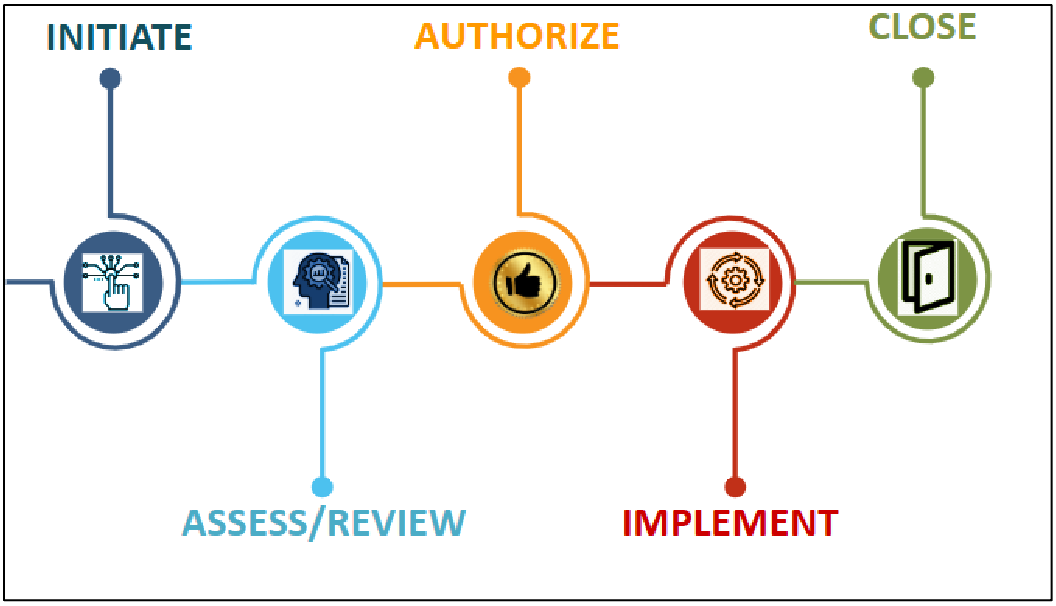


Fig 4. *Management of Change Framework*

Despite this technical agility, the findings identify a significant organizational barrier in the form of administrative centralization. During the interview it was learned that in terms of financial, the requirement to wait for a Budget Single Point of Contact (SPOC) to approve Internal Orders for emergency materials acts as a localized bottleneck.

During forced outages, emergency budget addition/supplement will be requested by the budget SPOC where a valid justification shall be submitted. A justification should provide the background of the item/activity and explain why the Budget Revision Request (BRR) is necessary and tagged as emergency. Several attachments are also needed for the budget request to be approved such as cost basis (quotation, bid summary, purchase order, cost estimate computation, etc), draft/final contract (if available), approved budget addition/supplement sign-off (BASS) kissflow.

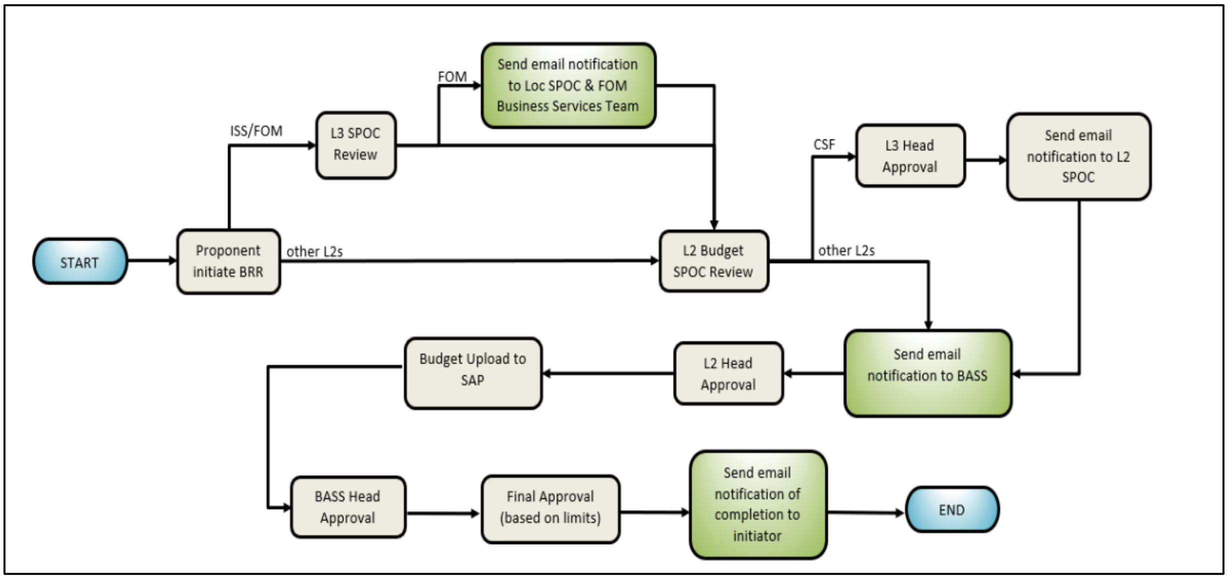


Fig. 5 *Emergency Budget Requests Workflow*

As per study, the only difference in the process workflow in requesting the budget from Non-Emergency and Emergency request was the skipping of L2 Budget SPOC review process visible below in Fig. 6 Non-Emergency Budget Requests Workflow.

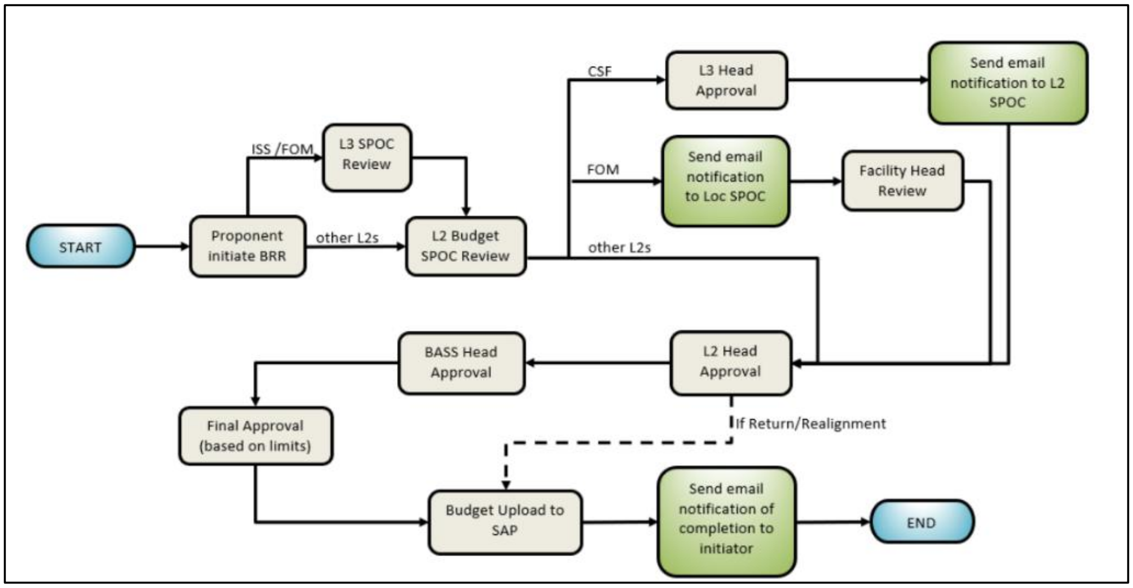


Fig. 6 *Non-Emergency Budget Requests Workflow*

The absence of decentralized financial authority, such as emergency petty cash or pre-approved vendor protocols for outages, suggests that the "Adaptive Governance" required for true resilience is currently constrained by the company's broader financial bureaucracy.

Finally, the Learning pillar represents the most significant area for growth within the BMGP ecosystem. Currently, the post-outage process is heavily weighted toward the "technical fix" through Root Cause Analysis (RCA), majority of interviewees responded. While this successfully addresses mechanical failures, it frequently overlooks the systemic and organizational precursors—such as procurement delays or staffing gaps—that allow a failure to escalate. When the respondents were asked if there's an existing formalized, searchable Lessons Learned Database, they all answered none so far. This situation may cause a failure to explicitly link outage findings to the revision history of Standard Operating Procedures. Without these elements, knowledge remains siloed within specific teams or shifts rather than being embedded into the organization. Consequently, it was also learned during the interview that while BMGP is proficient at fixing the machine, it has yet to fully implement the feedback loops necessary to evolve the system.

Challenges in Forced Outage Management

For this objective, the specific technical, financial, and organizational challenges that hinder effective outage management were identified. This was done through BMGP documents review such as the 2022 - 2024 BACMAN Outage Monitoring Database, BacMan Work Management System, Budget Revision Request Process, Post Outage Meeting Minutes and review of Table of Organization.

A. Technical and Operational Challenges

During the said review, it was found out that the primary technical challenge is the persistence of "known-knowns," as evidenced by the 2022–2024 Outage Monitoring Database.

Below are the summarized plant outages of BMGP for 2022 in terms of unit and system. In Fig. 10, it is shown that Unit 3 got the highest number of unplanned outages followed by Unit 1 and last was Unit 2. Fig. 7 describes that Switchyard system caused the greatest number of outages followed by the Circulating Water System. Fig. 8 shows that circulating water system caused the highest percentage of outages in Unit1 while the switchyard problem was the main cause of outages in Unit 2. Turbine system however was the main reason for Unit 3 shutdowns followed by switchyard again.

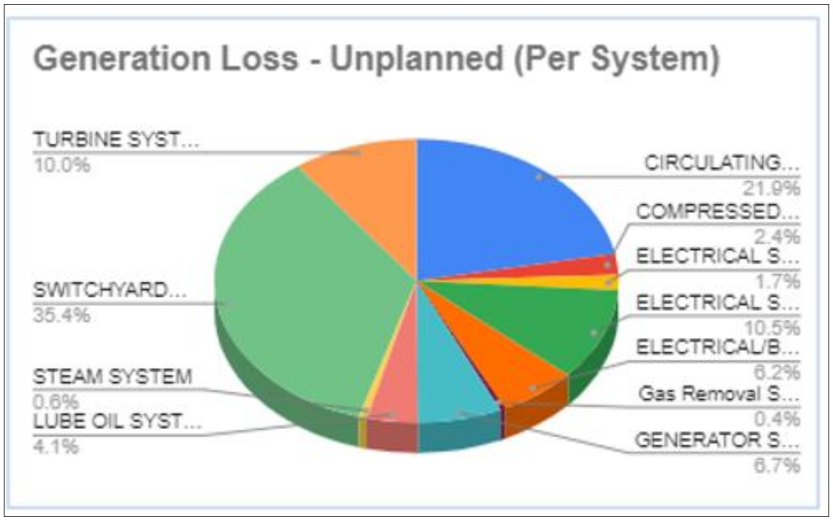


Fig 7. *Summary of Plant Outages per System (2022)*

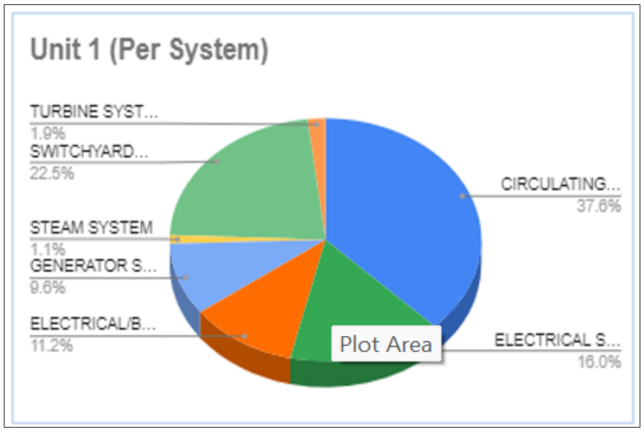


Fig 8. *Plant Outage Summary (Unit 1)-2022*

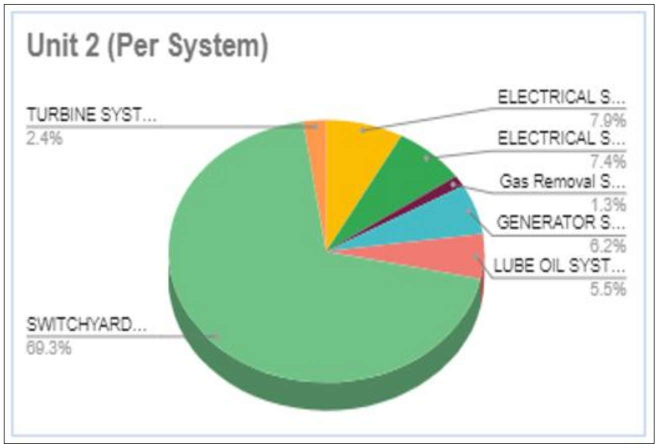


Fig. 9 *Plant Outage Summary (Unit 2)-2022*

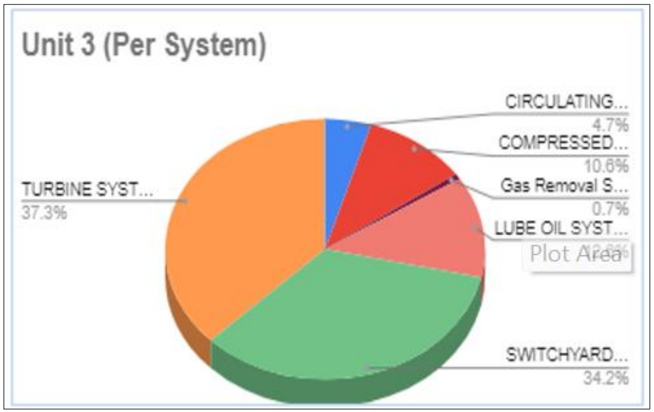
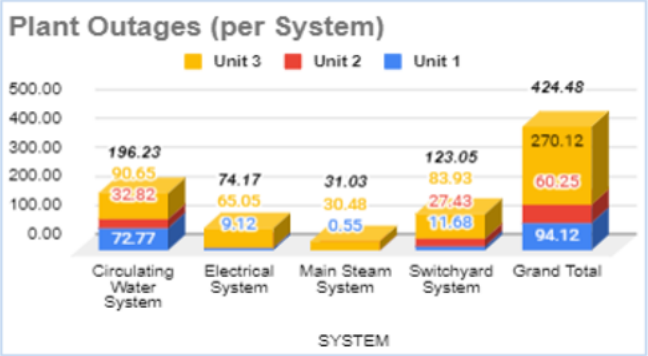


Fig. 10 *Plant Outage Summary (Unit 3)-2022*

Below are the summarized plant outages of BMGP for 2023 in terms of unit and system:



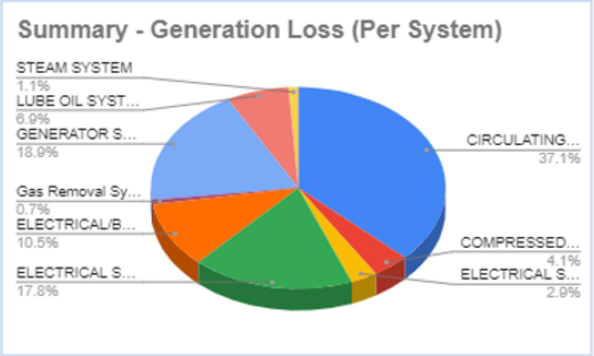
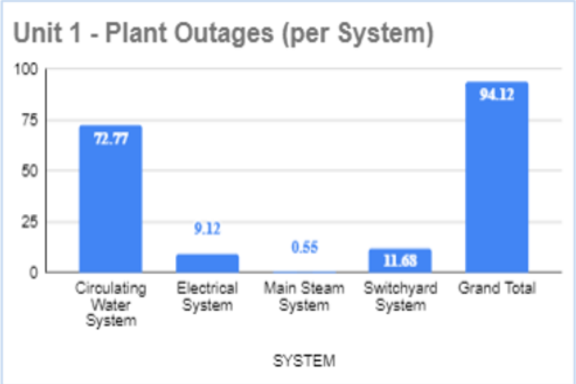


Fig. 11 *Summary of Plant Outages per Unit (2023)* Fig. 12 *Summary of Plant Outages per System (2023)*



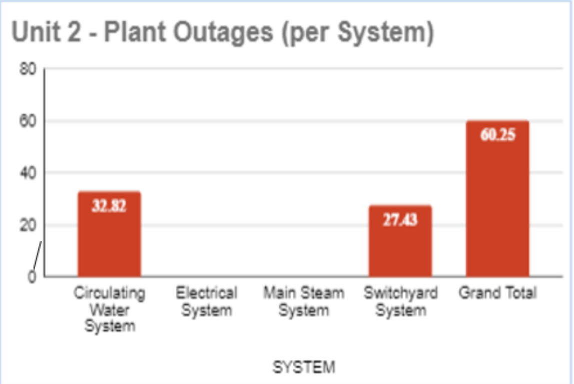


Fig. 13 *Plant Outages Summary Unit 1(2023)* Fig. 14 *Plant Outages Summary Unit 2 (2023)*

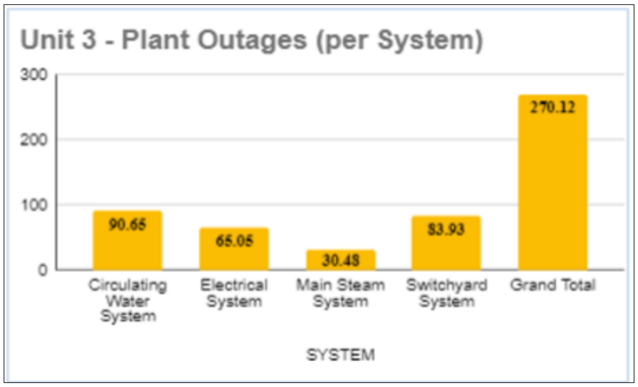
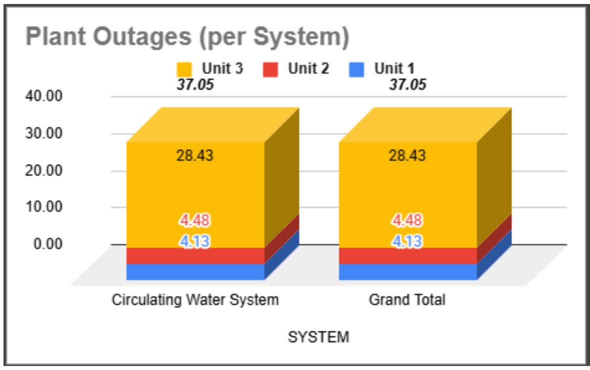


Fig. 15 *Plant Outages Summary Unit 3 (2023)*

The summarized graph shows that Unit 3 had the highest number of forced outages while Unit 1 has the lowest number of outages. Also, circulating water system has the greatest number of incidents causing the outages in the plant.



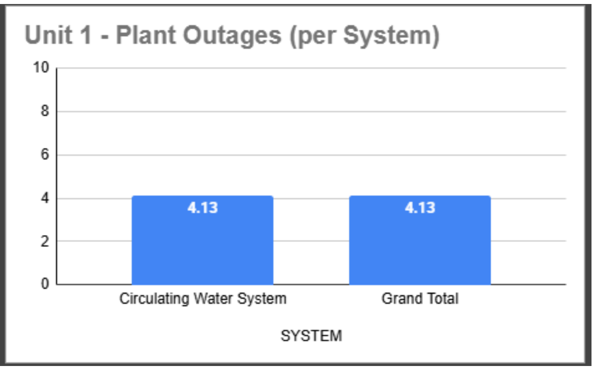
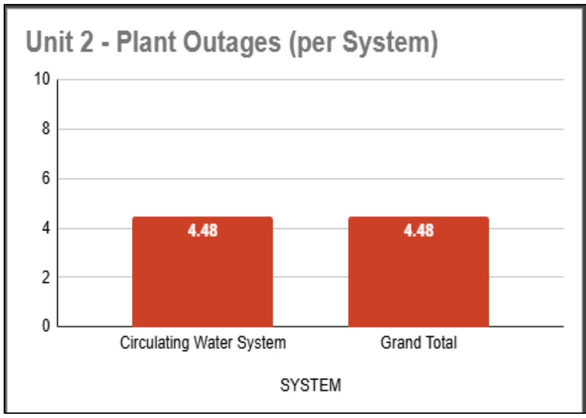


Fig.16 *Summary of Plant Outages per System (2024)* *Fig.17 Plant Outage Summary (Unit 1)-2024*



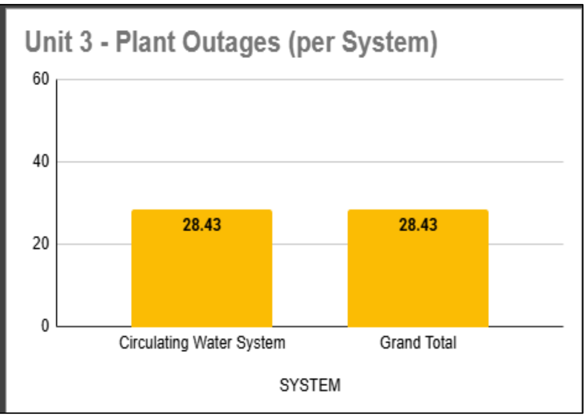


Fig. 18 *Plant Outage Summary (Unit 2)-2024* *Fig. 19 Plant Outage Summary (Unit 3)-2024*

Above are the summarized plant outages of BMGP for 2024 in terms of unit and system.

The Summary of Plant Outages per System (2024) in Fig. 16 including Figures 17, 18 and 19 shown that Circulating Water System dominated the cause of outages in all units in BacMan.

These results mean that despite being identified as a top failure driver in previous years, the Circulating Water System remains the leading cause of outages in 2024. This suggests a gap in the Learning pillar where technical fixes are being applied to symptoms rather than systemic root causes.

In terms of Work Management System, BMGP relies on the use of Maximo application. Both Preventive Maintenance (PM) and Corrective Maintenance (CM) plans and schedules can be extracted in this program.

Figure 20 below shows the PM Work Orders Monthly Statistics and Table 2 is for the PM Work Orders Monthly Trend. An analysis of the 2025 Preventive Maintenance (PM) Work Orders Monthly Trend reveals a highly active, yet fluctuating, maintenance schedule at the Bacon-Manito Geothermal Project (BMGP). Throughout the year, the volume of generated PMs varied significantly, peaking in August with 333 work orders and recording its lowest volume in December with 146. Notably, the data demonstrates that the plant maintained a perfect 100% "Closure Rate" across all twelve months, meaning that every generated PM work order (e.g., all 333 in August and all 183 in January) was formally closed out in the system.

However, a closer examination of the "Actual Completion Rate" reveals a nuanced operational reality. Despite the 100% closure rate, the actual completion of these tasks ranged from a low of 90% in January to a high of 100% in December. This discrepancy is driven by the volume of "Cancelled/Compnoact" work orders. Cancellations were particularly prevalent in the first quarter of the year, with 19 cancellations in January, 16 in February, and 14 in March, which dragged the actual completion rates down to 90%, 92%, and 94% respectively. Performance stabilized in the middle and latter halves of the year, with completion rates hovering between 97% and 99%, before finally achieving the 100% gold standard in December, where zero PMs were cancelled.

These findings strongly align with the systemic technical and operational challenges identified at BMGP. As noted in the broader assessment of the facility, while the Work Management System (WMS) indicates a proactive maintenance posture, consistently achieving a perfect actual completion rate remains elusive. The cancelled PMs observed in the 2025 data are indicative of the facility's vulnerability to external and internal disruptions. According to the interview PM schedules are frequently derailed by environmental factors, force majeure, or the necessity to overlap corrective maintenance tasks to address sudden failures.

Ultimately, this trend highlights a critical vulnerability in the plant's strategic anticipation. When proactive maintenance tasks are cancelled to accommodate emergent issues, it creates a maintenance backlog ripple effect. Consequently, PMs that are delayed or cancelled in one monthly cycle increase the systemic risk of equipment degradation and forced outages in the next, keeping the facility tethered to a reactive restoration culture rather than sustained proactive continuity.

Fig. *20 2025 PM Work Orders Monthly Statistics*

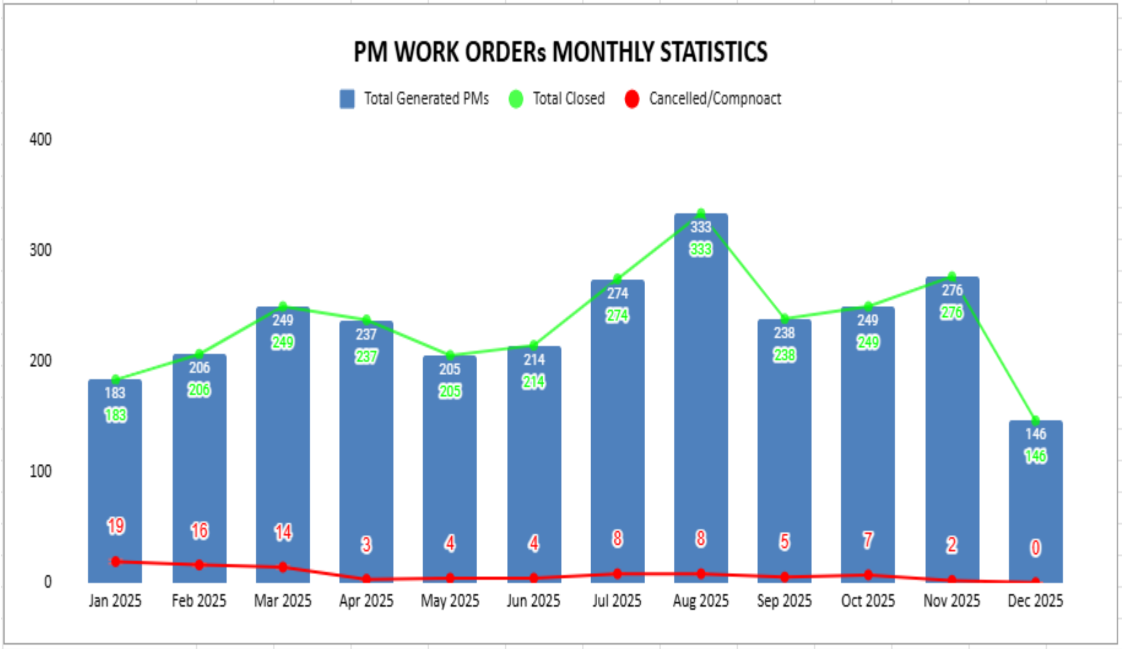


Table 2. *2025 PM Work Orders Monthly Trend*

2025 PM WORK ORDERS MONTHLY TREND												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Generated PMs	183	206	249	237	205	214	274	333	238	249	276	146
Total Closed	183	206	249	237	205	214	274	333	238	249	276	146
Cancelled /Compnoact	19	16	14	3	4	4	8	8	5	7	2	0
Actual Completion Rate	90%	92%	94%	99%	98%	98%	97%	98%	98%	97%	99%	100%
Closure Rate	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure 21 below shows the CM Work Orders Monthly Statistics and Table 3 is for the PM Work Orders Monthly Trend. An analysis of the 2025 Corrective Maintenance (CM) Work Orders Monthly Trend provides a stark visualization of the reactive operational challenges at the Bacon-Manito Geothermal Project (BMGP). Over the course of the year, the facility generated a total of 1,138 CM work orders, successfully closing 974, which resulted in an overall annual closure rate of 86%.

However, a month-by-month breakdown reveals a troubling downward trajectory in the plant's ability to keep pace with equipment failures as the year progresses.

In the first quarter, the facility demonstrated a strong capacity to manage corrective tasks, achieving a perfect 100% closure rate in January and February, and maintaining a high 98% in March. As the year advanced into the second and third quarters, the volume of generated CMs experienced significant spikes, particularly in July with 153 generated work orders and October with 154. These surges in corrective tasks are highly indicative of recurring systemic failures, such as the persistent issues with the Circulating Water System identified as leading causes of outages.

Crucially, as the volume of reactive work increased, the plant's closure rate steadily deteriorated. By the fourth quarter, the closure rate plummeted drastically, falling to 73% in September and October, 64% in November, and ending the year at 66% in December.

This declining trend vividly illustrates the maintenance backlog ripple effect discussed in the broader study. The data suggests that as corrective maintenance tasks pile up—likely aggravated by forced outages or sudden equipment degradation, the maintenance staff becomes overburdened and is unable to close out work orders efficiently. This accumulation of unresolved CMs directly derails preventive maintenance (PM) schedules, forcing proactive tasks to compete with urgent, reactive fixes.

Finally, this CM trend confirms that BMGP remains entrenched in a reactive restoration culture. The inability to sustain high closure rates during periods of increased failure demonstrates that the facility cannot simply repair its way out of systemic vulnerabilities. It reinforces the urgent need to implement the proposed Proactive Contingency Framework specifically the Condition-Based Operational Baseline to shift the plant's focus from merely fixing broken components to anticipating and mitigating these failures before they trigger a cascade of unmanageable corrective work orders.

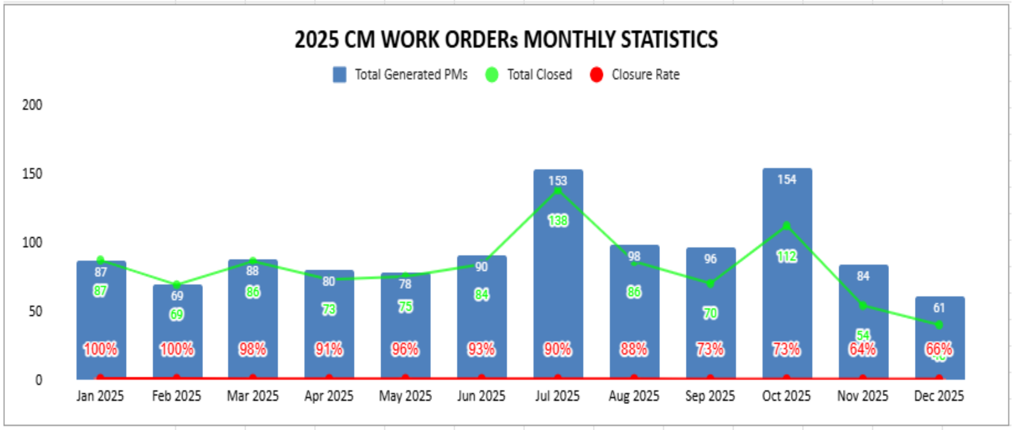


Fig. 21 2025 *CM Work Orders Monthly Statistics*

Table 3. 2025 CM Work Orders Monthly Trend

2025 CM WORK ORDERS MONTHLY TREND												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Generated CMs	87	69	88	80	78	90	153	98	96	154	84	61
Total Closed	87	69	86	73	75	84	138	86	70	112	54	40
Closure Rate	100%	100%	98%	91%	96%	93%	90%	88%	73%	73%	64%	66%

B. Financial and Budgetary Challenges

The financial framework at BMGP, while designed for fiscal discipline, introduces significant rigidity during emergency or proactive restoration efforts. This rigidity becomes a critical vulnerability when evaluating the immense cost of delayed recovery. A fast restoration response is absolutely essential, as every single hour of a forced outage translates directly to severe financial bleeding for the facility.

To illustrate the major financial impact of these delays, the Equivalent Generation Loss (EGL) can be computed using the formula: *EGL = Outage hours x Rated Capacity x Blended Tariff*. Assuming the current blended tariff is at Php 5.03:

- For Units 1 and 2: EGL = 1 hour x 60 MW x 1,000 KW/MW x Php 5.03 = Php 301,800.00 per hour
- For Unit 3: EGL = 1 hour x 20 MW x 1,000 KW/MW x Php 5.03 = Php 100,600.00 per hour

The empirical magnitude of these challenges is underscored by the 2022 and 2023 Outage Monitoring Databases. As shown in Table 4, BMGP incurred a total generation loss of approximately Php 92.6 million in 2022, with January alone accounting for over Php 56 million in losses due to 268.11 outage hours.

This trend continued into 2023, where the facility suffered around Php 81.5 million in generation losses. Notably, the months of April, October, and May experienced the highest financial impacts, driven by substantial outage durations. The impact of these recurring multi-million-peso losses on the BMGP organization is profound, as they directly threaten operational continuity and institutional stability. Centered on these staggering figures, centralized administrative processes and budgeting bottlenecks become critical threats. The current "zero-sum" Budget Revision Request (BRR) process forces departments to sacrifice one another to fund sudden technical necessities, often leading to inter-departmental conflict and the postponement of other activities. Furthermore, the five-stage "Stage Gating" process acts as a significant bottleneck; the focus on immediate Return on Investment (ROI) often results in the deprioritization of proactive resilience measures that lack an immediate Net Present Value (NPV) benefit.

Table 4. BACMAN Outage Monitoring Database 2022-2023

Month	2022			2023		
	Outage Hours	Generation Loss (MWh)	Equivalent cost (Php)	Outage Hours	Generation Loss (MWh)	Equivalent cost (Php)
January	268.11	11,189.57	56,283,537.10	29.883	1,184.32	5,957,129.60
February	31.05	666.23	3,351,136.90	47.52	875.98	4,406,179.40
March	69.316	1,638.73	8,242,811.90	0.55	29.38	147,781.40
April	37.62	222.96	1,121,488.80	118.12	5,673.82	28,539,314.60
May	15.63	624.99	3,143,699.70	80.55	1,958.81	9,852,814.30
June	51.98	1,820.43	9,156,762.90	38.07	1,092.64	5,495,979.20
July	7.38	363.22	1,826,996.60	5.6	285.82	1,437,674.60
August	0.233	12.92	64,987.60	52.05	1,786.25	8,984,837.50
September	8.60	474.13	2,384,873.90	27.7	542.48	2,728,674.40
October	66.67	1,232.69	6,200,430.70	51.15	2,726.02	13,711,880.60
November	4.4	168.38	846,951.40	0.4833	22.25	111,933.90
December	-	-	-	0.45	23.90	120,217.00
Total Generation Loss (Php)			92,623,677.50			81,494,416.50

Finally, the strict deadline for Purchase Requests (PRs) on long-lead items creates a dangerous fiscal cliff. If a vulnerability is discovered after this date, the organization must navigate a complex "Budget Lift" prohibition, exposing the plant to continuous hourly losses of hundreds of thousands of pesos while waiting for budget additions.

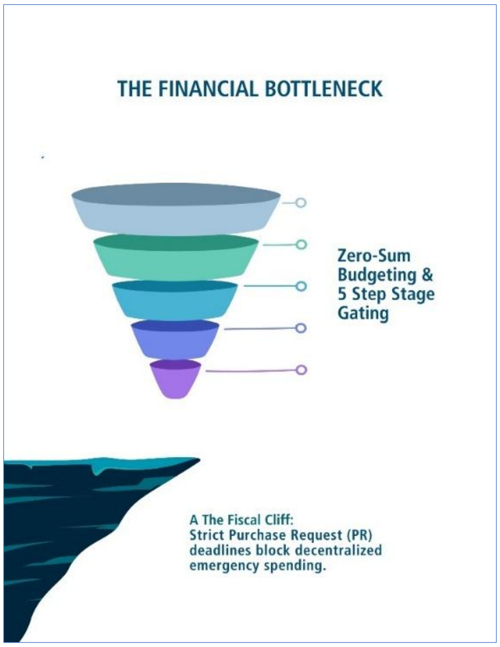


Fig. 22 *Financial Bottleneck*

While the exact monetary value of implementing the finalized Proactive Contingency Framework cannot be precisely pre-calculated, the integration of these results confirms that such a framework will surely lessen the recurring generation losses by addressing the systemic financial bottlenecks that currently hinder rapid restoration and proactive hardening.

C. Organizational and Structural Challenges

As revealed during BMGP documents review and interviews, organizational barriers at BMGP center on a lack of specialized resilience roles and a limited feedback loop in post-incident reviews. Part of the interview discovered that although a Risk Management Department exists at the head office, its focus is primarily on insurance and disaster risk rather than the granular, technical plant outage risks specific to geothermal operations. At the site level, risk management is not a dedicated function but is instead an added task for the Maintenance Manager, leading to a dilution of focus between daily operations and long-term strategic resilience.

This structural gap is mirrored in the Post-Outage Meeting Minutes, which consistently focus on the "what and how" of the mechanical fix rather than the "systemic why." The absence of a formalized feedback loop means that organizational precursors such as procurement delays, staffing gaps, or communication silos are rarely addressed. Consequently, the organization effectively repairs its assets but fails to evolve its processes, leaving the facility vulnerable to the same failure modes in a repeating cycle.

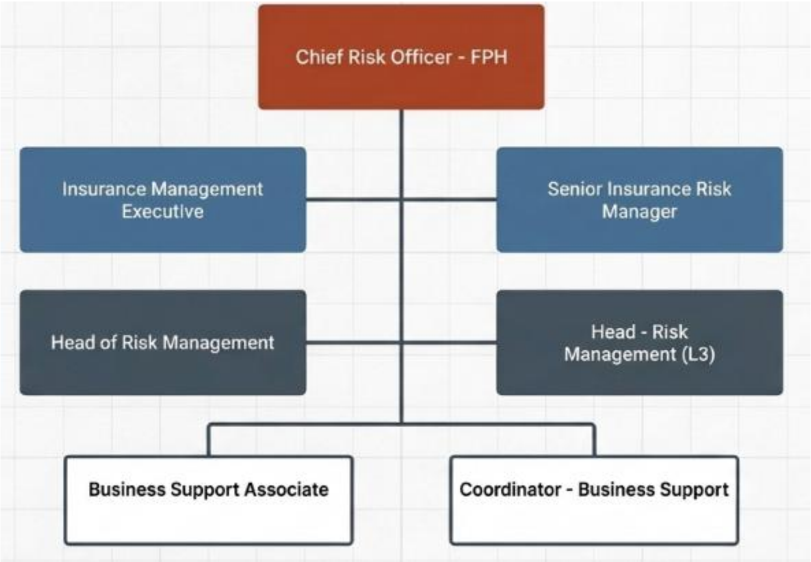


Fig. 23 *Risk Management Department Organizational Chart*

In conclusion, addressing Objective 2, systemic challenges were identified across three categories. Technically, the plant struggles with recurring issues, specifically the Circulating Water System being the leading cause of outages, compounded by a maintenance backlog ripple effect. Financially, a zero-sum budgeting approach and strict stage-gating cause severe bottlenecks, forcing proactive projects to compete with daily operational funds. Organizationally, risk management at the site level is an added task for the Maintenance Manager rather than a dedicated strategic role, diluting the focus on long-term resilience. This discussion is simplified in Fig. 24 below.

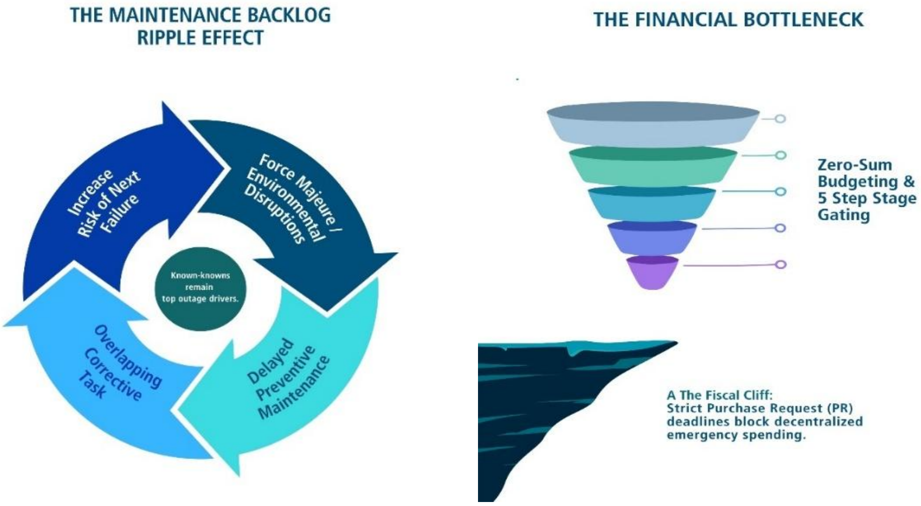


Fig. 24 *Systemic Challenges in BMGP*

Development of Proactive Contingency Framework

The development of the Proactive Contingency Framework was directly driven by the specific operational challenges or triggers identified during the assessment of the facility. Based on the framework's process flowchart shown in Fig. 25 below, these results and their corresponding framework interventions are structured into three distinct phases.

In Phase 1, the framework addresses the Technical Process Flow concerning operations and data, with the ultimate goal of shifting the plant from reactive maintenance to condition-based predictive operations. The assessment results revealed significant technical hurdles, primarily recurring failure modes such as those continuously detected in the Circulating Water System. Additionally, routine preventive maintenance was frequently hindered by overlapping corrective work and force majeure. The data also showed that long-term lifecycle planning was compromised because maintaining CARR-LTAP data integrity was treated as a secondary, add-on task. To resolve these triggers, the framework implements a Condition-Based Operational Baseline that integrates real-time brine chemistry data with Maximo systems, effectively replacing reactive fixes with a predictive operational model. It also activates a Chronic Unease Protocol to prioritize the detection of weak signals in non-critical assets, ensuring minor issues are caught and prevented from escalating into major outages. To secure data integrity, a Core Technical Reclassification is executed to elevate data auditing to a primary, core function, ensuring 30-year operational projections are accurately field-verified.

Phase 2 tackles the Financial Process Flow, targeting budget and procurement systems to eliminate the bottlenecks that prevent rapid emergency and proactive spending. The findings highlighted that the facility was heavily constrained by Zero-Sum Budgeting, which required budget offsets that essentially starved other critical departments whenever a sudden technical necessity arose. Furthermore, tedious Stage Gating bottlenecks delayed the procurement of proactive and long-lead items, while administrative centralization—such as waiting for a Budget SPOC to approve internal orders—significantly delayed restoration efforts during active outages. To overcome these financial constraints, the framework establishes a Pre-Positioned Resilience Fund designed to decouple infrastructure hardening and safety-critical projects from standard budget pools, allowing proactive projects to be funded without cannibalizing daily operational budgets. It further initiates "Green-Lane" Procurement, which exempts high-risk and long-lead items from standard purchase request deadlines and simplifies gating to procure resilience-critical assets faster. To ensure an immediate response during crises, the framework applies Emergency Financial Tiering, granting decentralized spending authority directly to the Incident Commander to enable immediate, over-the-counter emergency procurement.

Finally, Phase 3 addresses the Organizational Process Flow, focusing on governance and learning to break down institutional silos. Organizationally, site-level risk management was found to be siloed and treated merely as an extra task for the Maintenance Manager rather than a dedicated strategic role. Post-outage reviews suffered from a severe lack of feedback loops, focusing almost entirely on the mechanical technical fix. This resulted in severe knowledge fragmentation, where vital lessons learned remained unsearchable and completely unlinked to Standard Operating Procedure (SOP) revisions. To institutionalize systemic learning, the framework deploys an Adaptive Governance Structure that formalizes technical experts within the command chain, shifting the focus from generic insurance risk to plant-specific outage risk. It systematically mandates Systemic Root Cause Analysis (S-RCA) to formally evaluate procurement, staffing, and process delays alongside mechanical failures, establishing a holistic view of the failure as the official restoration record. Ultimately, this knowledge is centralized by creating a Dynamic Lessons Database that automatically triggers updates to engineering standards and training protocols, actively preventing the recurrence of known failures.

This alignment ensures that the Proactive Contingency Framework is not merely a theoretical exercise but a targeted intervention for the specific operational realities of the BMGP. By addressing these nine critical friction points, the organization can successfully transition to a state of sustained strategic resilience.

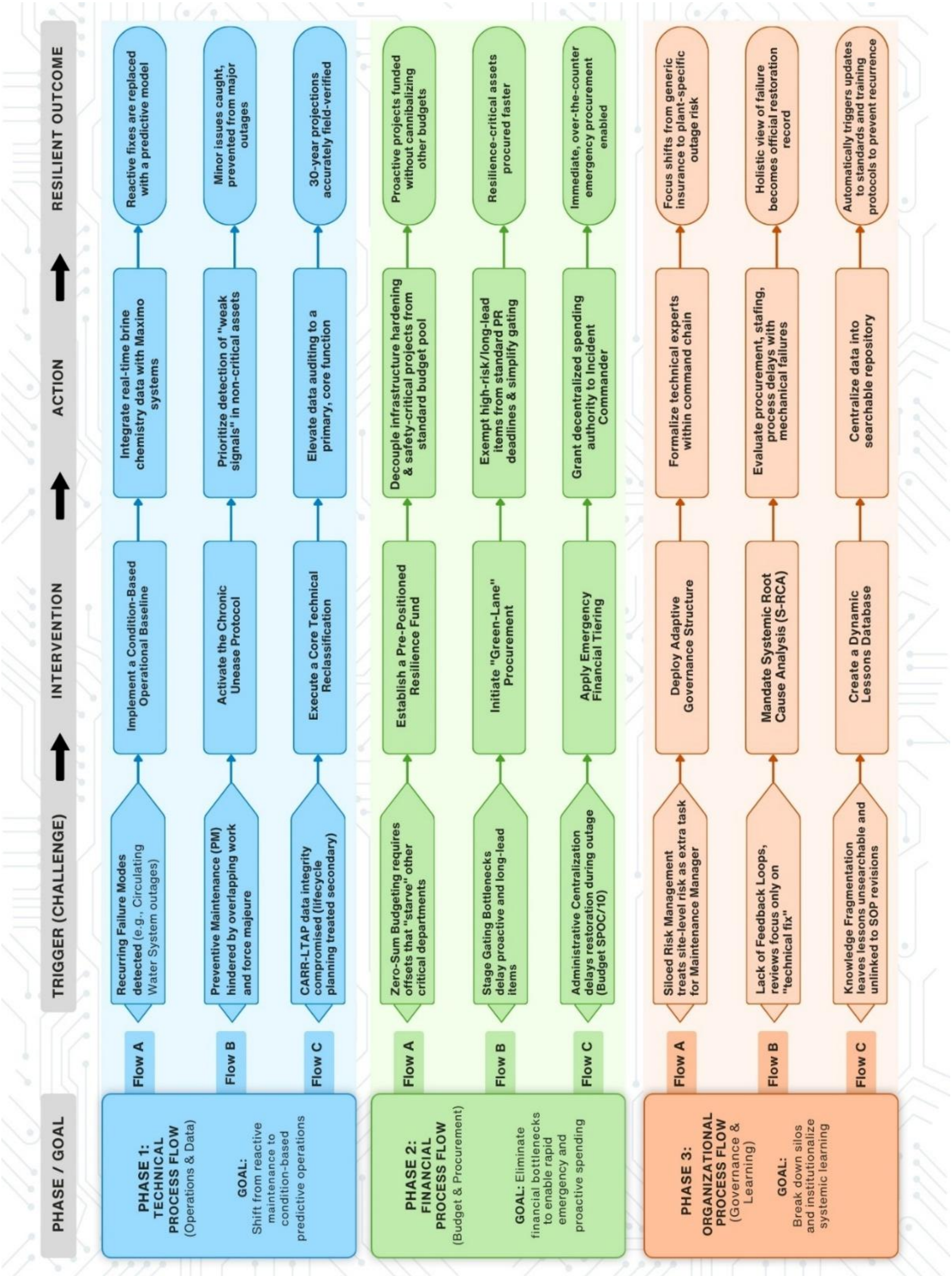


Fig. 25 *Operational Resilience Framework: Process Flow Chart*

Validation of Proactive Contingency Framework

To validate the proposed Proactive Contingency Framework and ensure its practical viability within the highly specialized environment of the Bacon-Manito Geothermal Project (BMGP), a Rapid Delphi method was conducted. This validation phase engaged a targeted panel of Subject Matter Experts directly involved in restoration responses, including representatives from maintenance, procurement, and finance. The panel evaluated the framework across three core areas: the realism of fast-tracked procurement, the actionability of predictive technical protocols, and the completeness of geothermal-specific triggers. The copy of the questions is attached in Appendix.

Validation of Phase 2: The Realism of "Green-Lane" Procurement

In evaluating Phase 2 of the framework, the panel was asked to rate the realism of implementing "Green-Lane Procurement" within a highly regulated and audited geothermal environment on a scale of 1 to 10. The experts provided scores ranging from 4 to 9, with the majority clustering around 7 and 8, indicating a moderately high level of realism but with strict contingencies. The consensus among the experts is that while the concept is strong and necessary, its success relies entirely on rigorous preparatory measures rather than reactive bypassing of rules.

The panel highlighted that in a heavily regulated environment like the Energy Development Corporation (EDC), exempting procurement from standard gating processes could present compliance challenges or be prone to abuse if not properly constrained. Therefore, the experts stressed that "Green-Lane Procurement" is only realistic if specific preconditions are institutionalized long before an outage occurs. These preconditions include establishing pre-approved vendor framework agreements (GFAs/MSAs), defining a strict catalog to hasten the Purchase Request to Purchase Order (PR-PO) process, and clearly defining criteria for what constitutes a "high-risk and long-lead item". Furthermore, several experts noted that without a robust spare parts strategy specifically stocking critical spares alongside the green lane expedited procurement merely shifts the delay to the supplier's lead time. The panel also warned that for aging geothermal equipment requiring non-standard parts, fast-tracked procurement can become prohibitively expensive due to price escalations, inflation, and exchange rates without forward planning and bulk agreements.

Validation of Phase 1: Actionability of the "Chronic Unease" Protocol

The panel then reviewed Phase 1 of the framework, specifically assessing whether the "Chronic Unease" Protocol provides clear, actionable indicators for ground-level maintenance crews or if it remains too theoretical. The experts largely agreed that while the protocol is a strong conceptual safety and generation target, it is currently too theoretical and vague for technicians to execute during a standard shift. Maintenance crews operate based on quantifiable numbers, alarms, and limits rather than abstract management concepts.

To transition this protocol from theory to practice, the experts recommended translating "weak signals" into specific, quantifiable triggers, such as vibration thresholds, temperature alarms, gradual pressure drops, or repeated minor trips within a set timeframe. The key, particularly for aging assets that frequently display minor anomalies, is clearly defining the threshold where a "minor issue" is no longer minor. Additionally, the panel suggested an organizational adjustment: the protocol would be most effective if a dedicated group, such as a Plant Reliability Team, is tasked with continuously collecting data and interpreting these weak signals to complement the execution-focused Maintenance Group. Without this translation into measurable metrics and dedicated monitoring, the protocol relies too heavily on subjective individual judgment, which could lead to further delays.

Identification of Overlooked Geothermal-Specific Triggers

Finally, the panel was asked to identify any critical geothermal-specific triggers that the proposed framework currently overlooks. The most significant finding from this inquiry was the framework's heavy concentration on surface-level mechanical systems, missing a vital focus on subsurface, reservoir, and fluid-related triggers.

Geothermal operations are inherently dependent on the condition of the reservoir; therefore, the experts pointed out that changes in steam pressure, flow rate, enthalpy, or reservoir temperature drops can severely impact generation output long before any physical power plant equipment fails. Furthermore, slow-developing well integrity issues, such as casing pressure changes or thermal breakthroughs, along with deviations in brine chemistry like scaling, silica content, and gas levels gradually damage equipment and must be explicitly codified as primary triggers in the framework. Addressing these specific geothermal realities is paramount because aging surface systems are less tolerant to reservoir fluctuations. Lastly, from a commercial perspective, the experts suggested strengthening vendor partnerships for critical equipment to ensure the facility has sufficient, cost-effective options pre-aligned with these specific failure scenarios.

Following the synthesis of the first round of feedback, the results were tallied, revealing a strong preliminary consensus among the experts with a median feasibility score of 7.1 out of 10. To formally finalize the framework's validation, a second round of questions was deployed to the same panel of Subject Matter Experts. The objective of this round was to propose concrete modifications based on the critical success factors that emerged from their initial feedback.

The panel was presented with an email containing three specific refined proposals and asked to indicate their agreement (Yes/No) on whether these changes adequately resolved their prior concerns.

For the refinement on Phase 2 (Procurement) to resolve audit risk, because the experts noted that "Green-Lane" procurement risks audit failure unless pre-established, the first proposed change introduced a mandatory "Pre-Approved Vendor Framework (GFA/MSA)" and a "Critical Spares Strategy" as strict prerequisites to Flow B. This modification was designed to ensure that procurement speed during a forced outage does not bypass regulatory compliance.

For the refinement on Phase 1 (Chronic Unease) to ensure actionability, addressing the panel's feedback that the concept of "Chronic Unease" is too theoretical for field crews without supporting numbers, the second proposed change replaced the vague terminology of "Weak Signals" with "Quantifiable Triggers" (such as vibration thresholds, pressure trends, and brine chemistry deviations). Furthermore, the monitoring of these concrete metrics was formally assigned to a dedicated Plant Reliability Team to make the protocol highly actionable.

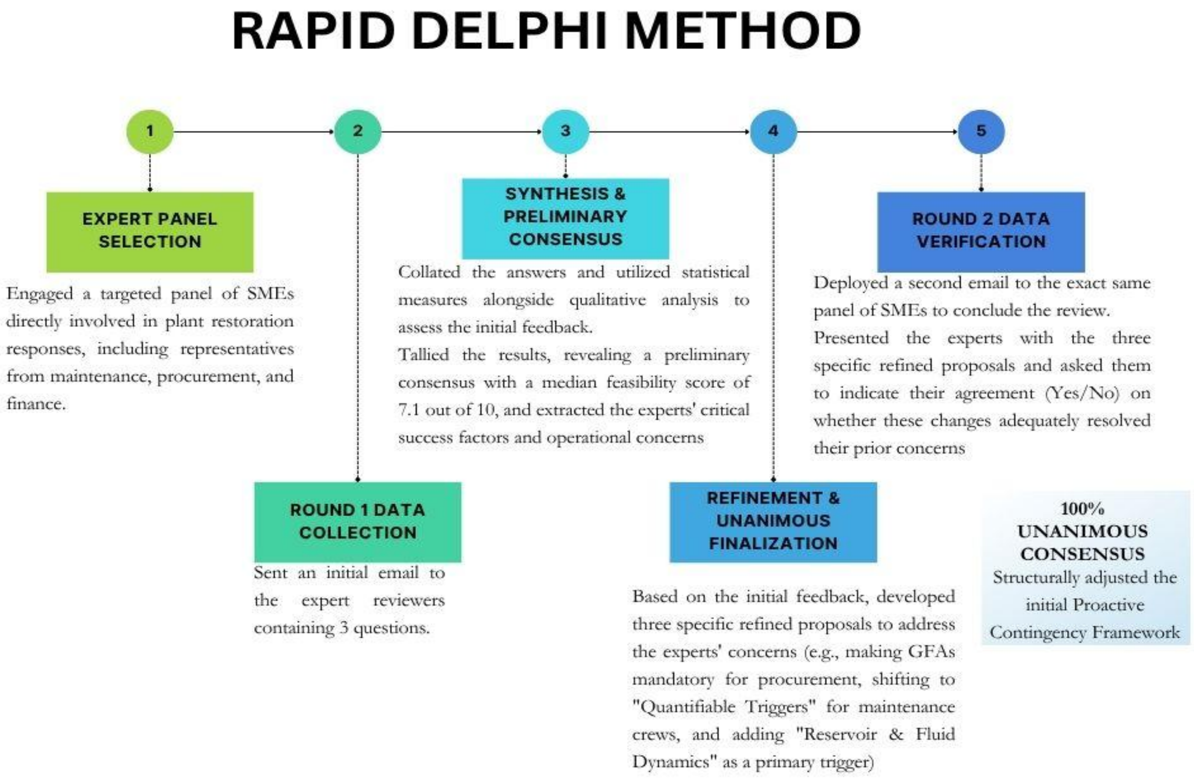
Moreover, for the refinement on Geothermal Triggers to complete the scope to resolve the missing "sub-surface" element highlighted by several experts, the final proposed change officially added "Reservoir & Fluid Dynamics" specifically monitoring steam pressure drops, enthalpy changes, and well casing pressure as a primary operational trigger in Phase 1.

Upon reviewing the refined proposals, all members of the expert panel unanimously agreed to all three questions.

Following the unanimous 100% consensus achieved during the second round of the Rapid Delphi validation phase, the initial Proactive Contingency Framework was structurally adjusted to incorporate the expert panel's critical success factors. This ensured that the model evolved from a theoretical construct into a highly actionable, geothermal-specific tool perfectly tailored for the Bacon-Manito Geothermal Project (BMGP). The adjustments directly addressed the panel's concerns regarding audit compliance, practical execution on the ground, and the unique environmental realities of geothermal energy extraction.

In Phase 1 (Technical Process Flow), the framework was expanded to include sub-surface conditions, adding "Reservoir & Fluid Dynamics" as a primary trigger, since experts noted that steam pressure and enthalpy changes dictate plant health long before surface equipment fails. Additionally, the "Chronic Unease Protocol" was heavily revised; instead of vaguely monitoring "weak signals," it now mandates tracking "Quantifiable Triggers" (such as vibration thresholds and pressure trends), managed specifically by a dedicated Plant Reliability Team.

In Phase 2 (Financial Process Flow), to mitigate audit risks, the "Green-Lane Procurement" pathway was updated to require a "Pre-Approved Vendor Framework (GFA/MSA)" and a "Critical Spares Strategy" as mandatory prerequisites, ensuring speed does not compromise regulatory compliance.
The summary of the rapid delphi method used is shown in Fig. 26 below.



Engaged a targeted panel of SMEs directly involved in plant restoration responses, including representatives from maintenance, procurement, and finance.

Sent an initial email to the expert reviewers containing 3 questions.

Collated the answers and utilized statistical measures alongside qualitative analysis to assess the initial feedback.
Tallied the results, revealing a preliminary consensus with a median feasibility score of 7.1 out of 10, and extracted the experts' critical success factors and operational concerns

Based on the initial feedback, developed three specific refined proposals to address the experts' concerns (e.g., making GFAs mandatory for procurement, shifting to "Quantifiable Triggers" for maintenance crews, and adding "Reservoir & Fluid Dynamics" as a primary trigger)

Deployed a second email to the exact same panel of SMEs to conclude the review.
Presented the experts with the three specific refined proposals and asked them to indicate their agreement (Yes/No) on whether these changes adequately resolved their prior concerns

Structurally adjusted the initial Proactive Contingency Framework

Fig. 26 *Rapid Delphi Method*

To close the results and discussions, Fig. 27 below is the detailed outline of the Final Validated Proactive Contingency Framework, incorporating all expert-approved adjustments.

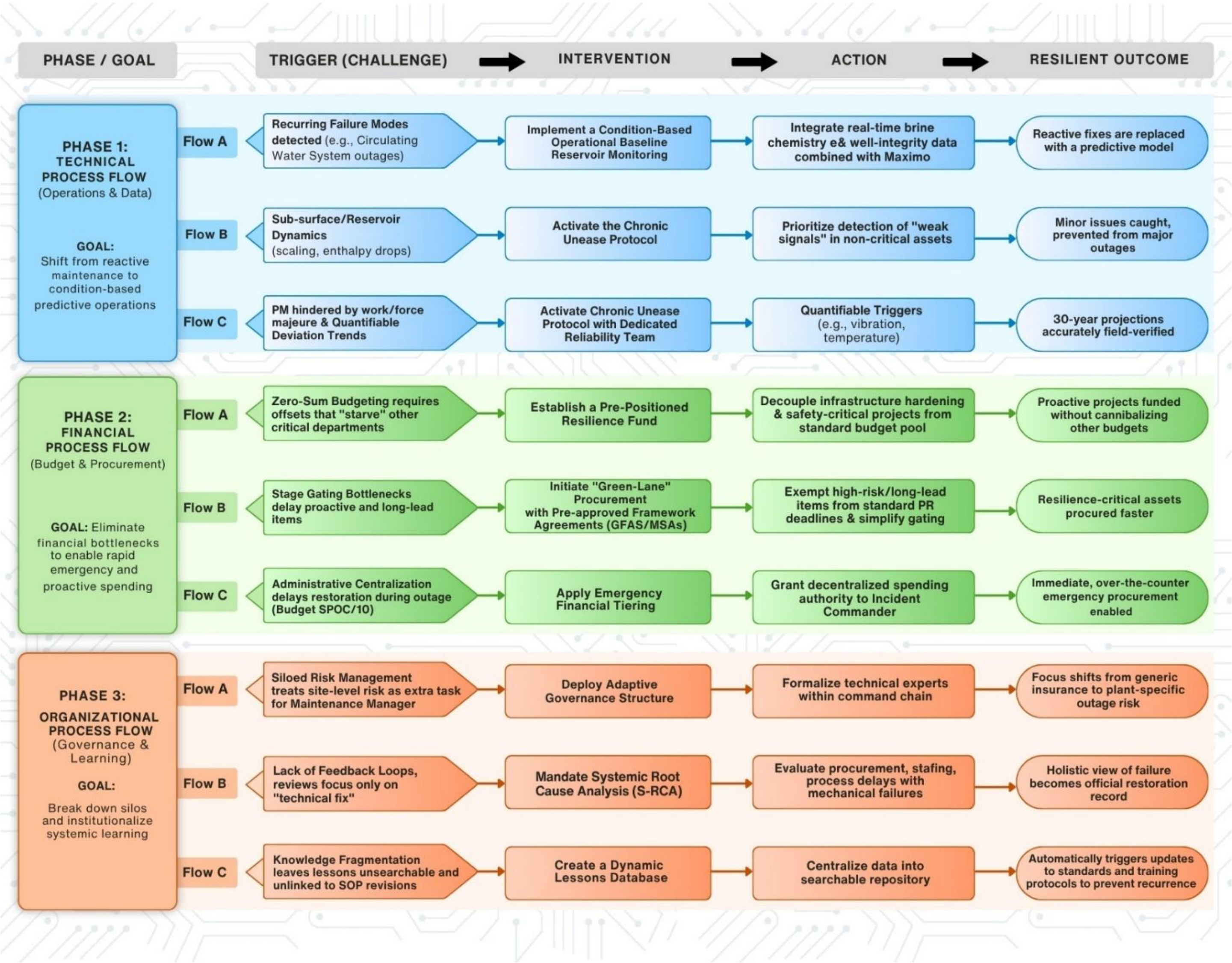


Fig. 27 *Proactive Contingency Framework for Forced Outage Management*

CONCLUSION

Based on a comprehensive assessment, this study concludes that the Bacon-Manito Geothermal Project (BMGP) is entrenched in a reactive restoration culture rather than one of strategic anticipation. While the facility exhibits a high degree of technical proficiency in post-incident recovery, it fundamentally lacks the framework or guide required to systematically anticipate and mitigate the precursors to forced outages before they escalate. This reactive posture is evidenced by the persistence of recurring failure modes, predominantly within the Circulating Water System, and by preventive maintenance schedules that are frequently hindered by force majeure and overlapping corrective work, creating a maintenance backlog ripple effect. Furthermore, the integrity of long-term lifecycle planning is compromised because the management of the Critical Asset Risk Registry (CARR-LTAP) is treated merely as a secondary add-on task.

Beyond technical execution, the study concludes that operational continuity is constrained by rigid financial and organizational bottlenecks. Financially, the plant operates under a "zero-sum" budgeting approach and tedious stage-gating processes that delay the procurement of long-lead components, forcing proactive resilience projects to compete with daily operational funds. Additionally, strict purchase request deadlines act as a "fiscal cliff," severely delaying emergency spending during actual outages. Organizationally, site-level risk management is structurally siloed, treated merely as an additional administrative task for the Maintenance Manager rather than a dedicated strategic function. Post-outage evaluations and Root Cause Analyses consistently focus on the "technical fix," overlooking the systemic organizational precursors—such as procurement delays, communication silos, and staffing gaps—that actually allow these failures to escalate.

Recommendations

To successfully transition BMGP toward sustained strategic resilience, it is highly recommended that management formally implement the finalized Proactive Contingency Framework. Because the framework has successfully passed a rigorous Rapid Delphi validation phase with a panel of Subject Matter Experts, it is now structurally prepared for operational rollout, having been refined to address the facility's unique geothermal realities and audit compliance standards.

To overcome technical frictions, BMGP must establish a Condition-Based Operational Baseline that integrates both surface diagnostics and sub-surface data (specifically reservoir and fluid dynamics, such as steam pressure and enthalpy changes) into a predictive model. This should be complemented by activating an actionable Chronic Unease Protocol, shifting away from vague concepts to the monitoring of "Quantifiable Triggers" (e.g., vibration thresholds and pressure trends) by a newly dedicated Plant Reliability Team. Furthermore, a Core Technical Reclassification must elevate data auditing to a primary function to ensure 30-year projections are field-verified.

To eliminate financial constraints, the facility should establish a Pre-Positioned Resilience Fund to decouple infrastructure hardening projects from standard budget pools. Crucially, management must initiate a Green-Lane Procurement pathway to bypass stage-gating bottlenecks for long-lead items; however, to ensure audit compliance, this must be strictly governed by mandatory pre-approved vendor agreements (GFA/MSA) and a robust critical spares strategy. During crises, Emergency Financial Tiering should be deployed to grant Incident Commanders decentralized, over-the-counter spending authority.

Finally, to break down organizational silos, BMGP must institutionalize an Adaptive Governance Structure that formalizes technical experts within the command chain, shifting the focus to plant-specific outage risk. Management should mandate Systemic Root Cause Analysis (S-RCA) for all outages to formally evaluate administrative and process delays alongside mechanical failures. These insights must be housed in a Dynamic Lessons Database that automatically triggers updates to engineering standards and training protocols, ensuring the facility does not merely repair its machines, but continuously evolves its systemic resilience.

In summary, while it may be impossible to predict the exact, down-to-the-peso monetary savings this framework will generate over the next decade, the financial mathematics of this study are undeniable. There are massive, guaranteed savings in mitigating and shortening forced outages. By pre-positioning the company resources, decentralizing emergency spending authority to the Incident Commanders, and systematically tracking quantifiable triggers before they become catastrophic failures, it can directly cut off the hourly financial bleed due to forced outages.

And the most powerful aspect of this solution is that it requires absolutely no additional capital expenditure. BMGP do not need to buy new systems; it simply needs to re-engineer the current organization because the mechanisms for proactive approach are already there, it's just organized in a simplified framework. This Proactive Contingency Framework is not an expense; it is the ultimate shield for BMGP's operational and financial future.

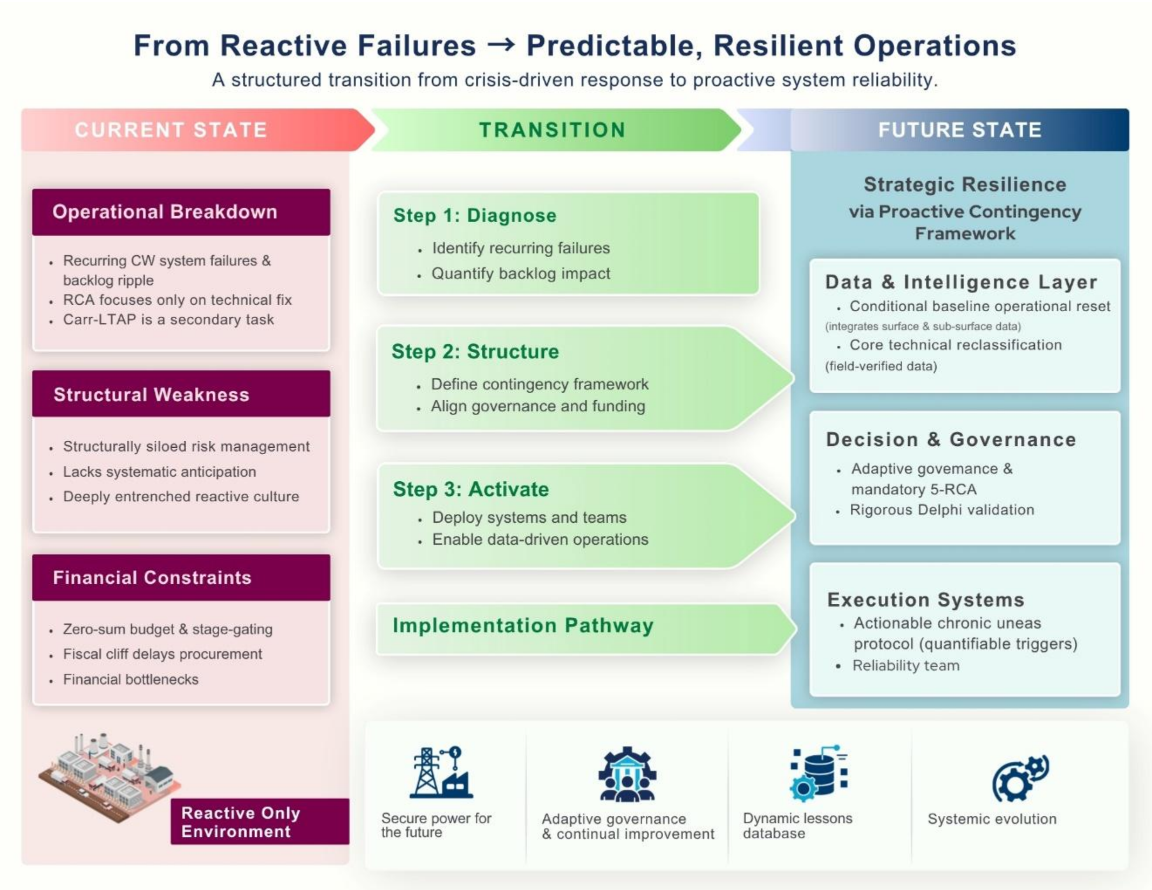


Fig. 28 *BMGP Path to Proactive Forced Outage Management*

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