



The Bleaching-Autophagy Theory of Safety System Collapse: Evidence from the Beirut (2020) and Shahid Rajaei (2024) Port Disasters

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ABSTRACT

This study introduces the Bleaching-Autophagy Theory (BAT) as a novel biological framework for understanding catastrophic industrial safety failure. Drawing on the biological processes of coral bleaching and cellular autophagy, BAT posits that organizations under sustained production pressure first expel their safety culture (bleaching) and then consume their safety structure (autophagy), leaving a formally intact but functionally dead safety system. Through a comparative case study of the Beirut port explosion (August 4, 2020) and the Shahid Rajaei port explosion (April 26, 2024), the theory is inductively developed and illustrated. The analysis reveals that both disasters followed a sequential trajectory: symbiotic safety culture loss followed by structural self-consumption, resulting in organizations that appeared institutionally alive but were biologically incapable of responding to minimal triggers. Four theoretical propositions are advanced to guide future empirical testing.

Keywords: Bleaching-Autophagy Theory, safety system collapse, coral bleaching, autophagy, organizational decay, catastrophic failure, Beirut explosion, Shahid Rajaei explosion, port safety.

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1. INTRODUCTION

On August 4, 2020, approximately 2,750 tons of ammonium nitrate stored at the Port of Beirut detonated with a force equivalent to 1.1 kilotons of TNT. The explosion killed more than 200 people, injured over 7,000, and left approximately 300,000 individuals homeless. The blast destroyed large sections of the city, including the port itself, grain silos, and residential neighborhoods extending several kilometers from the epicenter. Less than four years later, on April 26, 2024, a similar catastrophe struck the Shahid Rajaei port in Bandar Abbas, Iran, when improperly stored sodium perchlorate and ammonium perchlorate ignited, resulting in 57 to 70 fatalities, over 1,000 injuries, and the destruction of at least 10,000 shipping containers across 15 hectares of port infrastructure. These two disasters, separated by geography, political systems, and economic structures, share a common structural pattern that existing safety science frameworks fail to fully explain.

The progressive decay of safety systems within institutional frameworks responsible for hazardous material governance represents one of the most pressing yet under-theorized challenges in industrial safety research. Despite repeated warnings, documented

regulatory violations, and observable unsafe practices, both the Port of Beirut and the Shahid Rajaei port operated under conditions that would have been deemed unthinkable in robust safety regimes. The ammonium nitrate in Beirut sat in Hangar 12 for seven years, adjacent to grain silos and densely populated residential neighborhoods, while port officials issued multiple formal requests for judicial guidance on disposal, all of which were ignored. In Bandar Abbas, oxidizing chemicals were stored in standard shipping containers at a facility reportedly affiliated with military-industrial structures, limiting civilian regulatory oversight and creating a zone of operational autonomy where standard safety protocols could be circumvented without consequence.

Existing safety science frameworks have made remarkable contributions to understanding catastrophic industrial failure, yet they share a common limitation: they treat safety systems as engineering constructs that fail through design flaws, component malfunctions, or human error. System-Theoretic Accident Model and Processes (STAMP), developed by Leveson (2011), provides a powerful hierarchical approach to accident analysis by modeling control structures that should

prevent unsafe behavior. However, STAMP assumes that control structures, once properly designed, maintain their integrity over time. It does not adequately theorize the gradual erosion of control that occurs when political and economic pressures systematically undermine safety investments, not through overt dismantling but through slow institutional starvation. Similarly, the Functional Resonance Accident Model (FRAM), developed by Hollnagel (2012), captures the dynamic complexity of socio-technical systems by modeling functional resonance that emerges from performance variability. While FRAM acknowledges variability, it focuses on performance fluctuations rather than the irreversible organizational decay that transforms a living safety system into a hollow institutional shell.

The concept of normalization of deviance, developed by Vaughan (1996) through her seminal analysis of the Challenger space shuttle disaster, provides crucial insight into how organizations gradually redefine acceptable risk parameters. Vaughan demonstrated that the absence of catastrophic failure creates a feedback loop validating increasingly deviant practices, rendering them invisible to the institutions responsible for maintaining safety boundaries. However, normalization of deviance operates primarily at the micro-sociological level, explaining how organizations accommodate risk but not why political and economic systems permit such accommodation to persist until catastrophic failure becomes inevitable. The theory explains the organizational forgetting of danger but does not explain the structural consumption of safety resources that precedes such forgetting.

The Overton Window, conceptualized by Lehman (2010) at the Mackinac Center for Public Policy, offers a macro-level political framework for understanding how the boundaries of acceptable policy shift over time. While valuable for understanding political tolerance of risk, the Overton Window remains a qualitative heuristic that has never been operationalized to explain the biological-like decay processes within organizations. It describes what is politically thinkable but not how organizations physically lose their capacity to think about safety at all.

This persistent theoretical gap points to a fundamental question: How can we explain the observed phenomenon where organizations retain all the formal apparatus of safety management—committees, regulations, checklists, and organizational charts—while simultaneously losing the functional capacity to prevent catastrophe? In Beirut, safety committees existed. Regulations were written. Inspectors were employed. Yet the system was dead. In Bandar Abbas, similar formal structures existed. Yet when fire initiated, the system lacked the biological capacity to respond. This phenomenon, which we term the bleached-autophagic organization, cannot be fully captured by existing frameworks that view safety as either present or absent,

functional or broken. We need a theory that views safety as a living system capable of dying while its corpse remains visible.

This observation gives rise to the primary research question guiding this investigation: How can biological processes of symbiotic system collapse illuminate the trajectory of catastrophic industrial safety failure, and what does this biological analogy reveal about the structural similarities between the Beirut (2020) and Shahid Rajaei (2024) port disasters? Three subsidiary questions follow. First, what are the identifiable stages through which organizations expel their safety culture and consume their safety structure, and how do these stages map onto documented events in the Beirut and Shahid Rajaei cases? Second, how does the sequential process of cultural bleaching and structural autophagy interact to produce catastrophic failure? Third, what measurable indicators can operationalize the biological analogy to construct a diagnostic framework capable of identifying bleached-autophagic organizations before catastrophic failure occurs?

The theoretical contribution of this study lies in introducing a biological theory of organizational safety decay that treats safety systems as living symbiotic structures subject to death processes analogous to those found in marine biology and cellular physiology. By drawing on coral bleaching and autophagy, the study advances a vocabulary and conceptual framework that captures the living-dead condition of organizations that retain formal safety structures while having lost functional safety capacity. The practical contribution lies in identifying diagnostic indicators that can distinguish between healthy safety systems, stressed safety systems, and bleached-autophagic organizations that appear alive but are biologically incapable of preventing catastrophe.

The study employs a comparative case study methodology, analyzing the Beirut and Shahid Rajaei explosions as instances of a common structural pattern. Case study methodology is particularly appropriate because the research questions are explanatory rather than predictive, the phenomena are contemporary events over which the investigator has no control, and the boundaries between phenomenon and context are not clearly evident. The cases were selected using literal replication logic, where similar results are predicted for theoretically predictable reasons. Both cases involve catastrophic explosions of improperly stored hazardous materials in major commercial ports, both occurred in contexts of documented regulatory failure, and both resulted in significant loss of life and infrastructure damage.

Data for the analysis were drawn from multiple sources including official government statements, international organization reports, investigative journalism, and industry risk assessments. For the Beirut

case, the evidentiary base includes judicial investigations, parliamentary inquiries, and international forensic analyses documented in post-disaster reports. For the Shahid Rajaei case, data availability is more limited due to restricted information flows, but sufficient documentation exists from maritime safety organizations and supply chain risk analysts to reconstruct the basic trajectory of events. The analysis triangulates across these sources to establish reliability and validity.

The remainder of this article is organized as follows. Section 2 briefly reviews existing safety theories and their limitations. Section 3 introduces the biological foundations of coral bleaching and cellular autophagy. Section 4 presents the Bleaching-Autophagy Theory, including its core concepts, variables, and propositions. Section 5 details the methodology. Sections 6 and 7 present the case analyses of Beirut and Shahid Rajaei through the BAT lens. Section 8 offers cross-case analysis. Section 9 discusses theoretical and practical implications, acknowledges limitations, and concludes with future research directions.

2. Theoretical Background and Limitations of Existing Frameworks

Contemporary industrial safety science is dominated by three major frameworks, each offering valuable but incomplete insights into catastrophic failure. STAMP reconceptualizes accidents as resulting from inadequate control of safety constraints in complex systems. By modeling hierarchical control structures, STAMP identifies how safety requirements can be inadequately enforced at multiple system levels. However, STAMP treats control degradation as a failure of enforcement rather than a biological process of organizational death. It cannot explain why an organization might deliberately choose to starve its control structures while maintaining their formal existence.

FRAM shifts focus from linear cause-effect chains to the dynamic resonance of functional variability. By acknowledging that systems normally operate with performance variability, FRAM explains how normal variation can occasionally produce catastrophic outcomes. Yet FRAM assumes that the system remains fundamentally alive and capable of adaptation. It does not theorize the condition where a system has lost its adaptive capacity but continues to perform ritualistic functions.

Normalization of deviance, as articulated by Vaughan (1996), provides the most compelling micro-level explanation for how unsafe practices become culturally accepted. Through detailed ethnographic analysis of NASA's Challenger decision-making, Vaughan showed that successful launches with technical anomalies gradually redefined the boundaries of acceptable risk. The absence of failure became evidence of safety. However, Vaughan's framework focuses on

cultural redefinition within technical communities. It does not fully address the structural consumption of safety resources—budget cuts, personnel reductions, and maintenance deferrals—that often accompany and accelerate cultural normalization.

These frameworks share an implicit assumption that safety systems are either functional or broken, present or absent. They lack a conceptual vocabulary for the liminal state where safety structures exist as hollow shells, where safety committees meet but make no decisions, where inspections occur but identify no violations, where regulations exist but are universally known to be unenforced. This liminal state, which we argue precedes most catastrophic industrial failures, requires a biological rather than engineering metaphor.

3. Biological Foundations: Coral Bleaching and Cellular Autophagy

3.1 Coral Bleaching as Symbiotic Expulsion

Coral reef ecosystems depend on a symbiotic relationship between coral polyps and photosynthetic algae called zooxanthellae. These algae live within coral tissues, providing the coral with essential nutrients through photosynthesis and giving corals their characteristic colors. Under normal conditions, this symbiosis is mutually beneficial: the coral provides shelter and raw materials, while the algae provide energy. The relationship is so fundamental that without it, corals cannot survive (Brown, 1997).

When corals experience environmental stress—particularly elevated water temperatures, pollution, or acidification—they expel their zooxanthellae. This process, known as bleaching, leaves the coral structurally intact but biologically impoverished. The coral turns white because its calcium carbonate skeleton remains while its living symbionts have been expelled. Crucially, the coral does not immediately die. It enters a vulnerable state where it appears alive but lacks the functional capacity to respond to further stress. If favorable conditions return quickly, corals can reacquire zooxanthellae and recover. If stress persists, the bleached coral dies (Brown, 1997).

The bleaching metaphor illuminates organizational safety in the following way: safety culture functions as the organizational equivalent of zooxanthellae. It is not the formal structure of the organization but the living, symbiotic culture that enables the organization to detect and respond to danger. When organizations experience sustained production pressure, economic stress, or political interference, they expel this safety culture. The organization remains structurally intact—committees still meet, regulations still exist—but the living symbiosis that made safety functional has been lost.

3.2 Cellular Autophagy as Self-Consumption

Autophagy is a fundamental cellular process in which cells degrade and recycle their own components.

Under normal conditions, autophagy is a survival mechanism. When nutrients are scarce, cells digest non-essential organelles to provide energy for essential functions. This self-consumption allows the cell to survive temporary starvation (Mizushima, Yoshimori, & Ohsumi, 2011).

However, when starvation is prolonged or stress is severe, autophagy becomes destructive. The cell begins to consume essential structures. What began as adaptive self-preservation becomes pathological self-destruction. The cell literally eats itself to survive, thereby ensuring its own death. The Nobel Prize-winning work of Ohsumi and colleagues has elucidated the molecular mechanisms of this process, demonstrating that autophagy is not random but a highly regulated process that, under extreme conditions, escapes control and consumes the cell itself (Mizushima *et al.*, 2011).

The autophagy metaphor illuminates organizational safety in the following way: when organizations face sustained economic or political stress, they begin to consume their own safety structures. Budgets are reallocated from safety to production. Safety personnel are reassigned or dismissed. Maintenance is deferred. Training is curtailed. These actions are initially framed as temporary adaptations to ensure organizational survival. But when stress persists, the organization consumes its essential safety structures, leaving a skeletal framework that cannot perform safety functions.

3.3 The Sequential Biological Logic

The critical insight from combining these two biological processes is their sequential nature. Coral bleaching precedes coral death. The expulsion of symbionts is the first response to stress; death follows only if the symbionts do not return. Similarly, autophagy begins as survival and ends as self-destruction only if starvation persists. The sequence matters: first the living symbiosis is lost, then the structure is consumed.

This sequence challenges the prevailing assumption in safety science that structural failures cause cultural failures. The biological analogy suggests the reverse: cultural bleaching precedes structural autophagy. Organizations first lose their safety culture—their capacity to care about, think about, and respond to risk—and then, because the culture no longer protects the structure, they consume the structure itself.

4. The Bleaching-Autophagy Theory of Safety System Collapse

4.1 Core Concepts and Definitions

The Bleaching-Autophagy Theory (BAT) proposes that catastrophic industrial safety failure results from a two-phase biological process within organizations. The theory defines four core concepts:

Symbiotic Safety Culture (SSC): The living, mutually beneficial relationship between an organization's operational activities and its safety consciousness. SSC

includes shared beliefs about risk, informal practices of hazard identification, mutual accountability for safety, and the organizational equivalent of photosynthesis—the continuous generation of safety knowledge from operational experience. SSC is not documented in manuals but exists in the daily interactions of workers, managers, and regulators.

Safety Structure (SS): The formal organizational apparatus of safety management, including safety committees, regulatory compliance departments, inspection protocols, training programs, budget allocations, and organizational charts. SS is the coral skeleton—the visible, measurable architecture of safety governance.

Bleaching: The process by which organizations expel their Symbiotic Safety Culture under sustained production or economic pressure. Bleaching is characterized by the gradual disappearance of informal safety practices, the silencing of safety voices, the reinterpretation of near-misses as evidence of success rather than warnings, and the cultural shift from "safety as value" to "safety as compliance."

Autophagy: The process by which organizations consume their Safety Structure after bleaching has occurred. Because the living culture no longer defends the structure, the structure becomes vulnerable to budget cuts, personnel reassignments, and procedural erosion. Autophagy is characterized by the maintenance of formal safety appearances while substantively hollowing out safety functions.

4.2 The Two-Phase Trajectory

BAT proposes that organizations move through a predictable trajectory:

Phase 1: Symbiotic Safety (Healthy State). Both SSC and SS are robust. The organization functions as a living safety system capable of detecting and responding to hazards.

Phase 2: Stress Induction. External pressures—production targets, economic constraints, political interference—create environmental stress analogous to elevated water temperatures for coral.

Phase 3: Bleaching (Culture Expulsion). The organization begins to view its safety culture as a burden. Informal safety practices are discouraged because they slow production. Safety professionals are marginalized. Near-miss reporting declines not because safety improves but because reporting becomes politically dangerous. The organization expels its zooxanthellae.

Phase 4: Autophagy (Structure Consumption). With the safety culture no longer defending the structure, the organization begins to consume its safety resources. Budgets are reallocated. Inspections become perfunctory. Training is minimized. The organization eats its own skeleton to maintain operational momentum.

Phase 5: The Bleached-Autophagic State. The organization retains all formal safety structures but has lost both the culture that animated them and the resources that enabled them to function. It is structurally intact but

biologically dead. A minimal trigger—a spark, a procedural violation, a minor equipment failure—produces catastrophic failure because the organization lacks the living capacity to respond.

4.3 Theoretical Propositions

Based on the biological analogy and the inductive analysis of catastrophic port disasters, BAT advances four propositions for future empirical testing:

Proposition 1: When production pressure exceeds a critical threshold, organizations expel their Symbiotic Safety Culture (bleaching) before they consume their Safety Structure (autophagy). The sequence is culturally prior; bleaching precedes autophagy.

Proposition 2: The bleached-autophagic organization appears institutionally alive—possessing safety documentation, committees, and regulations—but is functionally dead in terms of safety capacity. Formal structure is not a reliable indicator of safety health.

Proposition 3: Catastrophic failure requires only a minimal trigger in bleached-autophagic organizations, whereas healthy organizations absorb identical triggers without incident. The magnitude of the trigger is inversely proportional to the organization's biological safety vitality.

Proposition 4: The velocity of bleaching-autophagy is inversely proportional to institutional transparency and directly proportional to resource scarcity. Organizations with opaque governance and severe resource constraints will transition from healthy to bleached-autophagic states more rapidly than organizations with transparent governance and resource abundance.

4.4 Operational Indicators

To transform BAT from metaphor to diagnostic framework, the theory proposes the following operational indicators:

Bleaching Indicators: (1) Declining near-miss reporting rates not accompanied by observable safety improvements; (2) Increasing social distance between operational and safety personnel; (3) Reinterpretation of safety incidents as production disruptions rather than learning opportunities; (4) Declining voluntary safety participation.

Autophagy Indicators: (1) Reallocation of safety budgets to operational budgets; (2) Reduction in safety personnel headcount while maintaining formal organizational charts; (3) Deferral of maintenance and inspection activities; (4) Proliferation of safety documentation without corresponding operational changes.

The Bleached-Autophagic State: Simultaneous presence of formal safety structures with absence of bleaching and autophagy indicators. The organization has the skeleton but no living tissue.

5. METHODOLOGY

This study employs a comparative case study methodology to analyze the Beirut (2020) and Shahid

Rajae (2024) port explosions through the integrated biological framework of BAT. The methodology follows Yin (2018) for explanatory case studies, using literal replication logic where similar results are predicted for theoretically predictable reasons.

Data sources include official government statements, international organization reports, investigative journalism, industry risk assessments, and parliamentary or judicial inquiry documents. For the Beirut case, the evidentiary base includes documented judicial investigations and international forensic analyses. For the Shahid Rajae case, data were drawn from maritime safety organizations and supply chain risk assessments. The analysis triangulates across these sources.

The analytical procedure involves chronological reconstruction of safety governance in each port, identification of documented safety violations and resource allocations, classification of each period according to the five-phase BAT trajectory, and comparative analysis of collapse patterns. Because BAT is inductively developed from these cases, the analysis does not test pre-existing hypotheses but rather identifies patterns that inform the theoretical propositions.

6. Case Analysis: The Port of Beirut (2013-2020)

6.1 Phase 1: Symbiotic Safety (Pre-2013)

Prior to the arrival of the Rhosus vessel in November 2013, the Port of Beirut operated as a functional commercial port with established customs procedures, port authority oversight, and operational safety practices. While not exemplary by international standards, the port possessed a Symbiotic Safety Culture in which hazards were recognized and addressed through informal channels. The Safety Structure included customs inspections, hazardous material protocols, and port authority governance.

6.2 Phase 2: Stress Induction (2013-2014)

The arrival of 2,750 tons of ammonium nitrate in November 2013 created immediate environmental stress. The cargo was impounded due to technical deficiencies and financial disputes. At this stage, the port's Symbiotic Safety Culture was still functional. Port officials recognized the hazard and sought guidance for disposal. The Safety Structure was activated. However, the judicial and political systems failed to respond, creating sustained stress on the port's safety system.

6.3 Phase 3: Bleaching (2014-2017)

Between 2014 and 2017, the Port of Beirut underwent progressive bleaching. Port officials issued multiple formal requests for judicial guidance on the ammonium nitrate disposal; no action was taken. The material remained in Hangar 12, adjacent to grain silos and residential areas. During this period, the informal safety culture began to dissolve. Safety personnel who raised concerns were ignored. The cultural interpretation

of the hazard shifted from "dangerous anomaly" to "administrative inconvenience."

By 2015, the presence of ammonium nitrate had become an established fact. Security personnel reported that Hangar 12's doors were improperly secured, and the material was exposed to environmental conditions. In 2016, port officials proposed selling the ammonium nitrate to the Lebanese Armed Forces or exporting it; both proposals were ignored. The Symbiotic Safety Culture had been expelled. The port was bleached.

6.4 Phase 4: Autophagy (2017-2019)

Between 2017 and 2019, the port consumed its own Safety Structure. Multiple warnings were issued by experts, but the reports were ignored. A 2016 report by a team of experts recommended immediate removal of the material; the report was ignored. In 2019, a chemical expert warned that the ammonium nitrate could destroy Beirut if not removed. The warning was not acted upon.

During this period, the economic and political crises in Lebanon intensified. The port, as a critical revenue source, faced immense pressure to maintain throughput. Safety budgets were implicitly or explicitly redirected to operational needs. Inspections became perfunctory. The Safety Structure existed on paper but had been consumed. The port had entered autophagy.

6.5 Phase 5: The Bleached-Autophagic State and Catastrophe (2020)

By 2020, the Port of Beirut was a bleached-autophagic organization. It retained all formal safety structures—committees, regulations, customs authority—but had lost both the culture that animated these structures and the resources that enabled them to function. The presence of 2,750 tons of ammonium nitrate in Hangar 12 had been normalized to the point of invisibility.

On August 4, 2020, a fire initiated in an adjacent warehouse containing fireworks and flammable materials. The minimal trigger—fireworks igniting—spread to the ammonium nitrate. The port lacked the biological capacity to respond. There was no functional safety culture to detect the danger early, no functional safety structure to mobilize resources. The explosion was not an aberration but the logical culmination of a seven-year biological process of organizational death.

7. Case Analysis: The Shahid Rajaei Port (2020-2024)

7.1 Phase 1: Symbiotic Safety (Pre-2020)

The Shahid Rajaei port, Iran's largest commercial port handling approximately 80 million tons of cargo annually, operated with established port authority procedures and customs oversight. While operating within a complex political environment, the port possessed functional safety protocols for hazardous materials. The Symbiotic Safety Culture included

operational practices for handling chemicals, fire suppression systems, and regulatory oversight.

7.2 Phase 2: Stress Induction (2020-2022)

The port faced sustained stress from multiple sources: international sanctions limiting equipment and technology access, economic pressures to maintain throughput as a critical trade gateway, and the complex overlay of military-industrial operations within the port complex. The storage of oxidizing chemicals such as sodium perchlorate and ammonium perchlorate in standard shipping containers created environmental stress on the safety system. These materials require specialized storage facilities with temperature control, fire suppression, and isolation from combustible materials. Standard container storage violated fundamental safety requirements.

7.3 Phase 3: Bleaching (2022-2023)

By 2022, reports indicate that chemicals were being stored in standard containers at the Sina Marine Services facility within the port complex. The facility operated with limited civilian regulatory oversight. Port safety inspectors, if they identified violations, lacked authority to enforce compliance against the facility's operational autonomy. The Symbiotic Safety Culture began to dissolve. Safety personnel who might have raised concerns faced institutional barriers. The cultural interpretation shifted from "violation" to "operational necessity."

By late 2023, the storage of hazardous chemicals in standard containers had become an operational norm. The absence of fires or chemical incidents during this period validated the practice. Workers and managers developed informal protocols that deviated from international standards but were functionally adequate for daily operations. The deviation had been normalized. The absence of catastrophe was interpreted as evidence of safety rather than temporary avoidance. The port was bleached.

7.4 Phase 4: Autophagy (Late 2023-Early 2024)

In the months preceding the explosion, no significant regulatory intervention occurred. The port continued to process approximately 80 million tons of cargo annually. The economic and political costs of halting operations to relocate or properly store the chemicals outweighed the perceived risk of maintaining the status quo. The Safety Structure was consumed. Inspections that might have identified the hazard were not conducted or not enforced. Safety resources were absorbed by operational priorities. The port had entered autophagy.

7.5 Phase 5: The Bleached-Autophagic State and Catastrophe (April 26, 2024)

On April 26, 2024, a fire initiated in the chemical storage area. The exact ignition source remains under investigation, but the presence of oxidizing

chemicals in improperly configured containers ensured rapid fire spread and eventual explosion. The explosion killed 57 to 70 people, injured over 1,000, destroyed 10,000 containers, and devastated 15 hectares of port infrastructure.

The Shahid Rajaei port, like Beirut, was bleached-autophagic at the moment of catastrophe. It retained formal safety structures but lacked the living capacity to respond. The minimal trigger produced maximal failure because the organization was biologically dead in safety terms.

8. Cross-Case Analysis

8.1 Comparative Trajectory

Both cases exhibit the predicted two-phase trajectory of BAT. In Beirut, bleaching occurred between 2014 and 2017, followed by autophagy between 2017 and 2019. In Shahid Rajaei, bleaching occurred between 2022 and 2023, followed by autophagy between late 2023 and early 2024. The compressed timeline in Shahid Rajaei (approximately two years versus seven years in Beirut) supports Proposition 4: higher institutional opacity and resource scarcity accelerated the biological decay process.

8.2 Structural Similarities in Collapse

Both disasters exhibit the defining characteristic of the bleached-autophagic state: the simultaneous presence of formal safety structures and the absence of functional safety capacity. In Beirut, safety committees existed, regulations were written, and inspectors were employed, yet the system could not remove 2,750 tons of explosives from a residential neighborhood. In Shahid Rajaei, port authority oversight existed, customs procedures were followed, and hazardous material protocols were documented, yet the system could not prevent the storage of oxidizing chemicals in standard containers.

8.3 The Minimal Trigger Phenomenon

Both cases support Proposition 3. The Beirut explosion was initiated by a fire in an adjacent warehouse containing fireworks—a relatively common industrial hazard that a healthy port would have contained. The Shahid Rajaei explosion was initiated by a fire in a chemical storage area—a hazard that a healthy port would have suppressed or isolated. In both cases, the trigger was minimal relative to the catastrophic outcome, precisely because the organizations lacked the biological capacity to respond.

8.4 Institutional Opacity and Velocity

The comparison supports Proposition 4 regarding the velocity of decay. Beirut, operating within a dysfunctional but relatively transparent democratic system, took seven years to progress from bleaching to catastrophe. Shahid Rajaei, operating within an opaquer system with limited civilian oversight, progressed through the same stages in approximately two to four

years. Institutional opacity accelerated the biological decay by removing the feedback mechanisms that might have slowed autophagy.

9. DISCUSSION

9.1 Theoretical Implications

The Bleaching-Autophagy Theory offers several theoretical contributions to safety science. First, it introduces a biological vocabulary for organizational safety decay that moves beyond engineering metaphors of failure. The concepts of bleaching and autophagy capture the living-dead condition of organizations that existing frameworks cannot adequately describe. Second, BAT advances a sequential theory of safety collapse, proposing that cultural bleaching precedes structural autophagy. This challenges prevailing assumptions that structural failures cause cultural failures, suggesting instead that cultural death is the precondition for structural consumption. Third, BAT provides a diagnostic framework for identifying organizations in the bleached-autophagic state before catastrophic failure occurs.

The integration of biological analogies with organizational analysis is not merely metaphorical. Coral bleaching and cellular autophagy are well-documented biological processes with established mechanisms, indicators, and trajectories. By drawing on these established processes, BAT grounds organizational safety theory in biological science, offering not just a new vocabulary but a new ontology for understanding safety as a living system subject to death.

9.2 Practical Implications

BAT suggests several practical interventions for safety governance. First, safety audits should distinguish between structural presence and biological vitality. The existence of safety committees, regulations, and inspections is not sufficient evidence of safety health. Auditors must assess whether the organization possesses a Symbiotic Safety Culture—whether workers and managers actively identify and respond to hazards, or whether safety has become a performative ritual.

Second, early warning systems should monitor bleaching indicators rather than relying solely on structural compliance metrics. Declining near-miss reporting, increasing social distance between safety and operational personnel, and the reinterpretation of incidents as production disruptions are early indicators of cultural bleaching. These indicators may precede structural failures by months or years.

Third, regulatory design should include mechanisms to prevent autophagy. Once bleaching is detected, regulators must protect safety structures from budgetary consumption. Organizations in the bleached state are particularly dangerous because they will consume their own safety resources to maintain

operational momentum. Regulatory intervention must prevent this self-consumption.

9.3 Limitations and Future Research

This study is subject to several limitations. The Bleaching-Autophagy Theory is inductively developed from two cases and two biological analogies. It requires further empirical testing across diverse industrial contexts—including mining, construction, chemical processing, and offshore oil and gas—to validate its generalizability. The biological mechanisms are used as generative analogies rather than literal claims that organizations are biological organisms. Future research should operationalize the proposed indicators and test the four propositions through quantitative analysis of safety culture and safety structure metrics across multiple organizations.

The Shahid Rajae case, in particular, suffers from limited data availability due to restricted information flows. Future research should seek additional primary sources to refine the analysis. Additionally, the theory does not yet specify the critical thresholds at which bleaching transitions to autophagy, or the precise velocity functions governing organizational decay. These parameters require further empirical specification.

10. CONCLUSION

The Beirut (2020) and Shahid Rajae (2024) port explosions were not isolated accidents resulting from technical failures or human errors. They were manifestations of a systemic biological process: the progressive death of organizational safety systems through cultural bleaching and structural autophagy. By the time of their respective catastrophes, both ports had become bleached-autophagic organizations—formally intact but biologically dead in terms of safety capacity.

The Bleaching-Autophagy Theory advances a new conceptual framework for understanding this phenomenon. It suggests that safety is not an engineering construct that can be designed and maintained through technical controls. Rather, safety is a living symbiotic system that can be expelled, consumed, and killed while its corpse remains visible. Reversing this trajectory requires not merely technical compliance or procedural enforcement but the active cultivation and protection of the living safety culture that animates formal safety structures. Without this living symbiosis, organizations become coral skeletons—beautiful in their formal architecture, but incapable of surviving the slightest stress.

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