A Systemic Analysis of the TAM Airlines Flight 3054 Accident: A Hybrid STEP and SWOT Approach

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***Abstract* – The crash of TAM Airlines Flight 3054 on July 17, 2007, is one of Brazil's most significant aviation disasters. While pilot error was initially identified as the primary cause, a deeper analysis reveals that the accident resulted from a complex socio-technical system operating under stress. This study employs a hybrid methodology, combining Sequentially Timed Events Plotting (STEP) and an analysis of Strengths, Weaknesses, Opportunities, and Threats (SWOT), to reconstruct the sequence of events and assess the operational environment. The critical crew error, influenced by human-automation interface flaws, triggered a series of interconnected failures, including compromised safety systems, a contaminated runway, and inadequate infrastructure. The analysis demonstrates that the catastrophic outcome was due to multiple vulnerabilities rather than a single failure. The study proposes multi-level recommendations targeting technical systems, human factors training, airport infrastructure, and regulatory oversight to enhance aviation safety and prevent future incidents.**

***Keywords* – STEP, SWOT, Safety**

I. INTRODUCTION

On July 17, 2007, an Airbus A320 operating as TAM Airlines Flight 3054 overran runway 35L at São Paulo's Congonhas Airport (SBSP) during landing. The aircraft crossed a major thoroughfare and crashed into a building, resulting in the deaths of all 187 people on board and 12 people on the ground, making it the deadliest aviation accident in Brazilian history at the time. The final report from Brazil's Aeronautical Accidents Investigation and Prevention Center (CENIPA) concluded that the accident was caused by the pilot's actions, specifically the incorrect positioning of the thrust levers during the landing roll[1].

However, attributing such a complex catastrophe to a single "root cause" like pilot error is an oversimplification that masks deeper, systemic vulnerabilities. Modern aviation accidents are rarely the result of a simple, linear chain of events. Instead, they are often emergent outcomes arising from the complex and dynamic interplay of human, technical, organizational, and environmental factors[4]. The TAM 3054 accident, with its confluence of a deactivated thrust reverser, a recently resurfaced but un-grooved wet runway, known airport infrastructure limitations, and subtle but critical flaws in the human-automation interface, serves as a quintessential example of this complexity[3]. Understanding how these disparate elements interacted to create a disaster requires an analytical framework that transcends linear causality.

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This paper argues that a more holistic and insightful understanding of the TAM 3054 accident can be achieved by applying a hybrid analytical framework that combines two distinct but complementary methodologies.

First, the Sequentially Timed Events Plotting (STEP) methodology is employed to meticulously reconstruct the event sequence, providing a clear, time-based map of the actions and interactions between the various actors involved the pilots, the aircraft, air traffic control, and the physical environment. This answers the critical questions of what happened, who was involved, and when.[7] Second, a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis is utilized to conduct a strategic assessment of the entire sociotechnical system. This approach, typically used in business management, is repurposed here to identify the pre-existing conditions, latent vulnerabilities, and external pressures that framed the accident, answering the crucial question of why the system was fragile enough to fail catastrophically.[9]

This paper posits that the TAM 3054 accident was an emergent property of systemic functional resonance, where latent organizational and infrastructural weaknesses created a high-risk environment. Within this environment, an active pilot error, made more probable by design features of the human-machine interface, triggered a non-linear collapse of the system's safety defenses. The structure of this paper is as follows: Section II outlines the theoretical framework, tracing the evolution from linear to systemic accident models. Section III provides a literature review contextualizing the key factors of the accident. Section IV presents detailed methodological application and integrated analysis. Finally, Section V offers conclusions and a set of multi-level recommendations aimed at strengthening aviation safety.

II. THEORETICAL FRAMEWORK: FROM LINEAR CAUSALITY TO SYSTEMIC MODELS

The scientific approach to accident analysis has evolved significantly over the past century, moving from simple, linear models to more complex, systemic frameworks that better reflect the nature of modern socio-technical systems.

A. The Evolution of Accident Causation Models

Early accident models were predominantly sequential, viewing accidents as the result of a linear chain of events, much like a series of falling dominoes.

This perspective naturally focused on identifying and removing the "root cause" to prevent recurrence. A significant advancement came with epidemiological models, most famously James Reason's "Swiss Cheese Model" (SCM) of accident causation.

The SCM introduced the critical concept of latent failures: dormant, unrecognized vulnerabilities within a system's defenses (e.g., inadequate training, poor design, flawed procedures).

In this model, an accident occurs when the "holes" in successive layers of defense align, allowing a hazard to pass through and cause a loss. While highly influential in shifting focus from solely active, front-line errors to organizational weaknesses, the SCM has been criticized for retaining sequential elements and not fully capturing the dynamic, non-linear interactions of complex systems. [5]

B. The Systemic Paradigm Shift

The contemporary paradigm in safety science is systemic. Systemic models view safety not as the absence of failures but as an emergent property of the system, arising from the interactions among its human, technical, and organizational components.[5] Accidents are therefore not caused by component failures alone but by a loss of control over system behavior and interactions. Key tenets of this paradigm include:

Non-linearity: Accidents often arise from complex, unpredictable, and tightly coupled interactions rather than simple, linear cause-and-effect chains. The failure of one component can have unforeseen and disproportionate effects elsewhere in the system. [5]

Performance Variability: Human and organizational performance is never perfect or perfectly repeatable. People and organizations must constantly adapt their performance to match the complexities and pressures of the real world. These "approximate adjustments" are the source of both everyday success and occasional failure. [11]

Functional Resonance: A key concept from Erik Hollnagel's Functional Resonance Analysis Method (FRAM) is that accidents can occur without any single component "failing" in the traditional sense. Instead, the normal, everyday variability in the performance of multiple system functions can, under specific conditions, couple and resonate in unexpected ways. This resonance can amplify the variability, leading to an extreme, out-of-scale outcome a catastrophic failure. [12]

C. Situating STEP and SWOT within a Systemic Framework

This paper proposes a hybrid methodology that leverages the strengths of two distinct analytical tools to practically apply systemic principles. While systemic models like FRAM offer a powerful theoretical lens, their application can be resource intensive. The proposed combination of STEP and SWOT provides a pragmatic yet robust alternative.

The STEP method is fundamentally a multi-linear event reconstruction tool. It organizes accident data by plotting events chronologically against the actors involved, creating a structured narrative of what happened.[8] While not a systemic model in itself, its strength lies in its ability to capture the complex, time-based interactions between multiple agents (e.g., pilots, aircraft systems, ATC), providing the essential factual foundation that a systemic analysis must explain.

The SWOT analysis, conversely, is used to map the static, pre-existing conditions of the socio-technical system.

By categorizing factors into internal Strengths and Weaknesses and external Opportunities and Threats, it effectively identifies the latent failures and contextual pressures that, according to systemic theory, create the conditions for an accident.[14]

The synergy of this hybrid approach is its power to connect the dynamic event sequence with the static systemic context. The STEP analysis provides the detailed, chronological "story" of the accident, while the SWOT analysis reveals the vulnerable, pre-configured "stage" on which that story unfolded. This pairing allows for a practical application of systemic principles, using the "why" derived from the SWOT analysis to explain the causal progression detailed in the "what" of the STEP matrix, thereby bridging the gap between event sequencing and true systemic understanding.

III. LITERATURE REVIEW: CONTEXTUALIZING THE TAM 3054 ACCIDENT

The TAM 3054 accident did not occur in a vacuum. It was embedded within a context of known risks in commercial aviation, specific design characteristics of the aircraft, and established industry practices. A review of the literature in these areas is essential for a comprehensive analysis.

A. Runway Excursions: A Persistent Global Safety Challenge

Runway excursions, defined as an event where an aircraft veers off or overruns the runway surface, are a leading safety concern in global aviation. Studies by major international bodies, including the International Air Transport Association (IATA) and the European Union Aviation Safety Agency (EASA), consistently identify runway excursions as a top key-risk area for commercial air transport. They are the most frequent type of runway safety incident, with a significant portion occurring during the landing phase.[15]

The causal factors are known to be multifaceted and cumulative. Unstabilized approaches, excessive air speed, high touchdown points (long landings), and delayed or ineffective use of deceleration devices are common precursors[16]. A critical environmental factor is runway surface condition. Contaminated runways whether by water, snow, or ice dramatically reduce the coefficient of friction, degrading braking effectiveness and increasing the risk of hydroplaning and subsequent loss of control.[17] The conditions at Congonhas on the night of the accident, with a wet and slippery runway, align perfectly with this well-documented high-risk scenario.[2]

B. Human-Automation Interaction in the Airbus A320 Cockpit

The Airbus A320 is a technologically advanced aircraft characterized by a high degree of automation and a "fly-by-wire" flight control system. A key element of its design philosophy is that the autothrottle system adjusts engine power without physically moving the thrust levers in the cockpit.

While this design is efficient under normal operations, it can create a potential disconnect between the pilots' physical interface and the aircraft's actual energy state.

The lack of tactile and visual feedback from moving levers can reduce situational awareness, particularly during high-workload phases of flight like landing.[18]

This design choice became critically important in the TAM 3054 accident. According to the Flight Data Recorder (FDR), one thrust lever was moved to the IDLE position while the other remained in the CLIMB (CL) detent.[1] The A320's system logic at the time did not include a specific, salient aural warning for this dangerous thrust lever asymmetry during landing.[19] This absence of a clear, unambiguous alert represented a latent flaw in the human-automation interface, leaving a gap in the system's defenses against a plausible, albeit incorrect, pilot input. Following the accident, this gap was addressed with the development of a dedicated warning system.

C. The Role of the Minimum Equipment List (MEL) in Safety Management

The Minimum Equipment List (MEL) is a regulatory-approved document that allows an airline to operate an aircraft for a specified period with certain non-critical items of equipment inoperative.[20] The operator's MEL is derived from the Master Minimum Equipment List (MMEL) produced by the aircraft manufacturer but must be equally or more restrictive.[4] The decision to dispatch an aircraft under an MEL provision is a formal risk management process.

In the case of Flight 3054, the aircraft was dispatched with the #2 (right) engine's thrust reverser deactivated and placarded as inoperative, a condition permitted by the TAM MEL.[30] While legally permissible, this decision reveals a potential systemic weakness in how MELs are often applied.

The risk associated with an inoperative component is frequently assessed in isolation, without fully accounting for its interaction with other operational variables. The deactivation of a key deceleration device like a thrust reverser presents a manageable risk under ideal conditions. However, its risk profile is amplified dramatically when combined with other adverse factors, such as a short, wet runway with no safety overrun area precisely the conditions at Congonhas. The MEL policy in place did not appear to require a dynamic, context-sensitive risk assessment that would prohibit such a dispatch into a known high-risk environment. This points to a failure in systemic risk management at both the organizational (airline) and regulatory (aviation authority) levels.[13]

D. Airport Infrastructure as a Systemic Defense

Airport infrastructure constitutes a critical layer of defense against runway excursions.

Two key features are particularly relevant to the TAM 3054 accident: Runway End Safety Areas (RESA) and runway grooving. A RESA is a cleared, graded area at the end of a runway designed to reduce the severity of an overrun by providing a safety buffer.[15]

At the time of the accident, Congonhas Airport lacked an adequate RESA, meaning there was no margin for error in the event of an overrun; the runway ended abruptly before a major public road and buildings.[6]

Runway grooving the practice of cutting transverse grooves into the pavement is a proven engineering solution to improve water drainage and increase tire friction on wet surfaces, thereby mitigating the risk of hydroplaning.[6] The main runway at Congonhas had been recently resurfaced but, critically, had not yet been grooved, a known deficiency that directly increased the risk on the rainy night of the accident.[1] Furthermore, modern technologies like an Engineered Materials Arresting System (EMAS), which uses a bed of crushable materials to safely decelerate an overrunning aircraft, provide an effective solution for space-constrained airports like Congonhas where a full RESA is not feasible.[15] The absence of these infrastructural defenses represented significant, well-understood holes in the airport's safety net.

IV. METHODOLOGY AND ANALYSIS OF THE TAM 3054 ACCIDENT

A. Methodological Framework

The analysis of the TAM 3054 accident is conducted using a hybrid framework that integrates Sequentially Timed Events Plotting (STEP) and SWOT analysis. This approach allows for a comprehensive examination that captures both the dynamic sequence of events and the static systemic vulnerabilities that preceded the accident. The analysis proceeds in three stages: (1) a detailed reconstruction of the accident timeline using the STEP matrix to establish the sequence of actions and interactions; (2) a mapping of the socio-technical environment using SWOT analysis to identify latent weaknesses and threats; and (3) an integrated discussion that synthesizes the findings from both methods to construct a systemic explanation of the accident's causation.

B. Event Reconstruction with STEP

The STEP methodology is a graphical accident analysis technique that organizes complex event data into a structured format. It plots events chronologically along a horizontal axis while listing the actors or entities involved (e.g., pilot, aircraft system, infrastructure) along a vertical axis.[8] This creates a clear and intuitive map of the parallel event streams and their interactions, facilitating an understanding of how the accident unfolded over time.

The detailed STEP matrix for the TAM 3054 accident, constructed from the final investigation report and associated analyses, is presented in Table 1.

The matrix reveals several critical event chains.

The sequence begins long before the flight, with organizational and maintenance decisions, such as the deactivation of the #2 thrust reverser under the MEL and a lack of specific crew training for this abnormal configuration.

During the approach, the crew was correctly informed by ATC of the wet and slippery runway conditions, heightening their awareness of the landing challenge.

The pivotal moment occurred at touchdown. The copilot, who was the pilot flying, correctly retarded the left thrust lever to IDLE but failed to do the same with the right thrust lever, leaving it in the CLIMB position.

This active error triggered a cascade of system responses that were, from a design perspective, correct but, from an operational safety perspective, catastrophic. The aircraft's logic, sensing one lever at CLIMB, disengaged the autothrottle, causing the right engine to spool up to climb power. Simultaneously, the system inhibited the deployment of the ground spoilers and the activation of the autobrake system, as both functions required both thrust levers to be at or near the IDLE position to arm. The combination of powerful asymmetric thrust and the failure of primary deceleration systems led directly to the loss of directional control and the subsequent high-speed runway overrun.

TABLE 1. DETAILED STEP MATRIX FOR THE TAM 3054 ACCIDENT SEQUENCE

Entity	*Event*	*Contribution to Accident*
Maintenance/ Organization		
TAM Company	MEL permitted operation with #2 thrust reverser inoperative.	Latent organizational failure allowing operation in a degraded state.
TAM Company	Lack of specific training for landing with an inoperative reverser.	Reduced flight crew preparedness for the abnormal configuration.
Pre-Landing Phase		
ATC Controller	Informed crew that runway was "wet and slippery".	Provided critical information, increasing crew workload and stress
Pilot in Command	Acknowledged challenging conditions.	Heightened situational awareness but also potential for stress-induced error.
Landing and Rollout Phase		
Copilot (Pilot Flying)	Maintained right thrust lever in CLIMB (CL) position after touchdown.	Critical active error; prevented aircraft from entering landing mode.
Pilot in Command	Retarded left thrust lever to IDLE and engaged reverser.	Correct action for the left engine, but created severe thrust asymmetry.
Aircraft System	Autothrottle disengaged as designed.	Expected system behavior, but allowed right engine to accelerate to climb power.
Aircraft System	Spoilers did not deploy automatically.	System logic inhibited deployment as right thrust lever was not at IDLE.
Aircraft System	Autobrake system did not activate.	System logic inhibited activation for the same reason as spoilers.
Aircraft System	No specific warning for asymmetric thrust lever position on landing.	Latent human-machine interface design flaw; failed to alert crew to error.
Runway Excursion Phase		
Aircraft	Veered sharply to the left due to asymmetric thrust.	Loss of directional control.
Aircraft	Failed to decelerate, overran runway at high speed (~90 kts).	Consequence of failed deceleration systems and right engine at climb power.
Runway Infrastructure	Runway surface was wet and lacked grooving.	Reduced braking friction, increasing the severity of the excursion.
Airport Infrastructure	Lack of a standard Runway End Safety Area (RESA).	No safety margin; failed to mitigate the consequences of the overrun.
Impact Phase		
Aircraft	Crossed public avenue and impacted TAM Express building.	Catastrophic final event, leading to mass fatalities on aircraft and ground.

C. System Vulnerability Assessment with SWOT Analysis

To understand why the events in the STEP matrix led to a catastrophe, a SWOT analysis was conducted to map the systemic context. This analysis identifies the internal Strengths and Weaknesses of the airline and airport operation, as well as the external Opportunities and Threats present in the wider environment.[10] The SWOT matrix in Table 2 codifies the latent conditions that shaped the accident.

The analysis reveals a system with some inherent strengths, such as a well-trained crew for normal operations and robust aircraft systems that performed as designed.

However, these strengths were fundamentally undermined by critical weaknesses.

These latent failures included the permissive MEL policy, inadequate airport infrastructure (no grooving or RESA), and the absence of redundant safety barriers, such as a specific cockpit alert for the lever mismatch.

These weaknesses were exacerbated by external threats, most notably the adverse weather conditions and underlying commercial pressures that encourage maintaining flight schedules even in high-risk situations.

The opportunities identified are largely prospective, representing the potential for safety improvements that could be realized after learning the lessons of the tragedy.

TABLE 2. SWOT ANALYSIS OF THE TAM 3054 SOCIO-TECHNICAL SYSTEM

	Internal Factors	*External Factors*
Helpful	**Strengths**	**Opportunities**
	- Experienced crew trained for normal operations. - Aircraft automated systems functioned correctly per design logic. - Clear procedures for routine flight phases. - Effective ATC communication for standard procedures.	- Implement enhanced training with complex, multi-failure scenarios. - Revise and update MEL policies to be context-sensitive. - Upgrade airport infrastructure with RESA/EMAS and runway grooving. - Develop and retrofit automated alerts for anomalous control configurations.
Harmful	**Weaknesses**	**Threats**
Pre-Landing Phase	- Undetected operational error (right thrust lever in CL). - Ineffective cockpit warning for the specific thrust lever anomaly. - MEL allowing operation with inoperative reverser without sufficient risk mitigation. - Inadequate airport infrastructure (no grooving, no RESA). - Lack of specific training for landing in the specific abnormal configuration. - Absence of redundant safety barriers to trap the error.	- Adverse weather conditions (frequent heavy rain in São Paulo). - Commercial pressures to maintain operational tempo and avoid delays. - Gaps in regulatory oversight regarding MEL application and airport standards. - An organizational culture potentially permissive of latent risks.

D. Integrated Discussion: The Convergence of Latent Failures and Active Errors

Synthesizing the findings from the STEP and SWOT analyses provides a powerful, systemic explanation of the accident. The tragedy was not the result of a single cause but rather the product of a convergence of a functional resonance where latent systemic vulnerabilities were activated by a front-line error, leading to the collapse of all available safety defenses.

The pathway to catastrophe began with the pre-existing conditions identified in the SWOT analysis.

The Weaknesses (a slippery, un-grooved runway; a permissive MEL policy for the thrust reverser; inadequate crew training for the specific scenario) and Threats (heavy rain, operational pressures) created a socio-technical system that was operating with eroded safety margins.[3] The system was fragile and primed for failure.

The active error by the copilot failing to retard the right thrust lever to IDLE, as detailed in the STEP matrix was the trigger that initiated the final, catastrophic sequence. This was not a random mistake but an error whose likelihood was increased by the latent.

Weakness in the A320's human-automation interface. The combination of non-moving thrust levers and the absence of a specific warning for that configuration meant the crew lacked the salient feedback necessary to rapidly detect and correct the mistake under high stress and workload.[6]

This trigger did not cause a single failure; it initiated a cascade of interacting failures. The non-deployment of spoilers and autobrakes was the aircraft's correct response to the incorrect lever inputs. This reveals a deeper systemic design flaw: the system's logic did not adequately protect against this specific, plausible human error, creating a "brittle" system that could fail catastrophically from a single input mistake.

The outcome was ultimately determined by the resonance of failed defenses. The accident unfolded as a result of the simultaneous and interacting failure of multiple, independent safety layers. The #2 thrust reverser was unavailable due to an organizational decision (MEL). The spoilers and autobrakes were unavailable due to the interaction between pilot input and system logic. The runway's braking friction was severely compromised by the lack of grooving and the presence of water. Finally, the last line of defense, a physical overrun area (RESA), was entirely absent. This is a practical and tragic demonstration of Hollnagel's functional resonance concept.[12] The negative performance variability of each of these functions organizational policy, human-machine interaction, infrastructure maintenance amplified one another, creating a resonant effect that drove the system to a catastrophic state that no single failure could have achieved on its own.

V. CONCLUSION AND RECOMMENDATIONS

A. Summary of Findings

The integrated analysis of the TAM Flight 3054 accident using the hybrid STEP-SWOT methodology shows that the disaster was a systemic failure rather than a simple case of pilot error.

It was an emergent outcome of a complex socio-technical system with multiple latent vulnerabilities. STEP reconstructed the chronological sequence of events, while SWOT revealed weaknesses in organizational policies, infrastructure, and human-automation interface design.

The crew’s error facilitated by design and training shortcomings aligned with these latent failures, resulting in the complete breakdown of safety defenses.

B. Contribution to the Field

This study's main contribution is demonstrating an effective hybrid methodology for complex accident analysis. Combining STEP's event reconstruction with SWOT's strategic vulnerability mapping bridges the gap between traditional linear investigations and abstract systemic models like FRAM. It offers a replicable and accessible approach that produces both detailed forensic insights and holistic understanding, supporting more robust safety recommendations.

C. Multi-faceted Safety Recommendations

Findings from the analysis lead to integrated recommendations across all levels of the aviation system:

Technical Systems (Aircraft Manufacturer): It is recommended that aviation authorities mandate clear visual and aural warning systems on all relevant aircraft to alert crews of asymmetric thrust lever positions during landing providing a redundant safeguard against a known critical error.

Operational Procedures (Airline Operators): Airlines should implement dynamic, context-based risk assessments for MEL dispatch. Aircraft with critical inoperative systems (e.g., thrust reversers, anti-skid) must not be dispatched when risk factors like adverse weather or short, wet runways are present.

Human Factors (Training): High-fidelity simulator training should be developed and mandated to address complex failure scenarios especially landings with degraded deceleration systems on contaminated runways enhancing procedural accuracy, crew resource management, and stress resilience.

Infrastructure (Airport Authorities): Mandatory runway grooving should be implemented, especially in areas with heavy rainfall. Where RESA is not feasible, EMAS systems should be installed to mitigate overrun consequences.

Regulatory Oversight (Civil Aviation Authorities): Regulators must adopt a more integrated, proactive stance. Oversight should ensure MEL policies and safety assessments account for interacting risks, and investigation findings must be translated more swiftly into binding safety directives.

D. Avenues for Future Research

This study highlights the value of a hybrid, qualitative approach to systemic analysis. Future research could focus on applying this STEP-SWOT framework to other major accidents to test its generalizability and further refine the methodology. Additionally, research should be directed towards developing quantitative models capable of assessing the compounded risk probabilities of interacting latent failures, moving safety management from a reactive, qualitative practice towards a more predictive, data-driven science.

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