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Lessons from Human Error: Building Airport Safety Culture

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Abstract
Purpose: This study evaluates the role of human error and the effectiveness of Apron Movement Control (AMC) supervision in developing a safety culture at the apron of a major airport in North Sumatra. It was motivated by a collision between a Lavatory Service Truck (LST) and a Boeing 737-800 aircraft on October 16, 2024, caused by personnel negligence, unserviceable equipment, and weak supervision.
Methodology: A qualitative case study approach was applied. Data were collected through observation, interviews, and documentation, and analyzed thematically using NVivo 15. The ORLIO model was employed to evaluate human error.
Result: The study identified repeated violations—normalization of deviance among Ground Support Equipment (GSE) personnel, limited AMC supervision, and non-compliant equipment. ORLIO-based evaluation enhanced personnel reflection and safety awareness, while AMC supervision acted as external enforcement. The synergy between reflection and supervision contributed to a shift in apron safety culture from permissive toward a more mature and sustainable one.
Conclusions: The apron accident shows that safety failures stem not only from individual errors but also from the interaction of human, equipment, and supervisory factors. Integrating ORLIO and AMC supervision effectively enhances safety awareness and procedural discipline.
Limitations: The study is limited to one airport, with qualitative data that may involve subjectivity. It focuses on operational staff, excluding higher management, and does not assess long-term impacts quantitatively.
Contribution: The study was limited to one airport, so findings may not represent all contexts. It contributes to aviation safety management by demonstrating how combining human error evaluation and AMC supervision strengthens apron safety culture, offering practical insights for airport authorities and regulators.

Keywords: *Apron Movement Control, Aviation, Human Error, Management, Safety Culture.*

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1. Introduction

The aviation industry has the highest level of safety compared to other modes of transportation; therefore, flight safety is a non-negotiable aspect (Low and Yang, 2019; Nasrullah et al., 2024). In general, incidents in the aviation industry are predominantly triggered by human error (Perboli et al., 2021). Indriani et al. (2023) recorded that more than 60% of aviation incidents in Indonesia were caused

by human factors, including negligence, lack of compliance with procedures, and weak supervision in the field. This finding echoes the conclusion of Chai et al. (2024), who showed that human factors make a significant contribution to operational failures in the aviation industry as a whole. These conditions highlight the importance of evaluating human error while simultaneously strengthening supervisory functions to maintain the operational safety of airports (Camlian and Baron, 2025).

While these patterns are widely observed across the aviation sector, their real-world implications can be better understood through specific incidents that reveal how human and organizational factors interact. real case illustrating this issue occurred on October 16, 2024, at a major airport in North Sumatra, Indonesia. The incident took place when a Lavatory Service Truck (LST) struck the rear section of a Boeing 737-800 aircraft operated by a national airline. The investigation conducted by the National Transportation Safety Committee Indonesia or Komisi Nasional Keselamatan Transportasi (KNKT) revealed that the accident was triggered by human error, involving unlicensed personnel, the use of unserviceable ground vehicles, and weak reporting to the Apron Movement Control (AMC) unit. In fact, AMC plays a strategic role in overseeing apron safety, monitoring vehicle movements, and ensuring compliance with Standard Operating Procedures (SOPs).

This case highlights the gap between the formal supervision in place and the actual level of safety awareness among ground personnel (Ismail et al., 2024). Several previous studies have highlighted either human error or AMC supervision as separate aspects. For example Can and Delice (2020) emphasized the application of the HEART method to assess the probability of human error in the context of the manufacturing industry. In addition, Dara and Meilani (2024) examined the limitations of AMC supervision at Komodo Airport, Labuan Bajo, without linking it to personnel awareness. However, there has been little research integrating human error evaluation with the effectiveness of AMC supervision, and how both contribute to shaping the work awareness of Ground Support Equipment (GSE) personnel.

To address this gap, this study adopts an evaluative approach based on the ORLIO model (Observation, Recognition, Learning, Improvement, Outcome). The model provides a structured analytical framework for identifying error patterns, recognizing their causes, and assessing the effectiveness of corrective actions. Furthermore, the LST–aircraft collision incident is framed as an organizational learning opportunity through the concept of Learning from Incidents (LFI), in which accidents are not merely recorded as individual failures but serve as triggers for system changes, training, and improvements in work culture Clare and Kourousis (2021). However, most prior studies examined human error or AMC supervision in isolation, providing only a partial understanding of apron safety dynamics. By integrating the ORLIO model into AMC supervision practices and adopting LFI principles, this study seeks to offer a more comprehensive understanding of how GSE personnel's safety awareness can be enhanced while simultaneously strengthening the safety culture at the airport.

This study introduces a novel integrative framework that combines human error evaluation using the ORLIO model with Apron Movement Control (AMC) supervision to explain how reflective learning and external oversight jointly foster a sustainable safety culture at the airport.Therefore, the objective of this research is to evaluate the interaction between human error analysis using the ORLIO model and the effectiveness of Apron Movement Control (AMC) supervision in developing a sustainable safety culture in airport apron operations. Building on this foundation, the study proposes a novel integrative framework that combines human error evaluation through the ORLIO model with AMC supervision, with the objective of assessing their interaction in developing a sustainable safety culture within airport apron operations.

2. Literature Review and Hypothesis Development

2.1 Human Error in the Aviation Operation

Aviation safety is a non-negotiable aspect since the industry carries higher risks compared to other modes of transportation (Low and Yang, 2019; Nasrullah et al., 2024). More than 60% of aviation incidents in Indonesia are attributed to human factors such as negligence, lack of compliance with procedures, and weak supervision (Indriani et al., 2023). This is consistent with Chai et al. (2024), who

highlighted the significant role of human factors in operational failures across the global aviation industry. Human error can be better understood through the Swiss Cheese Model, which explains how latent organizational weaknesses interact with active failures in the field to cause incidents (Larouzee and Le Coze, 2020). Perboli et al. (2021) emphasized that despite technological and regulatory advancements, human error remains the dominant source of aviation accidents.

2.2 Normalization of Deviance and Safety Culture

The phenomenon of normalization of deviance Vaughan (1996) describes how repeated violations become normalized and accepted as routine. Courtois and Gendron (2017) found that recurrent deviations without consequences transform into permissive organizational culture. Similar findings in Indonesian apron practices indicate frequent violations such as improper parking, failure to apply wheel chocks, and incomplete use of protective equipment (DiLisi and McLean, 2020). Safety culture is shaped by organizational values, attitudes, and collective habits. Cooper Ph.D. (2000) argued that compliance with safety is not only about rules but also about the internalization of organizational values. Albelo et al. (2023) further demonstrated that safety behavior is strongly influenced by consistent collective practices embedded within daily operations.

Recent studies have provided new insights into the transformation of safety culture in the aviation industry. Mahmoud et al. (2020) demonstrated that data-driven oversight through Key Performance Indicators (KPIs) can accelerate the transition from compliance-oriented behavior to a proactive safety culture, where continuous monitoring and feedback loops drive organizational learning and accountability. In a similar vein, Lee (2025) highlighted that sustaining safety culture within modern aviation maintenance requires balancing human-centered practices with technological adaptation, emphasizing the importance of continuous training, communication, and supervisory engagement. Taken together, these findings underscore that safety culture transformation is not a static process but an evolving organizational capability shaped by reflective learning, leadership commitment, and adaptive supervision. These perspectives reinforce the present study's aim to integrate human error evaluation and Apron Movement Control (AMC) supervision as complementary mechanisms for fostering a mature and sustainable safety culture.

2.3 Supervisory Roles in Apron Management

Effective supervision plays a crucial role in maintaining compliance and safety in apron operations. Can and Delice (2020) showed that the probability of human error increases when obsolete or unserviceable equipment is not strictly supervised. Dara and Meilani (2024) examined the limitations of Apron Movement Control (AMC) supervision at Komodo Airport, which mainly focused on administrative functions without fostering personnel awareness. Caras and Sandu (2014) in a study of social services, highlighted that supervision is not merely an administrative task but also an educational process that drives attitudinal change. This insight is applicable to apron operations, where AMC supervision should not only enforce compliance with SOPs but also cultivate deeper safety awareness among personnel .

2.4 Human Error Evaluation through the ORLIO Model

The ORLIO model (Observation, Recognition, Learning, Improvement, Outcome) provides a structured analytical framework for evaluating human error, identifying its causes, and assessing corrective measures. Clare and Kourousis (2021) linked this approach with the concept of Learning from Incidents (LFI), in which accidents serve as opportunities for organizational learning rather than merely individual failures. Mao et al. (2021) found that applying LFI principles can enhance personnel's safety awareness and lead to systematic improvements in work culture. Taken together, the Swiss Cheese Model provides a structural explanation of how latent organizational weaknesses lead to active failures, while the concept of normalization of deviance explains how such failures become culturally embedded. Integrating these perspectives through the ORLIO model and Learning from Incidents (LFI) framework enables a dynamic process of reflection and corrective learning, thus linking error evaluation with safety culture transformation.

2.5 Research Gap
Although several studies have examined human error (Can and Delice, 2020; Chai et al., 2024; Perboli et al., 2021) and AMC supervision (Dara and Meilani, 2024) separately, limited research has integrated both aspects in the context of apron safety culture. In fact, combining human error evaluation through ORLIO with AMC supervision is expected to improve GSE personnel's safety awareness while simultaneously strengthening a sustainable safety culture.

2.6 Hypothesis Development
Based on the literature review above, this study develops the following hypotheses:
H1: Human error evaluation using the ORLIO model has a positive effect on enhancing GSE personnel's safety awareness.
H2: Apron Movement Control (AMC) supervision has a positive effect on GSE personnel's compliance with SOPs.
H3: Human error evaluation through ORLIO and AMC supervision simultaneously contribute to strengthening apron safety culture.

3. Research Methods
3.1 Research Design
This study employs a qualitative approach using a case study method, as it focuses on a specific incident, namely the collision between a Lavatory Service Truck (LST) and a Boeing 737-800 aircraft operated by a national carrier at the apron of a major airport in North Sumatra on 16 October 2024. The case study approach was selected to provide an in-depth exploration of how human error occurred, how the Apron Movement Control (AMC) executed its supervisory function, and how the incident served as a medium for Learning from Incidents (LFI) towards fostering a safety culture in apron operations Clare and Kourousis (2021).

3.2 Research Subjects and Objects
The subjects of this study comprise Ground Support Equipment (GSE) personnel directly engaged in apron operations, along with Apron Movement Control (AMC) officers who act as the main supervisory authority on the apron. Their involvement is considered essential, as both groups play a pivotal role in ensuring the smooth and safe execution of ground handling activities.

The objects of the research include the assessment of human error factors contributing to the incident, the evaluation of AMC's supervisory effectiveness in preventing and mitigating such occurrences, and the examination of changes in work awareness and the development of a safety culture in the aftermath of the collision. This study involved six informants, consisting of two Ground Support Equipment (GSE) personnel, three Airside Operations officers (Junior Manager, Chief, and KP Airside Operation), and one representative from Apron Movement Control (AMC). The informants were selected using purposive sampling based on three criteria: (1) direct involvement in apron operations or supervision; (2) a minimum of two years of work experience; and (3) willingness to participate in in-depth interviews and data validation. The data collection process was conducted over a three-month period (November 2024 – January 2025), encompassing observation, documentation, and semi-structured interviews. Including these details enhances methodological transparency and strengthens the credibility of the study's findings. By focusing on these aspects, the study seeks to capture not only the operational dynamics between GSE personnel and AMC officers but also the broader implications for institutional learning and cultural transformation in apron safety management.

3.3 Data Analysis Technique
Data were analyzed qualitatively using NVivo 15 software, which was selected for its ability to manage, code, and visualize extensive textual data from interviews and operational documents in a systematic and transparent manner. NVivo is particularly suited for safety culture analysis, as it enables the identification of patterns of behavior, supervision, and learning that are often embedded within organizational narratives. Through features such as word frequency queries, node clustering, and thematic mapping, the software allowed the researcher to explore how key concepts such as *error recognition*, *supervisory control*, and *safety awareness* interrelate within participants' experiences.

The data analysis followed a systematic multi-stage process:

1. Data Familiarization and Reduction
   Reviewing interview transcripts and documents to identify relevant content.
2. Open Coding
   Generating initial codes related to *human error*, *supervision effectiveness*, and *safety awareness*.
3. Axial Coding
   Grouping similar codes into broader categories that captured *Human Error Evaluation*, *AMC Supervisory Function*, and *Safety Learning and Awareness*.
4. Theme Development and Validation
   Synthesizing categories into main themes and verifying them through source triangulation (interviews, observations, documents) and member checking to ensure interpretive accuracy.

These procedures, supported by NVivo visualizations, provided a structured basis for identifying how the evaluation of human error and AMC supervision contributed to the transformation of safety culture in apron operations. The validity of the data was ensured through source triangulation by comparing the results of observations, interviews, and documentation. It was also strengthened through methodological triangulation by combining field observations, document analysis, and interviews. In addition, member checking was conducted with informants to confirm the accuracy of the researcher's interpretations.

3.4 Data Collection and NVivo Justification

Data were collected through direct observation, semi-structured interviews, and documentation of operational records. The use of NVivo 15 software was justified by its capacity to manage large volumes of qualitative data, perform systematic coding, and generate visual representations (e.g., thematic maps and word frequency clouds). NVivo's analytical framework is particularly well-suited for safety culture studies, as it allows researchers to trace relationships between behavioral patterns, procedural compliance, and supervisory practices—key elements of aviation safety culture.

3.5 Data Analysis Procedures

The data analysis followed a systematic multi-stage process to ensure methodological rigor:

1. Data Reduction – identifying relevant data from observations, interviews, and documents.
2. Open Coding – segmenting the data into initial codes representing emerging concepts such as "safety awareness," "compliance," "human error," and "supervision."
3. Axial Coding – grouping related codes into broader categories such as "Work Practices," "Supervisory Effectiveness," and "Learning from Incidents."
4. Theme Development – deriving overarching themes from these categories to interpret the interaction between human error evaluation and AMC supervision.
5. Validation – ensuring reliability through source triangulation (observation, interview, documentation), methodological triangulation, and member checking with key informants to confirm interpretation accuracy.

4. Result and Discussion

Field observations, documentation, and interview data reveal consistent patterns highlighting the interaction between human, technical, and supervisory factors in apron operations. Three dominant findings emerged: (1) persistent procedural violations and normalization of deviance among Ground Support Equipment (GSE) personnel, (2) the prevalence of unserviceable equipment that creates *Error Producing Conditions (EPCs)*, and (3) limitations of Apron Movement Control (AMC) supervision in internalizing safety awareness. These elements collectively explain how the collision between a Lavatory Service Truck (LST) and a Boeing 737-800 aircraft occurred, representing an intersection of active and latent failures within the airport's safety defense layers.

Field observations recorded repeated unsafe practices in the apron area, such as improperly parked GSE, baggage carts scattered around the Equipment Parking Area (EPA), vehicles left in active lanes, non-application of wheel chocks, exceeding the speed limit, and incomplete use of Personal Protective Equipment (PPE). These behaviors exemplify what (Vaughan, 1996) termed the *normalization of*

deviance, wherein rule violations become normalized through repetition and lack of consequence. Documentation data further confirmed systemic issues in equipment serviceability. As illustrated in Figure 1, 53.4% of GSE units were classified as *Non-Motorized–Unserviceable*, while only 15.8% were *Motorized–Serviceable*. The LST involved in the accident was found to be 38 years old—far beyond the operational limit stipulated by KP 635/2015 (10–15 years depending on type). This situation aligns with Can and Delice (2020), who noted that unserviceable or obsolete equipment significantly increases the likelihood of human error. Such conditions correspond to Reason's *Swiss Cheese Model*, in which latent organizational weaknesses, such as inadequate maintenance and monitoring interact with active human errors to create accident pathways (Larouzee and Le Coze, 2020; Shabani et al., 2024).

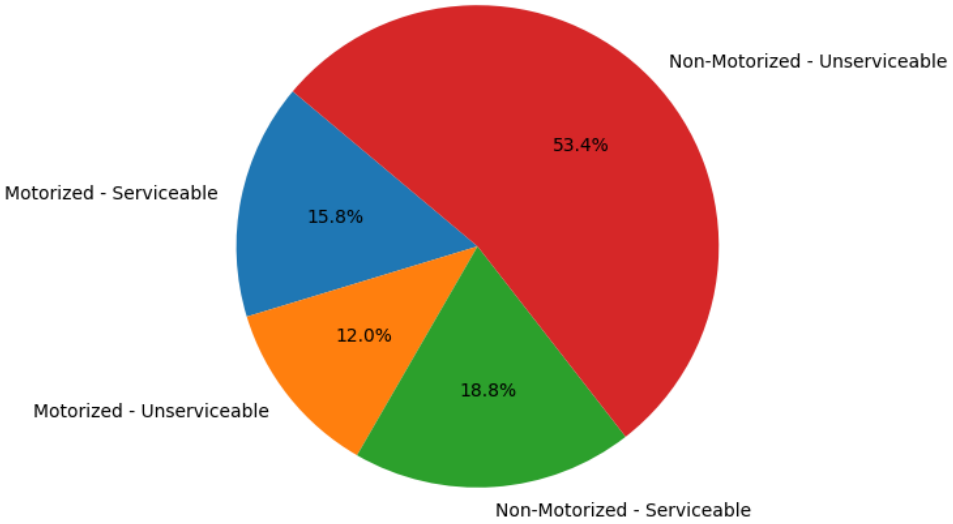

Figure 1. Distribution of Ground Support Equipment Serviceability at the Subject Airport
Source: Official Document Airport Subject

Interviews confirmed that human factors remain central to apron safety incidents. The Junior Manager of Airside Operations emphasized that "the main causal factors are human, method (SOP), and machine (GSE)". This aligns with the *SHEL* and *Swiss Cheese* perspectives, where operational errors arise from the interaction of people, procedures, and technology (Perboli et al., 2021). Several GSE personnel admitted that they often rushed their work or bypassed procedures because such actions had become common and rarely penalized, demonstrating a permissive culture consistent with (Courtois and Gendron, 2017; DiLisi and McLean, 2020), who showed that tolerance toward minor violations fosters systemic risk. The Airside Operation Chief added that during high-traffic periods, operators often managed multiple GSE units simultaneously, reducing concentration and increasing oversight errors this conditions resonant with fatigue and workload theory (Pandey, 2024).

In terms of supervision, AMC officers acknowledged structural and operational limitations. Despite conducting patrols four times daily, compliance tended to improve only during visible monitoring and decline once supervision ceased. As one officer noted, "AMC cannot monitor at all times; compliance depends heavily on presence". This indicates that personnel safety awareness remained externally driven rather than internally embedded. Similar weaknesses were also found by Dara and Meilani (2024) in their study at Komodo Airport, which reported that AMC supervision often remains administrative rather than developmental. Caras and Sandu (2014) conceptualized supervision as both administrative and educational ensuring procedural adherence while cultivating attitudinal change. Yet, in this case, AMC supervision largely operated as a control mechanism rather than as a catalyst for learning. Limited personnel, wide coverage areas, inconsistent sanction enforcement, and disparities in SOPs among ground-handling companies further constrained its effectiveness.

NVivo 15 analysis strengthened these findings by mapping the co-occurrence of key terms and concepts from the interviews. Word frequency queries and project maps identified central nodes such as *awareness*, *supervision*, *human error*, *compliance*, and *equipment condition*. The interconnections

among these nodes highlight how ORLIO-based human error evaluations stimulate reflective learning, while AMC supervision enforces procedural discipline. Together, they represent complementary mechanisms: ORLIO functions as an *internal driver* that fosters behavioral change through reflection and recognition, whereas AMC acts as an *external controller* ensuring short-term compliance. Nevertheless, the persistence of mechanical deficiencies (unserviceable GSE) and inconsistent rule enforcement continues to weaken both layers of defense. Supporting figures and analytical representations were refined to enhance conceptual clarity. Figure 2 provides visual context of the LST–aircraft collision, underscoring the real-world consequences of human and systemic failures. Figure 1 quantifies the scope of equipment unserviceability, reinforcing the mechanical dimension of latent failure.

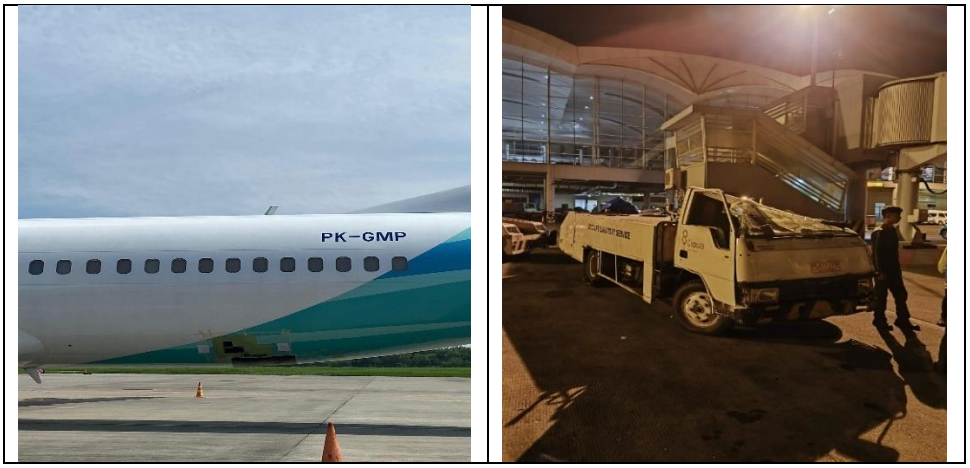

Figure 2. Structural damage aircraft and LST
Source: Author's own documentation (2024)

4.1 Synthesis of Thematic Findings

Table 1 presents the main themes derived from field observations and interviews, along with supporting evidence and corresponding practical implications. Meanwhile, Table 2 outlines the relationships between these themes, demonstrating how human, mechanical, and managerial factors interact within apron operations.

Table 1. Summary of Core Themes and Practical Implications

Theme	Key Evidence	Practical Implication
Normalization of Deviance	Repeated violations (parking, PPE, speed, wheel chocks)	Behavioral reform and consistent sanctioning needed
Equipment Unserviceability	53.4% GSE unserviceable; outdated LST vehicle	Enforce equipment renewal and maintenance compliance
AMC Supervision Limitations	Limited patrol coverage; compliance only under observation	Increase supervisory capacity and use digital monitoring
ORLIO Evaluation Impact	Personnel reflection and improved awareness	Institutionalize ORLIO in safety training and evaluations
Interaction Between Factors	NVivo nodes link human error–supervision–equipment	Integrated intervention across man machine management

Source: Thematic findings derived from field data and NVivo analysis are summarized from the author's own documentation (2024).

As shown in Table 1, normalization of deviance and equipment unserviceability emerged as dominant themes shaping the behavioral and systemic context of apron safety incidents.

Table 2. Inter-Theme Relationships

From	To	Mechanism
Unserviceable Equipment	Increased Error Potential	Latent mechanical failures weaken safety barriers
Normalization of Deviance	Routine Non-Compliance	Deviations embedded in culture erode SOP effectiveness
AMC Supervision	Short-Term Compliance	External control ensures temporary discipline
ORLIO Evaluation	Sustained Awareness	Reflective learning strengthens internal commitment
ORLIO + AMC Integration	Mature Safety Culture	Dual mechanisms bridge reflection and enforcement

Source: Thematic findings derived from field data and NVivo analysis are summarized from the author's own documentation (2024).

Beyond individual themes, Table 2 highlights how unserviceable equipment and normalization of deviance are mutually reinforcing, while the integration of AMC supervision and ORLIO evaluation represents a dual mechanism bridging reflection and procedural enforcement (Kundori et al., 2025). Figure 3 illustrates the integrated framework, showing the synergy between ORLIO evaluation, AMC supervision, and the continuous LFI feedback loop. This conceptual framework illustrates how the ORLIO-based human error evaluation (internal reflection) and Apron Movement Control (AMC) supervision (external enforcement) interact within the *Swiss Cheese Model* and *Learning from Incidents (LFI)* framework. The ORLIO process strengthens the human layer by reducing active failures through reflection and learning, while AMC supervision reinforces the managerial layer by closing procedural and oversight gaps (Fahrizal et al., 2025). Persistent unserviceable equipment represents a latent mechanical layer vulnerability that can weaken both human and managerial defenses.

At the base of the framework, the LFI loop represents a continuous feedback cycle that transforms incident findings into learning, SOP revisions, and recurrent training. This mechanism promotes continuous improvement and fosters a mature, sustainable safety culture. Structurally, the framework can be visualized as a vertical interaction among three layers: human, mechanical, and managerial. These layers are connected by downward and feedback arrows, while the LFI loop operates horizontally beneath them to symbolize institutional learning and safety reinforcement.

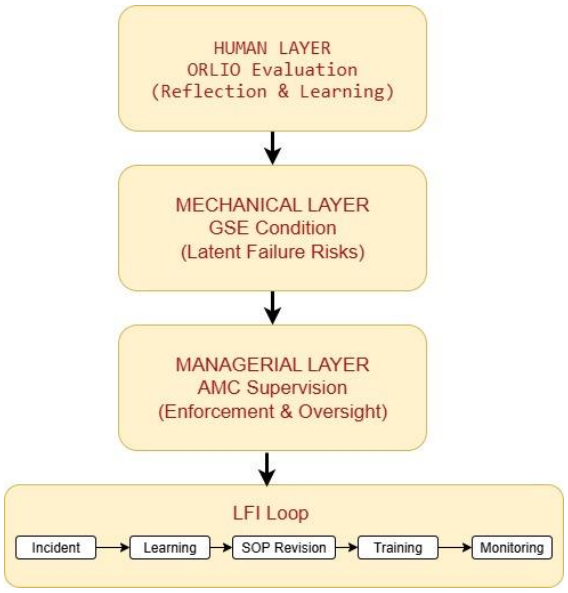

Figure 3. Integrated Framework: ORLIO AMC Synergy within Swiss Cheese and LFI Context
Source: Author's own conceptual framework (2024).

4.2 Theoretical Reflection: Safety Culture, Swiss Cheese, and LFI Integration

The results deepen theoretical understanding by integrating safety culture theory, Reason's *Swiss Cheese Model*, and *Learning from Incidents (LFI)* (Albelo et al., 2023; Cooper Ph.D., 2000). The collision case demonstrates how multiple defensive layers human, mechanical, and managerial contained "holes" that aligned to produce failure. The ORLIO model serves as a structured mechanism for reflection and behavioral improvement, strengthening the human layer by reducing active errors. Meanwhile, AMC supervision reinforces managerial defenses through procedural enforcement. However, the mechanical layer, represented by aging or defective GSE remains a persistent vulnerability that can compromise both.

From the perspective of safety culture, compliance and awareness are shaped not merely by rules but by internalized organizational values (Cooper Ph.D., 2000). When these values are not consistently reinforced through supervision and learning, a permissive culture emerges one that tolerates minor violations and normalizes deviance. Albelo et al. (2023) similarly emphasized that sustainable safety culture requires consistent collective practices embedded in daily operations. This study supports those conclusions by demonstrating that combining ORLIO reflection and AMC supervision transforms safety from a compliance-based mindset into an awareness-driven one (Rachman et al., 2025).

Theoretically, this research extends Reason's *Swiss Cheese Model* Larouzee and Le Coze (2020) and Shabani et al. (2024) by operationalizing its layers through practical mechanisms: ORLIO as a human-learning layer and AMC as a managerial-control layer. Yet, unless the mechanical layer (GSE condition) is strengthened, the system remains vulnerable. From an *LFI* standpoint, the incident became an opportunity for organizational learning rather than a disciplinary measure, consistent with Clare and Kourousis (2021) and Mao et al. (2021). However, for LFI to be effective, insights must be institutionalized converted into SOP revisions, refresher training, and stronger enforcement (Sihombing et al., 2025). Moreover, post-incident changes that follow High Reliability Organization (HRO) principles—continuous vigilance and preoccupation with failure, are critical to maintaining improvement, as discussed by Chambers et al. (2025) in her interpretation of Weick and Sutcliffe's (2011).

When integrated, ORLIO and AMC supervision create a dual mechanism that bridges internal reflection and external oversight, embodying both individual learning and systemic control. This synergy enables the transition from a permissive to a proactive and sustainable safety culture in airport apron operations. Overall, these findings affirm that apron safety failures arise not from isolated human mistakes but from the interaction of human behavior, equipment reliability, and supervisory consistency. The integration of ORLIO-based error evaluation and AMC supervision offers a multi-layered defense model linking reflective learning, procedural discipline, and continuous improvement essential for sustaining a mature airport safety culture.

5. Conclusions and Suggetions

5.1 Conclusions

This study concludes that apron safety failures arise from the interaction between human factors, unserviceable equipment, and limitations in supervisory control. The evaluation of human error through the ORLIO model strengthens internal safety awareness by promoting reflection and behavioral change, while Apron Movement Control (AMC) supervision functions as an external mechanism that enforces procedural discipline. Theoretically, this research contributes to aviation safety management literature by introducing an integrative framework that combines ORLIO-based human error evaluation and AMC supervision—two dimensions that are rarely analyzed together in Indonesia's aviation context. This integration operationalizes the *Swiss Cheese Model* and *Learning from Incidents (LFI)* principles, offering a dual mechanism of internal reflection and external oversight for building a resilient and sustainable safety culture.

5.2 Suggestions

Practical implications of this study highlight the need for stronger policy implementation and operational improvement at airport authorities and regulators. The following recommendations are proposed:

1. Strengthen AMC supervisory capacity through continuous training, standardized procedures, and the adoption of digital monitoring technologies (for example smart CCTV and real-time reporting).
2. Institutionalize ORLIO-based evaluations as part of regular safety training and post-incident assessments to promote reflective learning.
3. Renew and maintain Ground Support Equipment (GSE) according to regulatory lifespan standards to reduce error-producing conditions.
4. Integrate human error findings into SOP revisions to ensure that procedural updates are evidence-based.
5. Encourage a formal Learning from Incidents (LFI) system, transforming incident documentation into a continuous organizational learning process.

Limitations and Further Research

This study has several limitations, including its focus on a single incident of an LST-aircraft collision at one major airport in North Sumatra, which limits the generalizability of the findings to other airports in Indonesia. The research relied primarily on qualitative data, making the interpretation highly dependent on the perspectives of the informants and researchers. The analysis of AMC supervision was confined to a specific case and did not capture variations such as shift differences, traffic intensity, or the role of monitoring technology. Broader external factors, such as national policies, international standards, and individual psychological aspects, were also not extensively addressed. Future research is recommended to conduct comparative studies across multiple airports with varying levels of activity, quantitative analyses to measure the contributions of human error, equipment condition, and AMC supervision to apron safety, and interdisciplinary studies linking work psychology aspects such as stress and fatigue with safety culture. Furthermore, research integrating technological innovations, such as smart CCTV or IoT-enabled GSE, is essential to strengthen monitoring systems and enhance accident prevention.

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