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An Analysis of Commercial Aircraft Accidents Using the Human Factors Analysis and Classification System (HFACS): The Case of The United States

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Abstract

A significant portion of aviation accidents is attributed to human factors, highlighting the need for comprehensive and systematic analyses in this field. This study examines 57 scheduled commercial aircraft accidents that occurred in the United States between 2020 and 2024 using the Human Factors Analysis and Classification System (HFACS) framework, with the aim of evaluating the contributing human factors in a multi-layered manner. The research demonstrates that human errors are not solely the result of individual performance deficiencies but also stem from systemic, managerial, and organizational shortcomings. The study utilizes official accident reports from the United States National Transportation Safety Board (NTSB), analysed through content and descriptive analysis techniques. Only accidents involving turbofan-powered fixed-wing aircraft engaged in scheduled passenger transportation were included. NTSB reports are considered highly reliable primary sources due to their comprehensive analysis of technical, operational, and human factors related to aviation incidents. Based on 207 coding conducted according to the HFACS model, human errors were analysed across four levels: unsafe acts, preconditions for unsafe acts, supervisory factors, and organizational influences. The analysis revealed that the most frequently observed human errors were related to decision-making and perception, primarily resulting from cognitive limitations, information deficiencies, and inadequate situational awareness. Environmental factors such as turbulence and technological shortcomings were also identified as direct threats to operational safety. Furthermore, operational planning errors, the neglect of safety priorities, dysfunctional procedures, and insufficient resource management were highlighted as indirect contributors stemming from managerial and organizational deficiencies. The findings emphasize the necessity of developing accident prevention strategies not only at the individual level but also across organizational and systemic levels.

This study is derived from a Master's thesis completed at the School of Graduate Studies, University of Turkish Aeronautical Association.

1. Introduction

Since the late 1950s, the air transportation sector has taken significant steps to reduce accident rates. As a result of these efforts, traveling by commercial passenger aircraft has become a safer mode of transportation than driving in large cities (Wiegmann & Shappell, 2001). In achieving this level of safety, studies aimed at understanding human factors have been as decisive as technological advancements. It is widely accepted that approximately 80% of all accidents in modern civil and military aviation are caused by human factors (de Hoyos, 2023).

In the last twenty years, many aviation organizations have encouraged personnel working in safety and risk management to develop programs aimed at reducing the effects of human factors. Despite advancements in aircraft technology and increased system reliability, human errors continue to be one of the most significant safety risks. Although the contribution of human errors to accidents is well known, current analyses and preventive measures are often insufficient; while accident reports provide detailed accounts of the timing and manner of events, they rarely examine the underlying causes in depth. In many cases, the lack of concrete evidence leads to the assumption of pilot error, which in turn causes deeper structural reasons to be overlooked. However, scientific analyses aimed at revealing how and why accidents occur are crucial for preventing the recurrence of similar incidents (ICAO Circular, 1993).

According to the International Civil Aviation Organization (ICAO), the most effective step in preventing accidents is the comprehensive analysis of past accidents (ICAO, 2010). In recent years, safety is no longer seen as limited to individual errors; organizational structures, managerial processes, and environmental conditions are also considered among the causes of accidents (Xiong, Beckmann & Tan, 2018). Understanding the root causes of human errors in aviation is important not only for evaluating past events but also for shaping future safety policies.

This study aims to reveal the structural patterns behind incidents by systematically examining accident reports through multi-level, pre-defined thematic frameworks. For this purpose, the study employs one of the most widely used models in the literature, the Human Factors Analysis and Classification System (HFACS). Inspired by James Reason's Swiss Cheese Model, the HFACS model was developed by Wiegmann and Shappell to classify human errors into four basic levels: unsafe acts, preconditions for unsafe acts, supervisory factors, and organizational influences (Wiegmann & Shappell, 2001). Originally developed for the U.S. Navy, HFACS has gradually become widely used by many military institutions. Today, having been applied in more than 1,000 military aviation accidents, the model has improved the quality of data collection on human errors and strengthened the effectiveness of research strategies. Civil aviation organizations such as the FAA and NASA have also demonstrated the applicability of HFACS in civil aviation. Today, the model is used not only in the military but also in civil aviation and other sectors for safety analyses (Wiegmann & Shappell, 2001). HFACS provides an effective framework for systematically classifying and analyzing the underlying causes of human errors (Dönmez & Uslu, 2018).

The study focuses on identifying the most common types of unsafe acts encountered in the examined accidents and the environmental or technological conditions under which these behaviors occur. Additionally, based on the statements found in the reports, the analysis explores how deficiencies in managerial planning and elements of organizational structure are reflected in the accidents. The HFACS model enables the classification of human errors at different levels, and in this context, the findings obtained are expected to contribute to evaluations aimed at improving aviation safety.

2. Conceptual Framework

2.1. The Concept of Human Factors

Human factors is a multidimensional field of study that examines an individual's physiological, psychological, and cognitive capacities within the context of their interaction with the system. Particularly, understanding the internal and external variables that affect human performance plays a significant role in ensuring safety in high-risk sectors (Tamer, 2021). This concept not only addresses human behavior in terms of individual competencies but also includes the environmental, managerial, and organizational factors that lead to these behaviors (Demirhan, 2024).

Humans are inherently beings with limitations. These limitations manifest in areas such as attention, perception, decision-making, and reaction time, increasing the likelihood of errors, especially among individuals operating in complex systems. Indeed, the literature emphasizes that human errors are the most common cause of aircraft accidents and that the human factor is involved, either directly or indirectly, in approximately 80% of such incidents (Baber, 2007). However, this rate is seen more as an indicator of deficiencies in the design and operation of the system the individual is part of, rather than a reflection of the individual's incompetence.

The aviation sector is one of the most prominent fields for the systematic examination of human factors. Elements such as time pressure, information load, the necessity of decision-making, and environmental conditions in the working environment of flight personnel increase the likelihood of errors. As emphasized by Tamer (2021), determining and reducing the error tendencies of individuals involved in aviation activities is one of the fundamental components of the sector's safety approach.

The evaluation of human factors cannot be reduced merely to the analysis of individual competencies or errors; it also requires a holistic consideration of systemic elements such as organizational structure, management philosophy, task distribution, and workload planning. To accurately analyze the underlying causes of aircraft accidents, it is necessary to consider not only the individual's role within the system but also institutional deficiencies outside the organizational structure. This elevates the consideration of human factors beyond individual responsibility, requiring it to be addressed within a multi-actor and multi-layered systems approach (Kızıltepe, 2021).

Initially, the discipline of human factors in aviation developed with a focus on individuals' physical limitations and ergonomic needs. Early research concentrated on topics such as cockpit workload, attention processes, and human-machine interaction. Over time, the field began to be addressed from a broader perspective, incorporating not only individual performance but also environmental conditions, organizational structures, and managerial decision-making processes. Human factors have arguably found their greatest recognition in the field of aviation, becoming an integral part of the research, development, testing, and evaluation cycle (Deaton & Morrison, 2010). These developments have highlighted the need for a more systematic examination of the causes of human errors, leading to an increased focus on theoretical models.

2.2. Analysis of Aircraft Accidents Through Systematic Models and the HFACS Model

The analysis of aircraft accidents is an important approach used to enhance aviation safety and to develop strategies for accident prevention. Theoretical models developed in this context delve into the root causes of accidents by considering a wide range of variables such as human factors, technical problems, and environmental influences, thus contributing to safer flight operations. The evolution of safety management in aviation consists of four stages: the Technical Era, the Human Factors Era, the Organizational Era, and the Total System Era (ICAO, 2018). Theoretical models such as Heinrich's "Domino Theory," Hollnagel's "FRAM," Svenson's "AEB," Reason's "Swiss Cheese Model," Leveson's "STAMP," SHELL, and the 5M model are among the key tools designed to improve aviation safety (SIA, 2012). CASA recommends the continuous updating of these models to ensure sustainable safety, and Maurino (2017) defines safety management as an evolutionary discipline.

The Domino Theory posits that accidents occur through a sequential chain of cause-and-effect, suggesting that breaking any link in this chain can prevent accidents (Heinrich, 1931; Griffin, Young & Stanton, 2015). Reason's Swiss Cheese Model states that accidents occur when weaknesses in a system's defense barriers align (Reason, 1990, 1997). This model facilitates the analysis of not only human errors but also organizational and systemic deficiencies. The SHELL model highlights the risks arising from mismatches in the interactions between humans and software, hardware, environment, and other individuals (ICAO, 2014; CASA, 2014c). The 5M model aims to analyze accident causes multidimensionally by focusing on human, machine, media, mission, and management factors (Rodrigues & Cusick, 2012; Stolzer &

Goglia, 2015). The STAMP model argues that accidents result more from deficiencies in system control processes than from component failures (Leveson, 2003). The FRAM model presents a dynamic approach by analyzing performance variability and function interactions in systems to understand unexpected outcomes in complex systems (Hollnagel, 2012; Patriarca et al., 2020). All these models contribute to the development of a safety management culture in aviation.

The Human Factors Analysis and Classification System (HFACS) offers a taxonomy that classifies human errors across four hierarchical levels: unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences (Shappell & Wiegmann, 2000). Developed based on Reason's model of latent and active failures, HFACS has been effectively used in the analysis of thousands of accident records, particularly by the U.S. Navy and other military forces (Wiegmann & Shappell, 2003). HFACS comprises 19 causal categories analyzed at four levels:

1. Unsafe Acts (Decision Errors, Skill-Based Errors, Perceptual Errors, Violations)
2. Preconditions (Mental State, Physiological State, Mental/Physical Limitations, CRM Deficiency, Personal Readiness, Physical Environment, Technological Environment)
3. Unsafe Supervision (Inadequate Supervision, Inappropriate Operational Planning, Failure to Correct Known Problem, Supervisory Violations)
4. Organizational Influences (Resource Management, Organizational Climate, Organizational Processes)

Under unsafe acts, errors (including skill-based, decision, and perceptual errors) and violations (routine and exceptional) are categorized, while preconditions encompass factors such as the individual's mental and physiological states, CRM deficiency, lack of personal readiness, and physical environment (Wiegmann & Shappell, 2001). The third level, unsafe supervision, includes deficiencies such as inadequate oversight, flawed operational planning, and failure to correct known issues (Wiegmann & Shappell, 2001; NTSB, 1982). Organizational influences reveal how weaknesses in resource management, organizational climate, and processes shape individual behaviors (Tamer, 2021; Demirhan, 2024).

This system enables the identification of systemic deficiencies underlying accidents. Additionally, by analyzing past events, recurring human errors and systemic failures can be identified. This allows organizations to focus on weak areas, make data-driven improvements, and reduce accident rates (Wiegmann & Shappell, 2001). HFACS provides a structure for examining and analyzing historical accident and safety data. By separating human contribution in terms of performance, the analyst can identify the root factors associated with an unsafe act. The HFACS framework also serves as a useful tool for guiding future field investigations and for the development of more robust accident databases, ultimately enhancing the quality and accessibility of human factor-related accident data. Common trends within an organization can be uncovered by comparing the psychological origins of unsafe acts or the latent conditions that make them possible. Identifying these patterns supports the determination and prioritization of areas that require intervention.

Through the use of HFACS, an organization can identify where hazards have occurred in the past and implement procedures to prevent the consequences of these hazards. This contributes to improved human performance and the reduction of accidents and injuries. The HFACS framework has been successfully applied to analyze accidents in military, commercial, and general aviation sectors (Shappell & Wiegmann, 2001). The HFACS model provides a comprehensive framework for the systematic analysis of human factors in aircraft accidents. By contributing to the development of data-driven strategies for accident prevention in both military and civil aviation, it helps strengthen the culture of safety (Shappell & Wiegmann, 1999, 2001, 2003).

Table 1 presents various studies based on the HFACS model, including their methodologies and key findings. These studies employed different data collection and analysis methods to understand the role of human factors in aircraft accidents and to propose solutions based on these factors.

Table 1. Summary of HFACS-Based Aircraft Accident Studies

Author(s)	Year	Research Focus	Methodology	Key Findings
Liu et al.	2025	LLM-based reasoning in HFACS-guided accident investigations	HFACS-Guided LLM (GPT-4o) Reasoning	HFACS-CoT methods improved LLM accuracy in detecting human errors and precursors; in some cases outperformed experts.
Meng & Lu	2022	HFACS and Bayesian Network integration for CFIT analysis	Hybrid HFACS–Bayesian Network	The hybrid model effectively analyzed human factors in CFIT accidents, showing enhanced explanatory capacity.
Kılıç & Gümüş	2020	Night flight accident analysis (2015–2020)	HFACS Analysis	Environmental conditions were dominant; skill-based and decision errors also significant.
Kılıç & Gündoğdu	2020	Air cargo accidents (2010–2020)	HFACS Analysis	Skill and decision errors were prominent; organizational and environmental shortcomings contributed to accidents.
Kılıç	2019	General aviation and training accidents (2018)	HFACS Analysis	Skill-based errors accounted for 80% of unsafe acts; 58.57% of them were linked to physical environmental preconditions.
Dönmez & Uslu	2018	Organizational-Operational links in 21st-century aviation events	HFACS, Data & Statistical Analysis	Organizational and managerial faults directly impacted cockpit crew's unsafe behaviors.
Yeşilbaş & Cotter	2014	HFACS structure for manned vs. unmanned aircraft	Structural Comparison via HFACS	Identified operational and structural differences in human factor classifications between UAVs and manned aircraft.

Author(s)	Year	Research Focus	Methodology	Key Findings
Bilbro	2013	Inter-rater reliability of HFACS and HFACS-M in the U.S. DoD	Comparative Reliability Analysis	Found both HFACS versions reliable with nuanced differences in application.
Ergai	2013	Internal and inter-observer reliability of HFACS	Reliability Assessment	Demonstrated the consistency of HFACS classifications across observers and sessions.
Li, Harris & Yu	2008	HFACS application to Chinese civil aviation (1999–2006)	HFACS & Data Analysis	Organizational lapses correlated with unsafe acts; highlighted management's impact on operator behavior.
Li, Harris & Yu	2007	41 Chinese civil aviation accidents (1999–2006)	HFACS Analysis	Found most accidents resulted from decision and skill-based errors; supervisory and systemic issues were also evident.
ATSB	2007	HFACS applied to general, commercial, and agricultural flights in Australia	HFACS, Comparative Country Study	Highlighted national differences in human factor patterns between Australia and the U.S.
Shappell et al.	2006	Commercial aviation accidents (1990–2002)	HFACS & Data Analysis	Unsafe acts, especially skill and decision errors, were found to be leading contributors in commercial aviation accidents.
Wiegmann et al.	2005	14,436 general aviation accidents (1990–2000) from NTSB database	HFACS Large-Scale Analysis	Skill-based, decision, and perceptual errors were the most frequent human error types contributing to accidents.
Wiegmann & Shappell	2001	HFACS analysis of commercial accidents (1990–1996)	HFACS & Data Analysis	Demonstrated how human error shaped commercial aviation accidents, forming the basis of HFACS development.

The studies included in the table are significant works that comprehensively examine human factors in aircraft accidents. A majority of these studies employed the HFACS model to understand the impact of human errors on accidents and to develop applicable solutions to prevent such errors. In addition, studies conducted in different years analyzed various aviation accidents from a human factors perspective, thereby contributing to the development of a safety culture in the industry. Particularly, elements such as cockpit communication, decision-making processes, managerial errors, and organizational deficiencies are prominently featured in the findings of these studies. These studies reveal that human factors are among the primary causes of accidents and emphasize the necessity of considering human factors in ensuring aviation safety. The findings obtained from the studies will be useful in improving safety practices in the sector, enhancing training programs, and formulating policies for safer flight operations.

Several national and international studies that do not rely on the HFACS model have also examined commercial aviation accidents from a human factors perspective. Kharoufah et al. (2018) analyzed more than 200 commercial air transport accidents and incidents between 2000 and 2016, identifying lack of situational awareness and non-adherence to procedures as prominent human factors. The study also found that charter operations had a higher proportion of accidents related to human factors compared to other types of operations. Von Thaden et al. (2006) conducted a case-based analysis of commercial aircraft accidents between 1990 and 2000, revealing the role of organizational factors in events attributed to pilot error. Their findings indicated that inadequate procedures and directives were the most common organizational problems, suggesting that interventions targeting organizational-level improvements could be effective across the system. Studies conducted in Türkiye also highlight the importance of human factors. Terzioğlu (2007) examined pilots' awareness of Crew Resource Management (CRM), emphasizing that, in addition to technical competence, communication, teamwork, and decision-making skills are critical in preventing accidents. Işıldak et al. (2021) analyzed the statistical distribution of civil aviation accidents in Türkiye between 1909 and 2020, identifying notable trends in certain time periods, flight routes, and aircraft types. These findings demonstrate that human factors should be addressed not only at the operational level but also within organizational structures and at the sectoral level, and they show that, alongside HFACS-based research, alternative methodological approaches hold a significant place in the aviation safety literature.

3. Methodology

3.1. Research Design

This study was conducted within the scope of qualitative research methods aiming to systematically analyze human errors, which are considered one of the main causes of aviation accidents. Qualitative research designs are flexible, exploratory, and interpretative approaches used to gain a deep understanding of complex social phenomena within a specific context. The analytical strategies employed in the study include descriptive analysis and content analysis techniques. Descriptive analysis is an approach based on summarizing and interpreting the data obtained in line with predetermined themes. The main objective of descriptive analysis is to present the findings in a meaningful and interpretable manner to the reader (Özdemir, 2010: 336; Karataş, 2015: 73). Content analysis, on the other hand, is a method that enables the systematic and objective examination of written, verbal, or visual materials (Tavşancıl & Aslan, 2001). Within the scope of the study, the layers of the HFACS model were structured based on the cases presented in NTSB reports, and each level was analyzed through case-specific examples. In this way, the interrelations among human factors contributing to accidents were addressed in detail within a cause-effect framework.

3.2. Data Source and Sampling

The primary data source of the research consists of aircraft accident reports published by the National Transportation Safety Board (NTSB), which is responsible for conducting official investigations into aviation accidents in the United

States. NTSB reports are considered highly reliable primary sources for scientific research, as they contain comprehensive analyses of the technical, operational, and human factors related to accident events.The data analyzed within the scope of the research is limited to finalized reports of accidents that occurred between 2020 and 2024, involving only turbofan-powered fixed-wing passenger aircraft, and classified under 14 CFR Part 121 scheduled passenger transport operations. The study focuses exclusively on accidents that took place within the borders of the United States. The data collection process was carried out systematically through the NTSB's digital data archive. As a result of filtering, 57 finalized accident reports were obtained in digital format. These reports were coded in detail based on the HFACS model and analyzed using a dual-coder approach by two researchers. During the coding process, each event was structured according to the four fundamental levels of HFACS (unsafe acts, preconditions for unsafe acts, unsafe supervision, organizational influences). The data were transformed into thematic codes and compiled into an Excel-based analysis table. The distribution of the codes across HFACS layers enabled both numerical frequency analysis and qualitative contextual interpretation.

In data analysis, descriptive analysis and content analysis techniques were used together. In descriptive analysis, each report was classified according to HFACS themes, and comparative patterns were identified. In content analysis, the codes were grouped according to HFACS levels and thematic clusters were created. The main themes identified included violations, perceptual errors, planning deficiencies, physical environment, and inappropriate operational planning. These themes were matched with HFACS levels and interpreted through a multi-layered error chain approach.

4. Findings

The data on aviation accidents were analyzed according to the four levels of the HFACS model. Codings for each level were evaluated under separate headings, and the human factors leading to accidents were examined across different categories. When the overall distribution of the codes is considered, the highest proportion was found at the level of preconditions for unsafe acts, with 61.8%. This was followed by unsafe acts (16.9%), unsafe supervision (13.0%), and organizational influences (8.2%). This distribution indicates that a large part of the accidents stemmed from factors such as environmental, team-related, or technological conditions that set the stage for individual errors. The key findings at each level are explained below with relevant examples.

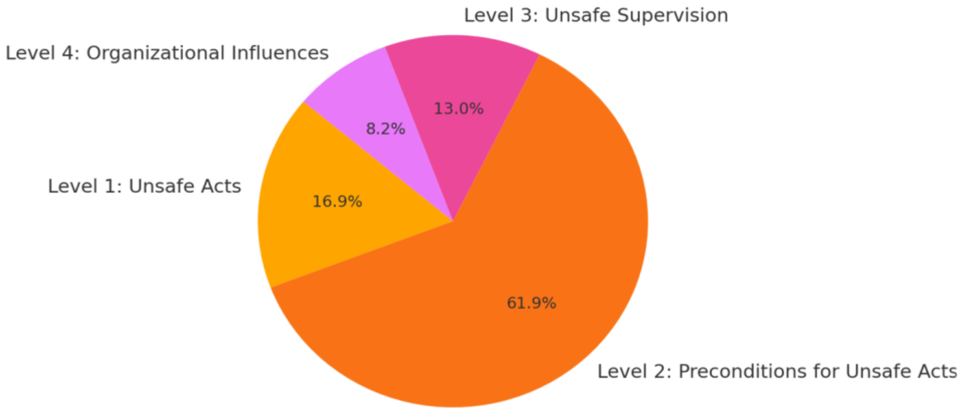

Figure 1. Overall Coding Distribution by HFACS Levels

4.1. Unsafe Acts (HFACS Level 1)

Within the scope of the 57 aviation accidents analyzed in this study, a total of 35 distinct codes were identified under the first level of the HFACS model, titled Unsafe Acts. This level encompasses individual behavioral errors that have a direct impact on the occurrence of accidents, including critical human factors such as decision errors, skill-based deficiencies, perceptual issues, and procedural violations. The coding results related to unsafe acts are presented in Table 2.

Table 2 – Coding Results Related to Unsafe Acts

Category	Frequency (n)	Percentage (%)
Decision Error	12	34.3%
Perceptual Error	11	31.4%
Violations	7	20.0%
Skill-Based Error	5	14.3%
Total	35	100%

4.1.1. Decision Errors (n=12, 34.3%)

The most frequently encountered type of unsafe act was decision errors. These errors occur when pilots make incorrect or incomplete assessments during operational decision-making moments. Examples classified under this category include approaching the wrong runway, continuing flight despite disregarding meteorological assessments, or failing to avoid turbulent areas. The frequent occurrence of decision errors may indicate underdeveloped situational awareness and risk assessment capabilities.

4.1.2. Perceptual Errors (n=11, 31.4%)

The second most common behavioral error was perceptual errors. This category includes errors that arise when the flight crew misperceives or misinterprets the external environment (e.g., weather conditions, other aircraft, runway conditions) or aircraft systems. Frequent causes include misinterpretation of cockpit instruments, visual illusions, distraction, or lack of sensory input. These findings suggest that factors such as sensory overload, information saturation, or visual-auditory discrepancies are influential during flight operations.

4.1.3. Violations (n=7, 20.0%)

Ranked third, violations refer to instances where personnel intentionally or unintentionally fail to comply with existing rules, procedures, or standard operating practices. In this study, violations were not classified as routine or exceptional within the HFACS analysis; rather, both types were evaluated together. Examples include landing without clearance from air traffic control, cabin crew movement during turbulence warnings, or non-standard approach profiles. These behaviors are often driven by factors such as time pressure, overconfidence, or organizational tolerance embedded in safety culture.

4.1.4. Skill-Based Errors (n=5, 14.3%)

The least observed category was skill-based errors, which refer to situations where an individual's knowledge or skills are insufficient to meet task requirements. Such errors often involved novice or inexperienced personnel struggling with complex tasks, mishandling aircraft systems, or failing to respond appropriately to unexpected situations. These findings highlight the importance of robust training systems, on-the-job observation processes, and assignment policies.

4.1.5. Overall Assessment

The findings at this level indicate that a significant portion of the accidents stemmed from individual errors, most of which were related to cognitive processes such as decision-making and perception. Furthermore, the presence of structured behavioral patterns such as violations in noteworthy proportions suggests that individual errors may not only result from personal shortcomings but also reflect organizational attitudes and norms. These findings underscore the need to address both individual-level interventions (e.g., training, awareness enhancement) and institutional-level factors that influence behavioral patterns in order to improve aviation safety.

4.2. Preconditions for Unsafe Acts (HFACS Level 2)

A total of 128 codes derived from the 57 aviation accidents analyzed in the study were categorized under the second level of the HFACS model: *Preconditions for Unsafe Acts*. This level includes environmental, physiological, psychological, and team-related conditions that create a foundation for the emergence of unsafe acts. The coding results are presented below:

Table 3 – Results Related to Preconditions for Unsafe Acts

Subcategory	Frequency (n)	Percentage (%)
Physical Factors	53	41.4%
Technological Environment	22	17.2%
Cognitive/Physical Limitations	20	15.6%
Inadequate Personal Preparation	16	12.5%
Lack of Crew Resource Management (CRM)	12	9.4%
Mental State	4	3.1%
Physiological State	1	0.8%
Total	**128**	**100%**

4.2.1. Physical Factors (n=53, 41.4%)

This subcategory emerged as the most frequently coded factor among the analyzed accidents. Physical factors refer to external conditions related to the flight environment, with turbulence being the predominant element identified in the majority of cases. Turbulence has been shown to cause significant loss of control, injuries, and secondary operational errors for both cockpit and cabin crew. This finding underscores that flight safety depends not only on human performance but also on the adequacy of preventive measures against environmental conditions.

4.2.2. Technological Environment (n=22, 17.2%)

This category involves deficiencies related to equipment, systems, and sensors used during flight. The most frequently encountered issue was the inability of weather radars to detect or fully display cloud structures associated with turbulence. Since radars often detect only precipitation-bearing clouds, dry but hazardous convective turbulence zones may go unnoticed, thus limiting the flight crew’s capacity to make preventive decisions. The findings reveal that perceptual limitations of technological systems hinder effective management of environmental risks such as sudden turbulence.

4.2.3. Cognitive/Physical Limitations (n=20, 15.6%)

This subcategory refers to cognitive and physiological capacity boundaries that constrain human performance. In many of the analyzed cases, cabin crew members standing during severe turbulence were physically unable to protect themselves, emerging as a central theme under this subcategory. Such events are not due to knowledge deficiencies or procedural errors but arise from the overwhelming effects of environmental conditions on human biomechanical and reflexive capabilities. For instance, when turbulence begins without warning, standing cabin crew members may not have the physical ability to brace or secure themselves. This limitation lies beyond individual control and should be evaluated from a systemic perspective in terms of human endurance and protectability. These findings highlight the critical role of timing, turbulence forecasting, and adequate alert systems in protecting human performance boundaries. Therefore, these cases reaffirm the principle widely cited in human factors literature: the system must adapt to human physical limitations.

4.2.4. Inadequate Personal Preparation (n=16, 12.5%)

This category refers to insufficient individual preparedness of crew members before or during flight. Common issues included a lack of operational briefings, outdated procedural knowledge, and poor anticipation of flight conditions. For example, in several cases, cabin crew were not adequately informed about potential turbulence and continued their tasks without taking precautions, resulting in safety risks. These examples suggest that individual errors can stem not only from momentary lapses but also from insufficient preparation processes.

4.2.5. Lack of Crew Resource Management (CRM) (n=12, 9.4%)

Deficiencies in CRM include weak information exchange between cockpit and cabin crews, unclear task allocation, and communication failures during decision-making processes. In many coded cases, coordination breakdowns occurred during rapidly evolving situations such as turbulence, which hindered timely safety decisions.

4.2.6. Mental State (n=4, 3.1%)

This category includes psychological factors such as stress, anxiety, or distraction that negatively influence cognitive processes. Although it represents a low frequency, the impact of such mental states on decision-making was clearly observed in certain cases involving turbulence or weather-related emergencies.

4.2.7. Physiological State (n=1, 0.8%)

This rarely observed category involves cases where the physical health status of crew members adversely affected their performance. In one case, a cabin crew member experienced a sudden physical ailment during flight, posing a risk to both personal and passenger safety.

4.2.8. General Evaluation

Findings at the level of preconditions for unsafe acts indicate that a significant portion of accidents stemmed not from individual errors but from environmental and systemic risk factors. The frequent coding of environmental factors such as turbulence, along with the limitations of radar systems in detecting such hazards, highlight external conditions as key contributors to human error. These results suggest the necessity of improving not only crew training and individual competencies but also environmental awareness, technological systems, and predictability in operational planning.

4.3. Unsafe Supervision (HFACS Level 3)

This level refers to failures to systematically prevent or appropriately guide unsafe acts and preconditions. The 27 coded entries in this study reveal the role of supervisory and managerial deficiencies in the development of accidents. The findings related to each subcategory are detailed below:

Table 4. Results Related to Unsafe Supervision (HFACS Level 3)

Category	Frequency (n)	Percentage (%)
Inappropriate Operational Planning	17	63.0%
Failure to Correct a Known Problem	6	22.2%
Inadequate Supervision	4	14.8%
Supervisory Violations	0	0.0%
Total	**27**	**100%**

4.3.1. Inappropriate Operational Planning (n=17, 63.0%)

This category includes deficiencies arising from unrealistic or insufficiently risk-aware operational planning conducted prior to or during flight. In most coded incidents, factors such as the failure to consider turbulent weather conditions in flight planning, lack of alternative landing scenarios, and scheduling of duty hours in a way that triggers operational fatigue were prominent. These findings indicate that airline management must conduct multi-layered assessments in operational planning that incorporate not only technical parameters but also human performance capacity and environmental variables.

4.3.2. Failure to Correct a Known Problem (n=6, 22.2%)

This category refers to instances where previously observed or reported operational risks were not systematically addressed. In the analyzed accidents, this included disregarding previously reported turbulence warnings on the same route, unaddressed maintenance requests for technical faults, and persistent deficiencies in crew training. These findings suggest that internal feedback mechanisms within the organization are limited in functionality and that the concept of a learning organization has not been sufficiently institutionalized.

4.3.3. Inadequate Supervision (n=4, 14.8%)

Inadequate supervision refers to managerial shortcomings in crew assignment, performance monitoring, training continuity, and the enforcement of procedural compliance. Coded cases revealed examples such as assigning crew members to flights without verifying their qualifications, irregular training cycles, and approving flights despite hazardous weather conditions. These findings emphasize that management must assume active responsibility not only in planning but also in the implementation and oversight phases of operations.

4.3.4. Supervisory Violations (n=0, 0.0%)

In the examined sample, there were no explicit findings indicating that managerial personnel deliberately violated existing regulations. However, this does not imply that such violations never occur; rather, it suggests that the 57 accidents analyzed did not provide sufficient open data to support such cases.

4.3.5. Overall Assessment

Findings under the third HFACS level—Unsafe Supervision—demonstrate that accidents may originate not only from operational failures but also from weaknesses in organizational decision-making structures. Strategic errors in operational planning, in particular, were found to expose flight crews to hazardous conditions and elevate the likelihood of individual errors. These results highlight that aviation safety must be addressed not only at the individual level but also in terms of institutional oversight and strategic governance.

4.4. Organizational Influences (HFACS Level 4)

The fourth level of the HFACS model, Organizational Influences, aims to analyze the systemic and structural factors underlying individual errors. A total of 17 codes at this level reveal the indirect yet significant impact of organizational structures and institutional policies on aviation accidents.

Table 5. Results Related to Organizational Influences (HFACS Level 4)

Category	Frequency (n)	Percentage (%)
Organizational Processes	11	64.7%
Resource Management	5	29.4%
Organizational Climate	1	5.9%
Total	**17**	**100%**

4.4.1. Organizational Processes (n=11, 64.7%)

This subcategory refers directly to the inadequacy or dysfunctionality of internal procedures, policies, and operational standards within the organization. Coded cases revealed issues such as poorly defined standard operating procedures, lack of systematic protocols for crisis situations, and discrepancies between procedures and real-world operational practices.

These findings highlight that organizations are not only responsible for generating procedures but also for ensuring their applicability and effectiveness in practice. One recurring theme under this subcategory was the lack of coordination between cockpit and cabin procedures during unexpected events such as turbulence.

4.4.2. Resource Management (n=5, 29.4%)

Resource management involves evaluating how effectively and sufficiently an organization utilizes its personnel, equipment, time, and financial resources. In the coded events, factors such as insufficient crew scheduling, equipment shortages, and rigid duty assignments due to operational pressure were particularly prominent. These results show that flight safety is not solely a function of individual competence but is also directly influenced by the structural support provided by the organization.

4.4.3. Organizational Climate (n=1, 5.9%)

This category includes intangible yet structural elements such as organizational culture, leadership style, prioritization of safety, and communication norms. In the single coded case, a management approach focused more on timeliness and performance metrics than on safety considerations was observed to negatively influence decision-making processes. Although rarely identified directly, the long-term role of organizational climate in shaping a safety culture should not be underestimated.

4.4.4. Overall Assessment

The findings at HFACS Level 4—Organizational Influences—demonstrate that aviation accidents may originate not only from individual or supervisory failures but also from structural deficiencies within the organization itself. The effectiveness of organizational processes, particularly the applicability of established procedures in real-world scenarios, contributes indirectly but significantly to accident causation. These results emphasize that strategic management areas such as process design, resource planning, and safety prioritization are fundamental determinants of flight safety in airline operations. Errors at this level generally point to systemic dysfunctions that go beyond the scope of individual decisions.

4.5. Evaluation of Accident Factors within the HFACS Framework

The analyses revealed that in the majority of the 57 examined accidents, multiple causal factors were simultaneously influential. For instance, in several cases, cockpit-related human errors co-occurred with adverse environmental conditions—especially turbulence. The findings identified a diverse range of contributing factors, including 44 environmental, 10 cockpit-related, 8 technological, and 3 each from cabin crew, air traffic control (ATC), operations, ground services, and management, as well as 2 related to maintenance. Among environmental factors, turbulence emerged as the most frequently recurring issue, underscoring the critical role of external conditions in maintaining flight safety.

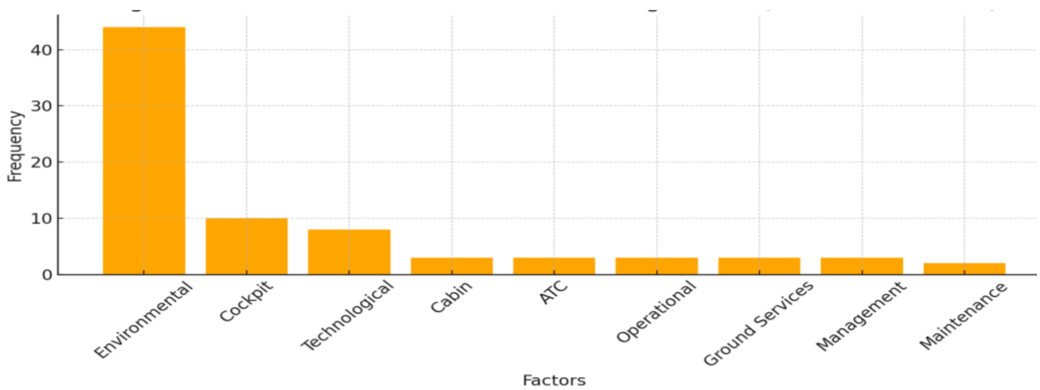

Figure 2. Frequency Distribution of Identified Accident Factors in 57 Aircraft Accidents

The findings reveal that aviation accidents cannot be reduced to a single human error or system failure; rather, multiple factors across various HFACS levels interact simultaneously. This condition of multi-causality underscores the importance of the HFACS model's multilayered structure and necessitates the adoption of a holistic and integrated safety management approach in accident prevention.

4.6. Distribution of Accidents by Flight Phase and Its Relationship with Environmental Factors

The analysis of the 57 investigated accidents showed a marked concentration during the descent phase, which accounted for 27 accidents—by far the most common. This was followed by the cruise phase with 14 accidents and the climb phase with 4. In contrast, significantly fewer accidents occurred during ground phases of flight, such as taxiing, parking, or pushback, which are generally considered less complex in terms of operational demands.

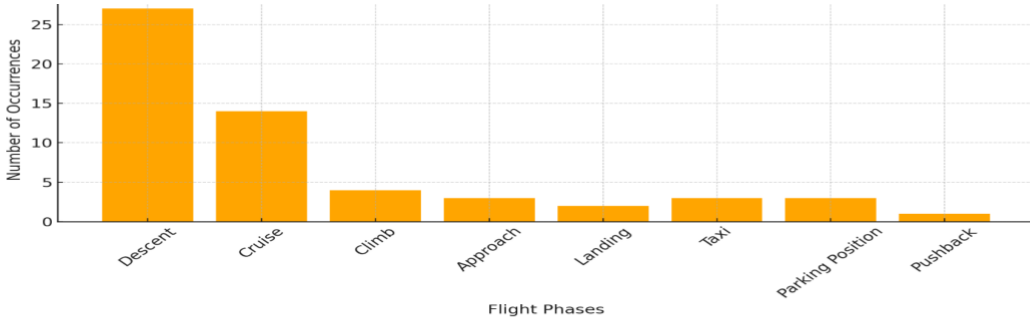

Figure 3. Distribution of Accidents by Flight Phase

5. Discussion

In this study, analyses based on the four levels of the HFACS model have clearly revealed that aviation accidents do not solely stem from individual errors but arise from complex, multi-layered, system-oriented causes. The findings indicate that individual behaviors often represent the final link in the accident chain, while environmental, managerial, and organizational factors play a decisive role in the development of such events. The findings related to each level of the HFACS model are discussed in detail below in light of the relevant literature.

5.1. Unsafe Acts Level

The data obtained indicate that the most common factors at the unsafe acts level are decision-making and perception errors. Decision errors such as failure to avoid turbulent areas and misaligned approaches are associated with a lack of situational awareness. In terms of perception errors, cognitive mistakes such as distraction and misinterpretation of cockpit indicators stand out. These results are largely consistent with Endsley's (1995) model of situational awareness. Similarly, Demirhan (2024) found decision errors in 60% and perception errors in 45% of the accidents examined in their study. These ratios are parallel to those found in the current study. Dönmez (2018), in an HFACS-based analysis, emphasized the impact of cognitive load and information flow on pilot decision-making processes, stating that perceptual and judgment errors are among the primary causes of accidents. Tamer (2021), in their analysis of the Tenerife air disaster, also highlighted the role of decision-making errors, communication breakdowns, and time pressure on pilot behavior. This finding aligns with the emphasis on stress and divided attention observed in the present study.

5.2. Preconditions for Unsafe Acts Level

According to the findings, the preconditions level had the highest coding density, and the impact of environmental factors was clearly observed. Environmental pressures such as turbulence, radar limitations, and cockpit conditions were identified as primary precursors of individual errors. In particular, injuries to cabin crew during turbulence suggest that the system has failed to develop adequate preventive measures. These findings are consistent with the deficiencies in defense layers as indicated in Reason's Swiss Cheese Model. Dönmez (2018) similarly emphasized that unpredictable conditions like clear-air turbulence could lead to incorrect pilot decisions. Furthermore, the inability of radars to detect clear-air turbulence—only identifying precipitation-based masses—demonstrates the negative impact of technological limitations on decision-making processes. In Demirhan's (2024) study, environmental factors were found to be directly influential in 40% of accidents. This rate is consistent with the current findings, indicating that external conditions in the flight environment play a critical role in accident causation.

5.3. Unsafe Supervision Level

Findings at this level show that strategic deficiencies in the planning stages of flight operations have created conditions conducive to accidents. Factors such as ignoring turbulence reports, lack of alternative scenarios, and unresolved known issues reveal significant managerial shortcomings. These findings appear to conflict with the "proactive safety management" principles emphasized in ICAO's (2021) Safety Management Manual. Dönmez (2018) statistically demonstrated that managerial deficiencies could directly cause individual errors and that management-originated violations are associated with unsafe behaviors. Similarly, Demirhan (2024) reported that managerial factors played a role in approximately 30% of the accidents. These results highlight the inadequacy of management in shaping a safety culture and monitoring safety processes systematically, suggesting that accidents are not merely operational but strategic problems.

5.4. Organizational Influences Level

The most significant problems identified at the organizational level were the impracticality of procedures and inadequacies in resource management. Safety procedures must not only exist but also be understood and practically applicable by personnel. Furthermore, deficiencies in time, equipment, and personnel planning were found to be contributing factors to individual errors. Tamer (2021), in the analysis of the Tenerife accident, noted that communication and authority issues at the organizational level had a direct impact on the accident. This finding supports the current study's identification of weaknesses in organizational climate and procedural processes. Dönmez (2018) also stated that organizational deficiencies are directly linked to "planned inappropriate operations." The findings at this level demonstrate that aviation safety is contingent not only upon individual skills but also on the operational efficiency of institutional structures.

5.5. General Evaluation

The examined reports show that approximately 61.8% of the causal factors were concentrated at the preconditions level, namely, in environmental and system-based contributors. Among the physical environmental factors, turbulence played a prominent role. Turbulence, characterized by sudden and unexpected air movements, can negatively affect pilots' attention and decision-making processes, reducing situational awareness and increasing the risk of errors. It may also lead to communication and coordination issues within Crew Resource Management (CRM). Therefore, environmental factors such as turbulence not only impact individual performance directly but also indirectly weaken intra-crew interaction, posing critical risks to aviation safety. Consequently, beyond enhancing individual competencies, system approaches that consider the interaction between human, machine, and organization form the cornerstone of aviation safety.

In this context, studies utilizing the HFACS model provide effective results in the systematic analysis of accidents. For example, Avcı and Ercan (2022) found that CRM problems were decisive in 41.4% of the 59 Turkish civil aviation accidents between 2003 and 2017. Their study confirms that intra-crew communication and coordination deficiencies can lead to serious vulnerabilities in aviation safety. Similarly, in their analysis of 30 commercial night flight accidents between 2015 and 2020, Kılıç and Gümüş (2020) found physical environment to be a factor in 63.33% of cases, skill-based errors in 33.33%, decision errors in 26.66%, and technological environment in 13.3%. These findings emphasize the impact of environmental conditions and human abilities on nighttime flights.

In another study by Kılıç and Gündoğdu (2020) analyzing 15 air cargo plane accidents between 2010 and 2020, skill-based errors were found in 53.3%, inadequate supervision in 46.66%, technological factors in 40%, decision errors in 33.3%, physical environment in 33.3%, and organizational processes in 33.3% of accidents. These results demonstrate the decisive roles of individual skills as well as managerial and technological factors. Furthermore, Dönmez (2018) found, in a study of 324 aircraft accidents in the U.S. from 2000 to 2016, that skill-based errors were present in 90%, personal factors in 79%, decision errors in 62%, environmental factors in 52%, and organizational processes in 35% of the cases. These figures clearly demonstrate the multifaceted nature of human factors in aviation safety.

The fact that perception errors were effective in 39% of accidents points to the need to improve personnel's situational awareness skills, while the 29.2% impact of environmental factors highlights the role of weather and external elements in accident formation. Risks related to human factors, such as fatigue, are important considerations for aviation safety. In conclusion, improving crew dynamics, perception capabilities, environmental conditions, and management processes emerges as a key area for accident prevention.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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