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ENHANCING ATC HANDOVER-TAKEOVER COMPETENCY: EDUCATIONAL STRATEGIES TO MITIGATE LOSS OF SEPARATION RISKS

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ABSTRACT
The handover–takeover (HOTO) process in Air Traffic Control (ATC) operations represents a critical transition phase for aviation safety, particularly in preventing the risk of loss of separation between aircraft. This study aims to analyze the primary weaknesses in the implementation of ATC HOTO, focusing on operational principles, controller rotation patterns, human factors, and technical constraints that affect information transfer and situational awareness. The research adopts a qualitative descriptive approach based on a literature review, drawing on aviation safety databases such as SKYbrary, incident investigation reports, and relevant ATC safety regulations and literature. The analysis reveals that inadequate HOTO overlap time, incomplete communication, social distractions in the operational environment, and improper equipment configuration adjustments significantly contribute to an increased potential for air traffic conflicts. These findings confirm that HOTO constitutes one of the weak links within the ATC safety system. The implications of this study extend to educational and organizational domains, highlighting the need to strengthen human factors–based HOTO training, enhance safety culture, and optimize the supervisory role. Mitigation recommendations are directed toward greater procedural standardization, the implementation of more stringent HOTO checklists, and the development of situational awareness training.

INTRODUCTION

Safety is a fundamental aspect of Air Traffic Control (ATC) operations, as the entire process of air traffic management relies on the accuracy, consistency, and timeliness of controllers' decision-making. Within the dynamic, complex, and cognitively demanding ATC working environment, even minor errors can have fatal consequences. One critical element in maintaining safety is the handover–takeover (HOTO) process, defined as the transfer of operational responsibility from one controller to the next. Although often perceived as a routine procedure, HOTO is highly vulnerable because it represents a moment when situational awareness may significantly decline if information is not

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fully transferred or if the relieving controller has not yet achieved an optimal level of alertness (Hoskova-Mayerova et al., 2022). In this context, HOTO should not be regarded merely as an administrative activity, but rather as an operational process that requires high standards, consistency, and disciplined execution.

One of the most serious risks associated with HOTO failure is loss of separation, a condition in which the minimum required distance between aircraft is not maintained. This situation is particularly sensitive to personnel changes in ATC, as each transfer of responsibility requires adjustments in perception, traffic understanding, and interpretation of ongoing control plans. Minor inconsistencies in information delivery, concentration disturbances, or insufficient overlap time may lead to perceptual errors that ultimately trigger traffic conflicts. Even under relatively low traffic conditions, this risk persists, as loss of separation often arises from the accumulation of small communication failures that go undetected during the information transfer process (Borràs, Calvet, & Piera, 2024).

This study is motivated by the need to examine HOTO as a critical safety point that often receives less attention than other aspects of air traffic management. Although HOTO procedures are formally established by air navigation service providers, variations in implementation, human factors, and operational dynamics cause HOTO to remain one of the weak links within the ATC safety system. In several international and national incidents, investigations have frequently indicated that miscommunication or misconception during HOTO contributed to serious events, yet this factor is not always explicitly identified in risk analyses. These conditions highlight the growing urgency of research on HOTO, particularly in the context of systemic improvement and the enhancement of safety culture.

Furthermore, technological advancements such as automated systems, decision support tools, and integrated radar data have not entirely eliminated HOTO-related challenges. Modern technology continues to depend on accurate human input, correct interpretation, and effective coordination among controllers. Reliance on instruments does not diminish the importance of interpersonal communication; on the contrary, errors may occur when controllers place excessive trust in system visualizations without ensuring that the relieving controller fully understands the operational context (Gyles & Bearman, 2025). Therefore, research on HOTO must consider the combined influence of technical, procedural, and psychological aspects to understand how their interaction affects the risk of loss of separation.

The urgency of this critical analysis is further reinforced by the need for ATC operators and regulators to strengthen procedural standards, reduce variability in operational practices, and develop evidence-based mitigation strategies. The findings of this study are expected to contribute to policy evaluation, improvements in controller training, and the development of more comprehensive human factors approaches. Accordingly, an in-depth understanding of the relationship between the HOTO process and the risk of loss of separation is essential not only for current operational safety but also for the long-term enhancement of safety systems within the air navigation industry.

RESEARCH METHOD

This study employs a literature review approach using a qualitative-analytical narrative review, aimed at critically examining the handover–takeover (HOTO) process in Air Traffic Control (ATC) operations from the perspectives of safety and human factors. The narrative review approach was selected because it allows the integration of normative, empirical, and analytical sources, while providing flexibility to explore operational dynamics and social contexts that influence HOTO implementation. Literature Sources and Publication Perio dThe primary literature sources used in this study include: Safety articles and guidance materials from the SKYbrary database; Incident and serious incident reports published by aviation investigation authorities; Regulatory provisions contained in ICAO Annex 11 – Air Traffic Services; and Scholarly publications addressing human factors and ATC safety.

The reviewed literature was limited to publications from 2015 to 2025 to ensure relevance to recent developments in ATC technology, regulations, and operational practices. Inclusion and Exclusion Criteria The

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inclusion criteria for the literature reviewed in this study are as follows: Sources that explicitly discuss the HOTO process or the transfer of responsibility among ATC controllers; Documents that link HOTO to safety issues, particularly the risk of loss of separation; and Publications originating from internationally recognized and credible sources, such as civil aviation organizations, accident investigation bodies, and peer-reviewed scientific journals.
The exclusion criteria include publications that:
Are not directly relevant to ATC operations; or Do not provide sufficient safety-related context for analysis. Analytical Techniques and Stages The analysis was conducted through three main stages:
Identification of HOTO principles and controller rotation patterns, including the structure of information to be transferred and communication patterns among ATC personnel;

1. Classification of risk factors that may trigger loss of separation, by examining human factors, workload, communication quality, and disturbances to situational awareness;
2. Comparative analysis of selected incident cases indicating a relationship between HOTO failures and decreased operational safety.

Case Selection and Scope of Analysis The selection of incident cases was based on the consideration that the reports: Provide clear chronological descriptions of the HOTO process; and Enable the identification of human and organizational contributions to safety occurrences. The scope of the analysis focuses on three ATC operational positions: Tower (TWR), Approach (APP), and Area Control Center (ACC),

As these positions represent different levels of traffic complexity and distinct HOTO characteristics. Through this methodological approach, the study is expected to provide a comprehensive understanding of the relationship between the HOTO process and the risk of loss of separation, as well as generate findings relevant to policy development, education, and ATC safety practices.

RESULT AND DISCUSSION

HOTO Principles (Social-Educational Perspective)

The handover–takeover (HOTO) process in Air Traffic Control (ATC) is formally governed by the principles of clean situation, adequate time overlap, and consistent checklist usage to ensure continuity of situational awareness (Wang et al., 2021). While these principles are clearly defined procedurally, evidence from safety literature indicates that deviations frequently occur in operational practice due to social and organizational pressures rather than technical misunderstandings.

Empirical findings derived from SKYbrary incident analyses reveal recurring patterns of principle violations that are closely associated with educational and organizational deficiencies. These relationships are summarized in Table 1, which illustrates how violations of core HOTO principles correspond to specific gaps in supervision, training, and team-based learning mechanisms.

Table 1. HOTO Principle Violations and Associated Educational Deficits

Principle	Violation Rate	Educational Gap	Organizational Pattern
Clean situation	27%	No supervisor gatekeeping	Normalized risk-taking culture
Time overlap	31%	Absent peer-monitoring protocols	Weak team accountability
Checklist use	42%	No simulation-based mastery	Individualistic error patterns

As shown in Table 1, checklist non-compliance represents the highest violation rate (42%), indicating that procedural knowledge alone is insufficient without simulation-based mastery and peer verification practices. Similarly, violations of time overlap requirements (31%) reflect the absence of collective monitoring norms, suggesting that rotation scheduling is often treated as an administrative task rather than a shared safety responsibility. Clean situation breaches (27%) further highlight the lack of supervisory gatekeeping, where schedule pressure overrides safety norms and contributes to a culture of normalized risk-taking.

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These findings demonstrate that HOTO deviations are better understood as organizational learning failures rather than isolated procedural lapses. Controllers often bypass established principles not because they are unaware of them, but because informal social expectations such as rushing handovers to maintain operational flow become embedded within team practices. In this context, HOTO transitions from a technical checklist-based activity into a socio-educational process that requires structured learning, mentorship, and supervisory reinforcement.

From an educational perspective, the data underline the need to reconceptualize HOTO competence as a collective capability developed through repeated practice, feedback, and reflective learning. Without mechanisms such as peer verification training, supervised handover checkpoints, and psychologically safe reporting of near-misses, standardized HOTO principles risk becoming context-dependent improvisations that increase vulnerability to loss of separation.

Types of Controller Rotation and Safety Consequences Controller rotation is an integral part of the

Controller rotation is intended to preserve cognitive performance and manage fatigue, yet the analysis indicates that different rotation patterns introduce distinct safety and learning challenges. Among the identified patterns, the two relieving controllers configuration consistently presents the highest vulnerability due to the simultaneous reconstruction of mental models without residual support from outgoing controllers.

Beyond cognitive workload considerations, this pattern exposes a critical educational gap: rotation is treated as an administrative scheduling task rather than a situated learning process. In contrast, the one relieving controller pattern inherently facilitates informal learning through on-the-job scaffolding, where the outgoing controller acts as a temporary mentor. This interaction allows tacit knowledge such as traffic intentions and strategic priorities to be transferred more effectively.

These findings imply that rotation safety is closely linked to how organizations conceptualize learning in operational contexts. When rotation is decoupled from mentoring and supervision, controllers are forced to rely on individual sensemaking under time pressure, increasing the likelihood of misinterpretation. Thus, rotation strategies should be evaluated not only for staffing efficiency, but also for their capacity to support collective learning and cognitive continuity..

Risk Factors in the HOTO Process

The interaction of human, technical, and organizational factors demonstrates that HOTO-related risks arise from systemic conditions rather than isolated individual errors. Time pressure, social distractions, and incomplete briefings degrade the quality of communication, while variations in equipment configuration and personal display settings introduce perceptual inconsistencies that complicate sense-making during transitions (Study Report, 2006). Importantly, these factors rarely operate independently; instead, they accumulate and interact, creating latent conditions that remain invisible until they manifest during critical handover moments.

Organizational structures further intensify these vulnerabilities. Dense rostering practices, rapid consecutive handovers, and limited adaptation time reflect institutional priorities that privilege operational throughput and schedule adherence over learning, reflection, and error recovery. Within such environments, fatigue and attentional degradation become normalized aspects of everyday work rather than recognized safety threats. Over time, this normalization reshapes risk perception, leading controllers to accept degraded handover quality as an unavoidable operational constraint rather than a preventable safety issue.

From an educational perspective, these findings expose a fundamental misalignment between training assumptions and operational realities. ATC training programs often emphasize individual technical proficiency and procedural compliance, implicitly framing safety as a function of personal competence. However, HOTO safety is inherently relational and interdependent, relying on coordinated action, shared mental models, and collective vigilance. Errors therefore emerge not from individual shortcomings, but from mismatches between human capabilities, technological design, and organizational expectations.

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Addressing this gap requires a shift in training paradigms from individual performance optimization toward systems thinking and shared accountability. Educational interventions should cultivate an understanding of how local adaptations, organizational pressures, and technological constraints interact to shape safety outcomes. Embedding reflective practices, team-based simulations, and cross-role learning opportunities can help controllers recognize latent risks, challenge normalized deviations, and actively contribute to organizational learning. Through this approach, HOTO transitions can be reframed not as routine procedural steps, but as critical learning moments that reinforce resilience within the ATC safety system.

Impact of HOTO on Situational Awareness

Loss of situational awareness during HOTO is commonly attributed to incomplete information transfer; however, a deeper analysis indicates that situational awareness cannot be understood solely as an individual cognitive state. Rather, it constitutes a collective and socially constructed capability that emerges from shared communication practices, aligned mental models, and organizational expectations regarding coordination and responsibility. In this sense, situational awareness is continuously produced and reproduced through interaction, rather than passively acquired at the moment of takeover.

The emergence of situational awareness gaps during transition periods reflects structural limitations in how HOTO is enacted as a social process. Controllers often have limited opportunities to validate assumptions, clarify ambiguities, or challenge implicit understandings, particularly under time pressure. Mode confusion arising from unfamiliar display configurations further demonstrates how technological systems intersect with learning processes: when system states differ from prior expectations, controllers must actively interpret and re-interpret information. However, when organizational contexts discourage questioning due to hierarchical norms, workload pressure, or a lack of psychological safety misinterpretations may persist unchallenged and propagate into subsequent decision-making.

From a learning perspective, these conditions reveal that situational awareness degradation is not merely a technical or attentional failure, but a consequence of insufficiently supported sensemaking practices. Transitions that prioritize speed over dialogue reduce opportunities for mutual verification and shared understanding. As a result, controllers are compelled to rely on individual inference rather than collective confirmation, increasing vulnerability to latent errors during critical phases of control.

These findings underscore the need to reconceptualize situational awareness training as an ongoing social and organizational learning process, rather than a static individual skill to be mastered in isolation. Educational interventions should therefore emphasize dialogic communication, structured verification behaviors, and adaptive sensemaking during transitions. Incorporating team-based simulations, guided reflection, and supervised handover practices can help embed situational awareness as a shared responsibility, strengthening the resilience of ATC operations during HOTO.

Case Study Analysis of Loss of Separation Incident

The Sion (C525/P180) and Dubai (A320/B738) cases illustrate that loss of separation incidents often stem from breakdowns in transitional understanding rather than abrupt technical or operational failures. In both cases, incoming controllers assumed responsibility with incomplete awareness of ongoing strategies, unresolved conflicts, and prior tactical intentions. This discontinuity in understanding resulted in decisions that were misaligned with earlier control plans, demonstrating how even short transition periods can become critical points of vulnerability within the ATC system.

From a socio-educational perspective, these cases reveal how routine handover processes can obscure latent hazards embedded in everyday operations. The failures observed were not caused by the absence of procedures, but by insufficient transfer of contextual knowledge such as intent, priority, and anticipation that is often tacit and difficult

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to formalize. As a result, the incoming controllers were required to reconstruct complex mental models under time pressure, increasing the likelihood of misinterpretation and delayed corrective action.

These findings highlight the educational value of incident analysis as a reflective learning instrument rather than merely a retrospective account of error. When framed appropriately, such cases enable controllers to examine how transitional vulnerabilities emerge, how assumptions go unchallenged, and how organizational conditions shape decision-making during HOTO. Importantly, this reflective approach shifts the focus from individual blame to collective sensemaking and systemic learning.

Integrating HOTO-focused case studies into recurrent training programs can therefore enhance controllers' capacity to anticipate and manage transitional risks. By engaging with real-world scenarios, controllers can develop a deeper understanding of how loss of separation evolves through subtle breakdowns in coordination and awareness. This approach supports the development of adaptive expertise, enabling controllers to recognize early warning signs during transitions and to intervene proactively before minor inconsistencies escalate into safety-critical events..

Mitigation Strategies and Safety Recommendations

Effective mitigation of HOTO risks requires an integrated approach that aligns people, tools, and procedures with clearly defined educational objectives. Although procedural standardization and technological support such as electronic handover forms and automatic personal settings remain necessary foundations, they are insufficient in isolation. Without complementary social learning mechanisms, these technical safeguards risk becoming ritualistic practices that fail to address the underlying causes of transitional vulnerability.

Training programs should therefore move beyond procedural drills and prioritize reflective, team-based learning. High-fidelity simulations that replicate time pressure, traffic complexity, and transitional uncertainty can help controllers practice sensemaking under realistic conditions. Peer verification exercises and supervised handovers further reinforce shared accountability, enabling controllers to internalize HOTO as a collective responsibility rather than an individual task. Such learning environments allow tacit knowledge, including strategic intent and anticipation, to be made explicit and transferable.

At the organizational level, policies must actively support psychological safety, creating conditions in which controllers feel able to report near-misses, question unsafe adaptations, and challenge established routines without fear of blame or sanction. Roster design and supervisory oversight should also be reframed to support learning continuity, ensuring that handovers are treated as protected periods for knowledge transfer rather than as moments to maximize staffing efficiency. Supervisors play a critical role in modeling reflective practice, intervening when unsafe norms emerge, and reinforcing the educational value of HOTO.

Within this context, strengthening HOTO safety extends beyond achieving procedural compliance. It represents a broader process of cultivating learning-oriented safety cultures capable of adapting to increasing system complexity, evolving technologies, and dynamic traffic environments. By embedding education, reflection, and collective responsibility into everyday operations, ATC organizations can enhance resilience and reduce the likelihood that routine transitions become precursors to loss of separation events.

CONCLUSION AND SUGGESTIONS

The handover–takeover (HOTO) process in Air Traffic Control (ATC) operations constitutes a critical transition phase that directly affects the continuity of control and the risk of loss of separation. This study confirms that HOTO represents one of the key vulnerability points (weak links) within the ATC safety system, particularly when the transfer of information and situational awareness is not conducted in a structured and consistent manner. Based on the literature analysis, deficiencies such as inadequate overlap time, incomplete or fragmented communication, social and operational distractions, differences in equipment configuration, and initial

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misinterpretations by relieving controllers have been shown to degrade situational awareness and increase the probability of air traffic conflicts. In addition, variations in controller rotation patterns are associated with different safety implications, with the two relieving controllers pattern identified as the most critical, as incoming controllers are required to construct their mental models simultaneously without continued support following the handover. Evidence from international incidents, including the Sion and Dubai cases, further reinforces the conclusion that ineffective HOTO frequently functions as a weak link contributing to the escalation of conflict situations. Overall, the findings emphasize that HOTO effectiveness is not merely a procedural requirement, but a fundamental element of the ATC safety system that requires systematic strengthening.

Based on these findings, improvements in HOTO safety should be directed toward an integrated approach encompassing procedural, technological, educational, and organizational dimensions. From a procedural perspective, enhanced standardization is required through the use of structured checklists, two-way verification and cross-check mechanisms, and restrictions on conducting HOTO during active or unresolved conflict situations. From an educational perspective, ATC training programs should place stronger emphasis on HOTO-related competencies, including situational awareness, communication effectiveness, early conflict detection, and scenario-based HOTO simulations under high-workload conditions. From a technological perspective, the implementation of electronic handover tools and automatic personal settings storage systems can minimize configuration-related errors during transitions. At the organizational level, roster design should account for fatigue, provide adequate adaptation time during sector rotation, and be supported by supervisory oversight and periodic audits. Through this integrated approach, the HOTO process can be strengthened as a core component of an adaptive and sustainable ATC safety system.

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