

A human-centric approach to understanding the contributing factors of pilot-related runway incursions

Yan Yan[1], Soufiane Boufous[2], Brett R.C. Molesworth[3]

School of Aviation, University of New South Wales, Sydney, NSW, Australia

Abstract

This paper examines pilot-related runway incursions from a human factors perspective and presents the key findings of four studies. The research progressed from a systematic literature review, to an epidemiological analysis of runway incursion reports from Australia and the United States, to interviews with aviation professionals, and finally to a simulator-based experiment examining pilot communication under degraded communication conditions. Miscommunication was the most consistent theme associated with pilot-related runway incursions, including readback/hearback errors, radio interference, non-standard phraseology, callsign confusion, language barriers, and hesitation in seeking clarification. These communication issues were closely linked to procedural non-compliance, loss of situational awareness, and uncertainty during taxi operations. The findings also highlighted the importance of human–technology interaction, particularly in relation to stop bar use, and showed that individual differences such as language background, flying experience, age, and personality traits influenced pilot communication behaviour. Overall, the findings support the need for more targeted runway safety interventions, including increased focus on standardised phraseology, degraded communication training such as clarification-seeking practices, and user-centred design of ground safety technologies.

Keywords: Runway Incursion, Runway Safety, Human Factors, Miscommunication

1. Introduction

Runway safety remains a major concern in aviation, with runway incursions (RIs) continuing to pose a persistent threat to safe aircraft operations. A runway incursion refers to the incorrect presence of an aircraft, vehicle, or person on the protected area designated for aircraft landing and take-off [1]. Although RIs vary in severity, their potential consequences can be catastrophic.

Over recent decades, considerable effort has been directed towards technological interventions to reduce RIs. Systems such as airport surface surveillance, runway status lights, and other ground movement monitoring technologies have improved the detection and management of surface movement conflicts. However, pilot deviations continue to account for a substantial proportion of reported events, suggesting that technology alone may not fully address the cognitive, behavioural, and communication-related factors that shape pilot performance during ground operations.

A human factors perspective is, therefore, essential for understanding why pilot-related RIs continue to occur. Ground operations often require pilots to manage multiple concurrent tasks, including radio communication, navigation, checklist completion, route monitoring, and coordination with air traffic control officers (ATCO). These tasks are often performed under time pressure and in complex operating environments, where communication and situational awareness can directly affect safety.

This paper presents an integrated summary of four interrelated studies examining pilot-related RIs from a human factors perspective. Rather than treating RIs as isolated procedural failures, the research

examines how communication, situational awareness, operational context, language background, and individual differences interact to influence pilot behaviour.

2. Previous studies analysing pilot-related runway incursions

Much of the existing literature has focused on technological or system-based approaches to runway incursion prevention. These include airport surface surveillance systems, runway status lights, runway incursion prevention systems, and other alerting or detection technologies [2, 3]. While these systems provide important safety barriers, they do not fully explain why pilot-related incursions continue to occur, particularly when contributing factors involve broader human factors issues.

A systematic review undertaken as part of this research examined peer-reviewed scientific publications on pilot-related runway incursions from a human factors perspective [4]. The review identified a limited body of relevant research, with only 13 studies meeting the inclusion criteria between 1985 and 2021. These studies used a range of approaches, including historical accident analysis, risk factor analysis, scenario simulation, and risk prediction modelling [5, 6, 7, 8, 9].

Across the reviewed literature, two common types of pilot-related runway incursions were identified. The first involved failure to comply with air traffic control instructions, including failure to hold short, crossing a runway or taxiway without clearance, or continuing an unauthorised manoeuvre after receiving an instruction [5, 7, 8, 9, 10, 11]. The second involved positional errors, where pilots misidentified their location, missed a turn, turned in the wrong direction, or became uncertain of their position on the aerodrome surface [6, 7, 11, 12, 13].

Miscommunication was the most frequently reported pilot-related contributing factor, followed by loss of situational awareness. Communication-related issues included misunderstood air traffic control instructions, readback/hearback errors, improper or non-standard phraseology, radio frequency congestion, blocked transmissions, and failure to seek clarification when uncertainty existed [9, 10, 12, 14, 15, 16]. Loss of situational awareness was commonly linked to pilots being head-down during taxi, conducting checklists, managing competing tasks, operating under time pressure, or navigating unfamiliar and complex aerodrome layouts [6, 13, 16, 17].

Although the reviewed studies identified several technical and procedural mitigation strategies, they provided limited explanation of the cognitive and behavioural mechanisms through which communication errors occur. In particular, less attention has been given to how pilots interpret unclear or degraded instructions, how they decide whether to seek clarification, and how individual differences may influence communication behaviour during taxi operations. To address this gap and extend previous work, the present paper synthesises findings from four related studies, including a systematic review, epidemiological analysis, interviews with aviation professionals, and a simulator-based investigation of pilot communication under degraded communication conditions.

3. Methods

This paper summarises the methods and the findings of four studies examining pilot-related runway incursions from a human factors perspective. The studies were designed to build progressively from literature review, to retrospective analysis, to stakeholder perspectives, and finally to controlled experimental testing of pilot communication behaviour.

Study 1 – Systematic literature review

The first study was a systematic review of peer-reviewed literature on pilot-related runway incursions. The review followed PRISMA methodology and searched eight academic electronic databases. Studies were included if they examined runway incursions involving pilot-related causal factors. Content analysis was used to extract study characteristics, methods, and key findings.

Study 2 – Epidemiological analysis of runway incursion reports

The second study analysed historical runway incursion investigation reports from Australia and the

United States. Reports were sourced from the Australian Transport Safety Bureau (ATSB) and the National Transportation Safety Board (NTSB). Included reports were coded to identify pilot-related precursor events, contributing factors, and prime causal factors using a human factors classification framework.

Study 3 – Interview study with aviation professionals
The third study used semi-structured interviews to examine aviation professionals' perspectives on runway incursion causes and prevention. Participants included pilot trainees, flight instructors, commercial airline pilots, and air traffic control officers. Interview data were analysed using thematic analysis.

Study 4 – Simulator experiment
The fourth study used a flight simulator experiment to examine pilot communication behaviours during taxi operations. The experiment applied a two-by-two within-subject design involving radio interference and air traffic control phraseology. Pilot communication responses were recorded, transcribed, and coded, alongside demographic, flight experience, and psychometric measures.

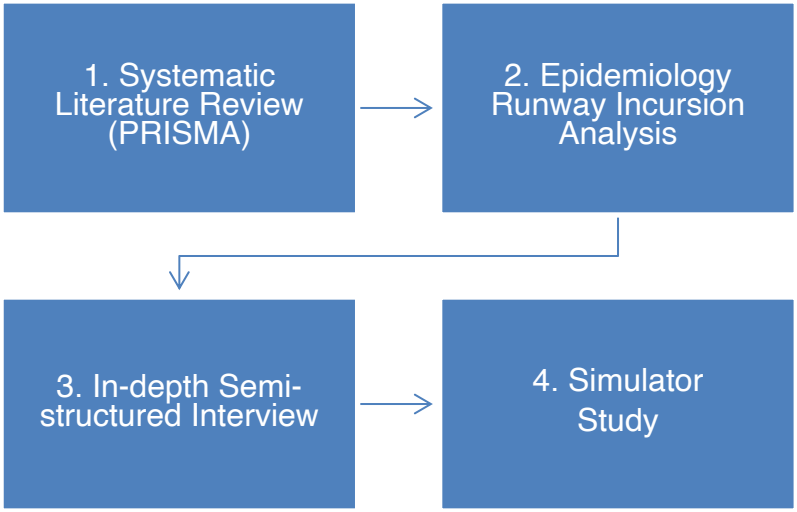


Figure 1 – Overview of the sequential research design across the four studies

4. Results and Analysis

4.1 Key finding of the studies

The systematic review first established a baseline for understanding pilot-related runway incursions from a human factors perspective. It identified non-compliance with air traffic control instructions and positional errors as the two most common RI types. Miscommunication was the most frequently reported contributing factor, appearing in 77% of the reviewed studies. However, the review also showed that existing research provided limited explanation of how and why communication-related errors develop in operational settings [4].

To examine whether these patterns were reflected in real-world occurrences, the second study applied an epidemiological approach to official RI investigation reports from the Australian Transport Safety Bureau and the National Transportation Safety Board. In total, 31 reports from 1993 to 2021 were identified. The analysis showed that accidents were more common at non-towered aerodromes, whereas incidents were more common at towered aerodromes. It also supported the systematic review findings by showing that procedural non-compliance was predominant in the temporal sequence of RI events. In particular, "Procedure Not Followed Correctly" was identified as one of the most frequent factors, both as a precursor event and as a prime cause. Findings also suggest that many pilot-related RIs are linked to earlier communication issues, inaccurate expectations, workload,

radio interference, or loss of situational awareness [18].

Semi-structured interviews were then conducted with 56 aviation professionals, including 15 trainee pilots, 18 instructor pilots, 12 airline pilots, and 11 air traffic control officers, to explore how these causal factors are understood in practice. The findings of this study further confirmed the importance of miscommunication, which was frequently reported by both pilots and ATCOs. Participants identified several real-world contributors to miscommunication, including readback/hearback errors, callsign confusion, radio congestion, inconsistent phraseology, language barriers, and hesitation in seeking clarification. The findings also highlighted broader system-related issues, including the use of standard operating procedures, differences between training and operational practice, and user experience with advanced ground technologies [19].

Finally, the experimental study examined the communication issue identified across the broader research program. A flight simulator experiment was conducted to investigate pilot communication behaviour during taxi operations under degraded communication conditions, including radio interference and non-standard phraseology. The results showed that radio interference significantly increased communication errors. Communication errors most commonly involved pilots either failing to capture critical information or stating inaccurate information. The study also showed that communication performance was influenced by individual differences, including language background, flying experience, age, and personality traits such as locus of control, ambiguity tolerance, self-esteem, and conscientiousness [20].

Table 1: Summary of methods, analysis, and key results across the studies

Study	Method and data source	Analysis	Key results
Systematic review	Systematic review of peer-reviewed literature on pilot-related runway incursions. Eight electronic databases were searched for studies published between 1985 and 2021.	PRISMA-guided screening and content analysis of included studies.	Thirteen studies met the inclusion criteria. The most common pilot-related runway incursion types were non-compliance with ATC instructions and positional errors. Miscommunication was the most frequently reported contributing factors.
Epidemiological analysis	Retrospective analysis of official runway incursion investigation reports from Australia and the United States. Reports were sourced from ATSB and NTSB databases.	Reports were coded using a human factors classification framework (DoD-HFACS) to identify precursor events, contributing factors, and prime contributing factors.	Procedural non-compliance, communication breakdown, inaccurate expectations, and technical or environmental conditions were identified within the event pathways leading to runway incursions.

Study	Method and data source	Analysis	Key results
Interview study	Semi-structured interviews with aviation professionals, including pilot trainees, flight instructors, commercial pilots, and air traffic control officers.	Thematic analysis	Participants highlighted miscommunication, readback/hearback errors, callsign confusion, radio congestion, language barriers, airport layout complexity, and inconsistent phraseology as contributors to runway incursion risk.
Simulator experiment	Flight simulator experiment examining pilot communication during taxi operations under degraded communication conditions. Radio interference and ATCO phraseology were experimentally manipulated.	Communication responses were transcribed and coded. Statistical analyses examined the effects of communication conditions, pilot background, and psychometric traits.	Radio interference increased communication errors. Pilot responses varied according to language background, licence type, and personality-related traits, suggesting that individual differences influence communication behaviour under degraded conditions.

4.2 Communication as a central contributing factor

Communication was identified as a central issue throughout the research program. It appeared to shape how pilots interpreted ATCO instructions, maintained situational awareness, complied with instructions and procedures, and responded to uncertainty during taxiing. Non-compliance should, therefore, not always be interpreted as intentional behaviour. Instead, it may represent the visible outcome of earlier communication breakdowns. For example, unclear or incomplete instructions, degraded radio transmissions, expectation bias, or inconsistent phraseology may affect how pilots understand a clearance and decide whether to proceed.

This interpretation is consistent with the epidemiological analysis, which identified miscommunication as a critical initial event leading to procedural errors, particularly when compounded by radio interference [18]. It also aligns with interview findings showing that pilots and ATCOs associated miscommunication with readback/hearback errors, radio congestion, language barriers, callsign confusion, frequency changes, and hesitation in seeking clarification [19].

Language background and the use of standard phraseology also emerged as key communication-related themes during ground movements. Although standard phraseology is intended to minimise ambiguity and support the readback/hearback loop, the overall findings identified gaps between formal requirements and real-world operational practice. The interview findings suggested that ATCOs tended to emphasise stricter phraseology when communicating with non-native English-speaking pilots, while being more flexible with native English-speaking pilots. However, the experimental findings indicated that non-native English-speaking pilots were more cautious under radio interference and were more likely to wait for the full transmission before proceeding when critical information was missing. This suggests that plain language or flexible phraseology during taxi operations may introduce avoidable ambiguity, regardless of the pilot's language background [20].

The evidence further indicates that communication vulnerability is shaped by both system conditions and individual differences. Degraded communication conditions, particularly radio interference and clipped transmissions, increased the likelihood of communication error, while traits such as internal locus of control, self-esteem, conscientiousness, and ambiguity tolerance influenced pilots' communication behaviour and error propensity [20]. This extends conventional human factors frameworks such as HFACS and CRM, which recognise communication as important but often treat it as a broad competency. The present synthesis provides a more specific account by identifying the conditions under which communication breaks down and the pilot characteristics that may influence how degraded or ambiguous information is managed.

4.3 Stop bar use and human technology interaction

Another critical finding concerned the practical use of stop bar systems as a runway safety defence. Stop bars are intended to prevent unauthorised runway entry by providing a clear visual barrier at runway holding positions. However, the interview findings suggest that their effectiveness depends heavily on how well the system is integrated with controller workload, pilot expectations, and real-time ground movement.

Although stop bars were recognised as a valuable technological defence, participants also reported operational challenges, including false alarms, unexpected reactivation, system time-outs, and reduced controller control over the system. These issues were reported by 11 interviewees, including 4 airline pilots and 7 ATCOs. More than 60% of interviewed ATCOs had experienced problems such as false alarms, reactivations, or perceived loss of control over the system [19].

This implies that stop bar systems should not be viewed as purely technical solutions to runway incursion prevention. Instead, they should be conceived as part of a wider human–technology system. When stop bars reactivate unexpectedly or generate false alarms, they may increase workload and create psychological stress for both the pilots and ATCOs. Future technological implementation should, therefore, also consider the usability, timing logic, alert accuracy, controller authority, and pilot expectations. From a human factors perspective, this finding reinforces the need for user-centred design of runway safety technologies before and after implementation [19].

4.4 Personality traits

Individual differences further complicate the relationship between procedures, communication, and technology. The experimental findings showed that pilots did not respond uniformly to degraded communication conditions. Demographic factors, including language background, flying experience, and age, were associated with specific types of communication errors. Personality traits such as internal locus of control, ambiguity tolerance, self-esteem, and conscientiousness also influenced how pilots processed, clarified, and reproduced verbal information under operational pressure [20].

This suggests that two pilots may encounter the same degraded instruction or non-standard phraseology but respond differently depending on their confidence, tolerance for ambiguity, communication strategy, and tendency to seek clarification. These findings indicate that communication performance is shaped not only by external conditions, such as radio interference or phraseology, but also by individual characteristics.

4.5 Key Implications

The findings have both theoretical and practical implications. Theoretically, they extend existing human factors models by showing that communication error is shaped by both operational conditions and individual characteristics. In the same environment, one pilot may seek clarification, maintain procedural discipline, or accurately reproduce a clearance, while another may be more vulnerable to ambiguity, incomplete information, or non-standard communication.

Practically, the findings suggest that personality and cognitive traits could inform more targeted training and competency development. Such assessments should not be used as exclusionary criteria, but

could help identify areas where pilots may benefit from additional support, such as clarification-seeking practice, degraded communication scenarios, or reinforcement of standard phraseology. Overall, the findings support a more tailored approach to runway safety training, where individual differences are considered alongside procedures, technology, and operational context.

In operational settings, procedures remain essential, but they need to be supported by realistic training that exposes pilots to degraded communication and time pressure. Technology also remains valuable, but it should be designed around how pilots and ATCOs actually communicate, navigate, and make decisions during surface movement. Individual differences should, therefore, be considered in training and competency development to better tailor communication solutions to pilots.

5. Conclusion

This paper synthesised four studies examining pilot-related runway incursions from a human factors perspective. Across the systematic review, epidemiological analysis, interview study, and simulator experiment, communication was identified as one of the most consistent factor linking pilot-related runway incursions. The findings highlight the need to move beyond technology-centred approaches to runway safety. While standard procedures and surface movement technologies remain essential safety barriers, their effectiveness depends on how pilots and ATCOs interpret, use, and respond to them in real operational conditions. Limitations of the current research should be acknowledged. The studies were primarily situated within Australian, which may limit the generalisability of the findings to other regulatory, linguistic, and cultural environments. Future research could replicate and extend these findings using larger and more internationally diverse pilot and ATCO samples. Studies could also evaluate practical interventions, including scenario-based training, improved clarification-seeking protocols, and user-centred assessments of advanced ground technologies, speech recognition systems, and AI-supported communication tools. Further investigating these areas would help translate the present findings into more targeted and effective runway safety interventions.

Reference:

[1] Federal Aviation Administration. (2008). Runway safety report: June 2008. https://www.faa.gov/airports/runway_safety/media/pdf/rsreport08.pdf

[2] Ru, J., & Nanduri, S. (2006). Evaluation of runway incursion prevention systems. 51st Air Traffic Control Association Annual Conference & Exposition, 96-101.

[3] Schoenefeld, J., & Moeller, D. P. F. (2012). Runway incursion prevention systems: A review of runway incursion avoidance and alerting system approaches. Progress in Aerospace Sciences, 51, 31-49. https://doi.org/10.1016/j.paerosci.2012.02.002

[4] Yan, Y., Boufous, S., & Molesworth, B. R. C. (2024). A systematic review of pilot-related runway incursions from a human factors perspective. The International Journal of Aerospace Psychology, 34(1), 1-19. https://doi.org/10.1080/24721840.2023.2247441

[5] Goodheart, B. (2014). Identification of causal paths and prediction of runway incursion risk by means of Bayesian belief networks. Transportation Research Record: Journal of the Transportation Research Board, 2400(1), 9-20. https://doi.org/10.3141/2400-02

[6] Hooey, B. L., & Foyle, D. C. (2006). Pilot navigation errors on the airport surface: Identifying contributing factors and mitigating solutions. The International Journal of Aviation Psychology, 16(1), 51-76. https://doi.org/10.1207/s15327108ijap1601_3

[7] Kim, D., & Yang, H. (2012). Evaluation of the risk frequency for hazards of runway incursion in Korea. Journal of Air Transport Management, 23, 31-35. https://doi.org/10.1016/j.jairtraman.2012.01.011

[8] Stroeve, S. H., Som, P., van Doorn, B. A., & Bakker, G. J. (2016). Strengthening air traffic safety management by moving from outcome-based towards risk-based evaluation of runway incursions. Reliability Engineering & System Safety, 147, 93-108. https://doi.org/10.1016/j.ress.2015.11.003

[9] Wang, Y., Liu, Y., Sun, Z., & Tang, P. (2018). A Bayesian-entropy network for information fusion and reliability assessment of national airspace system. Annual Conference of the Prognostics and Health Management Society 2018.

[10] Joslin, E. R., Goodheart, J. B., & Tuccio, A. W. (2011). A mixed method approach to runway incursion rating. International Journal of Applied Aviation Studies, 11(2), 13-35.
[11] Torres, K. R., Metscher, D. S., & Smith, M. L. (2011). A correlation study of the relationship between human factor errors and the occurrence of runway incursions. International Journal of Professional Aviation Training & Testing Research, 5(1), 3-25. https://ojs.library.okstate.edu/osu/index.php/IJAR/article/view/8111/7457
[12] Adam, G. L., Lentz, R. H., & Bair, R. W. (1992). Study of the causes of runway incursions and related incidents. Proceedings of the First IEEE Conference on Control Applications, 539-543. https://doi.org/10.1109/CCA.1992.269816
[13] Cardosi, K., Chase, S., & Eon, D. (2010). Runway safety. Air Traffic Control Quarterly, 18(3), 303-328. https://doi.org/10.2514/atcq.18.3.303
[14] Cardosi, K. (2002). Operational errors in air traffic control towers. Air Traffic Control Quarterly, 10(2), 147-163. https://doi.org/10.2514/atcq.10.2.147
[15] Chang, Y. H., & Wong, K. M. (2012). Human risk factors associated with runway incursions. Journal of Air Transport Management, 24, 25-30. https://doi.org/10.1016/j.jairtraman.2012.05.004
[16] Kelley, D. R., & Steinbacher, J. G. (1993). An analysis of pilot deviations in runway incidents. Air Traffic Control Quarterly, 1(2), 197-221. https://doi.org/10.2514/atcq.1.2.197
[17] Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. Human Factors, 37(1), 32-64. https://doi.org/10.1518/001872095779049543
[18] Yan, Y., Boufous, S., & Molesworth, B. R. C. (2025). Pilot-related factors involved in runway incursions: An epidemiological approach. The International Journal of Aerospace Psychology, 1-20. https://doi.org/10.1080/24721840.2025.2452443
[19] Yan, Y., Boufous, S., & Molesworth, B. R. C. (2025). Speaking of human factors: An interview study on the causes and prevention of runway incursions with aviation professionals. Safety Science, 190, 106913. https://doi.org/10.1016/j.ssci.2025.106913
[20] Yan, Y. (2025). A human-centric approach to understanding the contributing factors of pilot-related runway incursions [Doctoral thesis, University of New South Wales]. UNSWorks. https://doi.org/10.26190/unsworks/31599

Authors:

Yan Yan[1]
School of Aviation, University of New South Wales, Sydney, NSW, Australia
E: yan.yan5@unsw.edu.au
M: (61) 406 260 924

Soufiane Boufous[2]
School of Aviation, University of New South Wales, Sydney, NSW, Australia
E: soufiane@unsw.edu.au
T: + 61 (2) 9385 6227

Brett R.C. Molesworth[3]
School of Aviation, University of New South Wales, Sydney, NSW, Australia
E: b.molesworth@unsw.edu.au
T: + 61 (2) 9385 6757

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