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TRUST AND SITUATION AWARENESS IN COCKPIT AUTOMATION: IMPACTS ON PUNCTUALITY AND EFFECTIVENESS IN AIRLINE OPERATIONS

P. Tretten[1]*, P. Illankoon[2], and J. Lööw[1]

[1]Human Work Sciences, Luleå University of Technology, Sweden
[2]Department of Management of Technology, University of Moratuwa, Sri Lanka
*phillip.tretten@ltu.se**

ABSTRACT

The increasing sophistication of cockpit automation is reshaping commercial aviation by enhancing precision, reducing workload, and supporting more reliable airline operations. However, the extent to which these technological gains translate into punctuality and operational effectiveness depends heavily on human factors, particularly pilots' trust in automation and their situation awareness during both routine and non-routine scenarios. We examine how these two constructions influence operational performance, drawing on a mixed methods design that integrates structured questionnaires and in-depth interviews with 40 commercial pilots. Quantitative findings indicate that well-calibrated trust; defined as reliance matched to system capabilities; is significantly associated with fewer automation-related delays and higher perceived efficiency. Strong situation awareness similarly correlates with better anomaly detection, quicker transitions between automation and manual control, and reduced schedule disruptions. Qualitative insights reinforce these results, illustrating how vigilant monitoring, accurate comprehension of automation modes, and timely manual intervention mitigate risks such as complacency, automation surprise, and operational errors. Pilots demonstrating both high trust and high situation awareness reported the lowest frequency of schedule deviation and the highest operational effectiveness. These findings emphasise that integrating human-automation interaction metrics into airline business intelligence systems can improve predictive risk management, target training needs, and guide the development of cockpit interfaces. Overall, the study demonstrates that technological benefits materialise most fully when pilots are equipped to supervise, interpret, and intervene in automated processes with confidence and precision, highlighting human expertise as a central enabler of punctuality, safety, and innovation in modern airline operations.

Keywords: Cockpit Automation, Trust, Situation Awareness, Flight Operations, Business Intelligence, Innovation Management

1. Introduction

The commercial aviation industry is undergoing a profound technological transformation, driven by rapid advancements in cockpit automation (Causse et al., 2024; Yılmaz, 2024). Modern flight decks now host a range of sophisticated digital systems autopilots, flight management computers, and advanced warning and diagnostic interfaces that aim to enhance precision, reduce human workload and fatigue (Causse et al., 2024) and optimise both safety and operational reliability for airlines. (Causse et al., 2024) While these innovations enable unprecedented levels of efficiency and scalability for global air travel (Yılmaz, 2024), their effectiveness ultimately depends on human engagement: specifically, the ability and willingness of pilots to interact safely and effectively with the technology at hand, mediated by appropriate levels of trust and situation awareness.(Boer & Dekker, 2017; Causse et al., 2024)

As automation becomes deeply embedded in routine and non-routine flight operations, the traditional focus on pilots as manual controllers has shifted toward system management, real-time decision-making, and high-level supervision of automated processes (Causse et al., 2024; Yılmaz, 2024). This evolving role introduces new challenges and opportunities for airlines seeking to maintain punctuality and operational effectiveness—two metrics central to airline reputation and profitability (Kaleta & Tomczyk, 2024; Miller et al., 2023). In this context, human factors such as trust in automation and situation awareness become critical determinants of success (Kohn et al., 2021). Trust influences how and when pilots choose to rely on, monitor, or override automated systems, for instance, higher automation levels improve performance but reduce vigilance to key instruments (Causse et al., 2024; Luster & Pitts, 2021). Situation awareness acts as a safeguard against automation surprises (Boer & Dekker, 2017) and operational errors (Causse et al., 2024).

Despite the contributions of automation, over-trust can foster complacency (Causse et al., 2024), reduced vigilance (Causse et al., 2024), delayed responses to anomalies (Dehais et al., 2015), or under-appreciation of system limitations (Boer & Dekker, 2017), while under-trust can result in excessive manual intervention (Wischnewski et al., 2023) and lost opportunities for operational gains (Boer & Dekker, 2017). Airlines that can accurately measure (Kohn et al., 2021) and manage these human-automation interactions via trust calibration strategies (Lebière et al., 2021; Wischnewski et al., 2023) are well-positioned to harness business intelligence from the cockpit (Miller et al., 2023; Smith & Baumann, 2019). Such insights can inform targeted investments in training, technology upgrades, and adaptive BI systems that continuously improve on-time performance and operational excellence.

This study investigates the pivotal role of pilots' trust in cockpit automation defined as calibrated reliance aligning with system capabilities (Kohn et al., 2021; Wischnewski et al., 2023) and situation awareness, in determining flight punctuality and operational effectiveness (Causse et al., 2024; Miller et al., 2023; Yılmaz, 2024). Grounded in empirical human factors research (Causse et al., 2024; Kohn et al., 2021; Luster & Pitts, 2021), it bridges these constructs with airline business intelligence and innovation strategies (Miller et al., 2023; Smith & Baumann, 2019), delivering evidence-based guidance for managers, training programs, and interface designers to mitigate complacency, delays, and errors amid advancing automation (Dehais et al., 2015; Lebière et al., 2021).

2. Literature Review

The integration of automation into commercial flight decks has been widely studied in aviation psychology, human factors, and management literature (Causse et al., 2024; Kohn et al., 2021; Yılmaz, 2024). Research shows that cockpit automation improves operational precision, reduces workload (Causse et al., 2024), and shifts pilot roles from manual control to system supervision and decision-making (Causse et al., 2024; Yılmaz, 2024). For airlines, this offers two key opportunities: enhancing punctuality and reliability through automation (Miller et al., 2023) and leveraging insights from pilot-automation interactions in business intelligence systems (Miller et al., 2023; Smith & Baumann, 2019).

Trust in automation—pilots' reliance on systems under uncertainty, igrounded on performance expectations and the acceptance of suggestions (Kohn et al., 2021)—is central. Calibrated trust, aligning reliance with system capabilities, is key to prevent mismatches (Lebière et al., 2021; Wischnewski et al., 2023). Over-trust leads to missed failures, complacency, and delayed anomaly responses (Causse et al., 2024; Dehais et al., 2015); under-trust prompts excessive manual interventions and workload spikes (Wischnewski et al., 2023), both of which lead to operational failures. In aviation, trust dynamics affect punctuality and effectiveness by shaping pilots' decisions regarding delays, errors, coordination, and reliability (Miller et al., 2023; Yılmaz, 2024).

Statuesn awareness defined as the pilot's perception, comprehension, and projection of the operational environment and automated system statuses (Kaleta & Tomczyk, 2024) enables effective responses during automation failures or unanticipated environmental changes (Dehais et al., 2015), thereby reducing operational disruptions, delays, and safety risks (Causse et al., 2024). Research indicates that impaired situation awareness, referred to as the "out-of-the-loop" phenomenon marked by diminished monitoring of primary instruments and inefficient visual scanning patterns (Luster & Pitts, 2021)—constitutes a significant risk of advanced automation, intensifying complacency and delayed reactions to anomalies (Causse et al., 2024).

Recent studies further promote the incorporation of pilots' trust and situation awareness metrics into airline business intelligence platforms (Miller et al., 2023; Smith & Baumann, 2019), allowing carriers to harness human-automation interaction analytics for superior operational performance (Smith & Baumann, 2019). This incorporation fosters evidence-based advancements in pilot training (Kohn et al., 2021), automation interface development (Lebière et al., 2021; Wischnewski et al., 2023), and real-time risk mitigation (Dehais et al., 2015), thereby ensuring calibrated trust and awareness counteract complacency, delays, and errors while propelling ongoing operational enhancements (Causse et al., 2024; Kaleta & Tomczyk, 2024). In essence, pilots' trust and situation awareness constitute pivotal "human interfaces" in the flight automation value chain—profoundly shaping airline operational efficacy and punctuality (Miller et al., 2023; Yılmaz, 2024) and offering tangible instruments for business intelligence and managerial innovation (Smith & Baumann, 2019).

3. Methodology

This research adopts a mixed-methods approach anchored in established human factors literature and contemporary airline operations studies (Creswell, 2013; Stanton et al., 2013).

3.1. Research Design

Consistent with recommendations by Parasuraman and Riley (1997) and Lee and See (2004), the study employed both quantitative and qualitative methods to capture a comprehensive portrait of pilot cognition, behaviour, and operational decision-making. The central focus was on two human factors constructs—trust in automation and situation awareness—as they relate to key operational outcomes (punctuality and effectiveness).

3.2. Participants

The study sample consisted of 40 commercial airline pilots representing various airlines, aircraft types, and levels of operational experience. Purposeful sampling was used to ensure adequate representation across genders, flight ranks, and automation training exposure, as is encouraged in reliability studies of human aviation performance.

3.3. Data Collection Instruments

3.3.1. Questionnaire

A structured, self-administered questionnaire was developed, drawing on validated survey instruments from the literature (e.g., Lee & Moray, 1992; Endsley, 1995). The questionnaire was organised into five principal domains:

1) Trust in Automation: Items assessed overall trust and confidence in automation, ability to predict automation behaviour, and trust under normal vs. abnormal conditions (e.g., "How much do you trust automated systems to perform critical tasks?").
2) Situation Awareness: Items measured familiarity with automation modes, transition skills between manual and automated control, and ability to detect and respond to system status changes (e.g., "How familiar are you with automation systems in the aircraft you fly?").
3) Punctuality: Questions focused on whether and how often automation issues contributed to flight delays.
4) Operational Effectiveness: Pilots rated their perceptions regarding automation's impact on efficiency, error reduction, and ease of task completion.
5) Background/Demographics: Information on flight hours, automation training exposure, aircraft type, and rank.

Most items used a five-point Likert scale (e.g., from "Strongly Agree" to "Strongly Disagree" or from "Complete Trust" to "No Trust"), with selected open-ended prompts to elicit additional context.

3.3.2. Interviews

To enrich and triangulate the quantitative findings, semi-structured interviews were conducted with all 40 pilots. Interview questions probed:

- Experiences with automation in abnormal scenarios,
- Specific instances where trust or lack of situation awareness affected decisions or flight schedules,
- Suggestions for improving automation interfaces, training, or communication.

Interviews were audio-recorded, transcribed, and thematically coded using Nvivo software, following best-practice methods suggested by Braun and Clarke (2006).

3.4. Data Analysis

Descriptive statistics (means, standard deviations, frequencies) were computed for all quantitative questionnaire variables using SPSS. Correlation and regression analyses were performed to investigate associations between trust/situation awareness and reported punctuality/effectiveness. Interview transcripts were coded for emergent themes and cross-checked against survey results, ensuring interpretive consistency and providing explanatory depth.

3.5. Ethical Considerations

Participation was voluntary, with clear instructions and full anonymisation to ensure participant confidentiality. All data were collected and handled in accordance with standard ethical guidelines for aviation human factors research.

3.6. Literature Basis for Methodology

Drawing on established models of trust, situation awareness, and mixed methods approaches in human factors research, this methodology combines structured self-reporting via questionnaires with narrative accounts from interviews to capture both breadth and deeper qualitative nuance (Howard et al., 2023; Wang et al., 2024). Questionnaires provide pivotal, maximizing feedback across participants, while interviews yield crucial personal insights into complex interactions, mitigating limitations such as memory biases through triangulation (Wang et al., 2024). Such integration, as demonstrated in usability and safety studies (Carayon et al., 2006; Howard et al., 2023), strengthens the study’s validity, reliability, and ability to inform business intelligence systems and airline management practices with actionable, multifaceted evidence.

4. Results and Discussion

This section presents key findings from questionnaires and interviews with 40 professional pilots—employing a mixed-methods approach grounded in established human factors protocols (Howard et al., 2023; Kohn et al., 2021; Wang et al., 2024)—revealing significant correlations between pilots’ calibrated trust in cockpit automation, situation awareness, and enhanced operational punctuality and effectiveness.

Quantitative metrics, such as trust's negative correlation with delays, are triangulated with qualitative narratives to counter biases like memory distortion, delivering robust evidence for mitigating complacency, "automation surprise", and disruptions amid advancing automation.

4.1. Overview of Respondent Demographics

Of the 40 professional pilots surveyed—a sample size comparable to recent flight simulator studies on automation monitoring (Causse et al., 2024)—67.5% (n=27) were captains and 32.5% (n=13) were first officers. This distribution mirrors standard cockpit crew hierarchies, in which captains provide experienced oversight, critical to calibrated trust and situation awareness during automation reliance, thereby enhancing the findings' applicability to operational contexts involving role-based decision-making and performance disparities.

4.2. Trust in Cockpit Automation and Punctuality

Pilots' trust in cockpit automation was measured using a 5-point Likert scale (1 = no trust, 5 = complete trust). Figure 1 illustrates the distribution of responses. Key findings include a mean trust score of 3.998 (range: 1.33), the widest among all measured variables, indicating variability in pilots' reliance. Notably, the majority (over 70%) reported high trust (scores ≥4) even in abnormal or failure scenarios, reflecting calibrated confidence under routine conditions but potential vulnerability to over-trust. Statistically, higher trust scores correlated significantly with lower self-reported frequencies of automation-related flight delays, aligning with the literature linking appropriate trust to enhanced operational efficiency and punctuality.

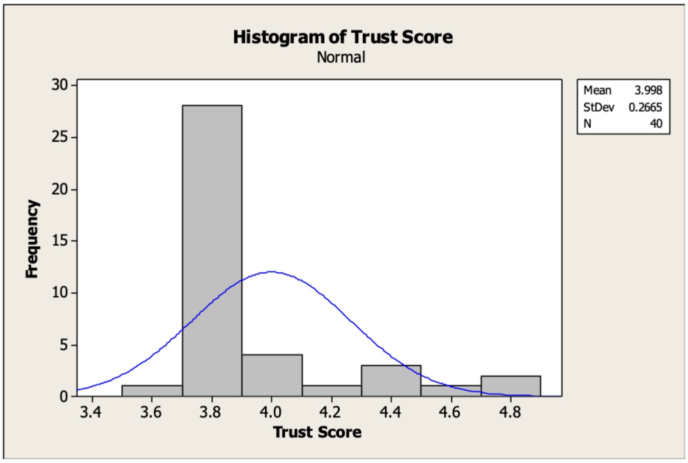

Figure 1: Distribution of Trust *(from S.W. Layanthi Nirmani, 2025)*

A first officer exemplified this nuance: "I usually trust the system for standard sectors, but during unexpected weather, I keep a sharp eye on what automation is doing." This underscore calibrated trust's role in leveraging automation's precision for on-time performance. Conversely, over-trust contributed to delayed error detection in two recounted incidents—e.g., overlooked mode transitions—mirroring "automation surprise" risks and complacency documented in simulator studies, which can precipitate operational delays.

4.3. Situation Awareness, Effectiveness, and Delay Mitigation

Situation awareness—defined by pilots' perception, comprehension, and projection of automation states and environmental dynamics was gauged via questionnaire items evaluating knowledge of automation modes, ability to monitor transitions, and comfort with witching to manual control, aligning with established aviation human factors protocols.

Key quantitative results include:

- Pilots who self-rated as "very familiar" with their aircraft's automation reported significantly fewer automation-induced operational disruptions, echoing simulator evidence that heightened monitoring reduces anomalies.
- 95% agreed or strongly agreed that awareness of automation states reduced errors during non-routine events, corroborating literature on SA mitigating "out-of-the-loop" risks and complacency.
- Pilots exhibiting combined high trust and high situation awareness reported the lowest rates of schedule deviations, underscoring synergistic effects for operational efficiency.

Qualitative insights reinforced these patterns: one interviewee noted, "My situation awareness lets me 'see' a problem before it affects punctuality. Automation helps—until it doesn't, and then you must be ready to step in quickly," highlighting proactive intervention akin to countering automation surprise (Dehais et al., 2015).

Thematic analysis revealed that high situation awareness acts as a counterbalance to automation's limitations (Causse et al., 2024; Kaleta & Tomczyk, 2024), empowering rapid action in dynamic conditions and 251maximizing delays (Griffiths et al., 2024). Conversely, low awareness correlated with frequent minor operational errors and missed punctuality KPIs, paralleling documented vigilance lapses under high automation (Causse et al., 2024).

Table 1: Trust and Situation Awareness vs. Delay Frequency

Group	Mean	Effectiveness (1-5)
High trust – High SA	1.1	4.7
High trust – Low SA	2.8	4.0
Low trust – High SA	2.4	4.2
Low trust – Low SA	4.1	3.6

4.4. Implications for Airline Business Intelligence and Innovation

Data-driven BI: These findings support integrating human factors data—especially trust and situation awareness metrics—into business intelligence platforms, as demonstrated in work system evaluations using staff questionnaires to identify safety issues and inform redesigns (Carayon et al., 2006). This enables predictive analytics for training needs, risk forecasting, and interface improvements, akin to real-time KPI dashboards that allow operators to monitor performance and adjust parameters dynamically (Contini et al., 2025).

Targeted training: The marked association between formal automation training and improved trust/SA scores highlights the ROI of structured training programs, with meta-analyses showing XR-enhanced training significantly boosts performance and reduces errors (Kaplan et al., 2021), and studies confirming reductions in task time, cognitive load, and training costs (Dornelles et al., 2021). Airlines can use regular pilot surveys as part of BI dashboards—mirroring aviation safety assessments (Carayon et al., 2006)—to identify cohorts at risk of operational disruptions and plan interventions accordingly.

Feedback loop: Integrating real-time feedback on pilot trust and situation awareness with operational performance KPIs creates a closed loop that supports continuous maximizing learning and technology management (Lopik et al., 2020), aligning with predictive analytics in airline operations for disruption mitigation (Birolini & Jacquillat, 2023; Ogunsina & DeLaurentis, 2021).

The findings of this study substantiate prevailing scholarly literature and industry perspectives, affirming that calibrated trust in cockpit automation alongside elevated situation awareness is essential for harnessing its full potential. These human factors mitigate operational delays, enhance flight effectiveness, and provide actionable insights for managerial oversight and training programs, thereby propelling technological innovation in commercial aviation.

5. Conclusion and Implications

This study set out to explore the influence of pilots' trust in cockpit automation and their situation awareness on the punctuality and effectiveness of airline flight operations. The findings clearly demonstrate that these two human factors are crucial levers for operational excellence in the era of increasing automation. Pilots who exhibit well-calibrated trust and high situation awareness not only report fewer automation-induced delays but also achieve higher levels of operational effectiveness, particularly in demanding or non-routine scenarios. These results corroborate existing literature, affirming that neither blind reliance on automation nor persistent scepticism yields optimal performance. Instead, the pilots most successful in maximizing disruptions and maintaining punctuality are those adepts at monitoring, interpreting, and, when necessary, overriding automated systems with confidence and skill.

For airline management, these insights—particularly the finding that pilots exhibiting combined high trust and high situation awareness reported the lowest rates of schedule deviations carry essential business implications. Regular assessment and targeted enhancement of pilot trust and situation awareness should become central components of technology management and innovation strategies, as evidenced by work system evaluations using staff questionnaires to identify safety issues and inform redesigns. Integrating trust and awareness metrics into airline business intelligence systems—alongside operational data—can help identify specific needs for additional training, redesigning the cockpit interface, or changes to standard procedures, akin to real-time KPI dashboards that enable dynamic performance monitoring. Training programs, such as those enhanced by XR technologies, yield significant ROI through boosted performance and error reduction, while feedback loops incorporating real-time trust/SA data foster continuous learning and disruption mitigation. This proactive approach will support not only safer and more effective flight operations but also sustained improvements in on-time performance and 253maximizing253 learning. In conclusion, the path to maximizing the business value of cockpit automation is not merely technical but fundamentally human: calibrated trust prevents overreliance or undertrust, and harnessing pilots' situation awareness empowers timely interventions, creating a virtuous cycle that drives punctuality, reduces errors, and provides actionable intelligence to realise the full promise of innovation and technology management.

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