# Improving Pilot Safety Performance Assessment: a Focus on Human Errors with Fuzzy Bayesian

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# Improving Pilot Safety Performance Assessment: A Focus on Human Errors with Fuzzy Bayesian

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**Abstract.** Safety is one of the objectives of ergonomics in human-machine interaction. Accurately assessing human errors is of great significance for improving ergonomic design of human-machine interfaces and enhancing the safety of human-machine systems. Human errors in aviation are key factors affecting flight safety. Current flight data records a large amount of interaction data between pilots and aircraft, which can provide reference for the evaluation of human errors in aviation. This study extracts typical human error interpretation rules based on Flight Crew Standard Operating Procedures (SOP), including four evaluation dimensions: speed control, attitude control, configuration control, and trajectory control, to form indicators for judging pilot human errors based on flight data. Furthermore, an evaluation model for human errors in aviation is constructed based on fuzzy Bayesian networks using expert experience, identifying key human errors that affect flight safety, and guiding pilots' daily flight training. This research aims to enhance human-machine interaction safety from the perspective of human factors, providing references for further reducing aviation accident risks and enhancing ergonomic design of human-machine interfaces.

**Keywords:** Human errors; human pilot; safety performance; Fuzzy Bayesian.

## 1 Introduction

With the continuous improvement of aviation safety management and the increasing reliability of aircraft equipment, the human factors of pilots become more and more critical factors affecting the performance of flight systems [1]. Ergonomics improves the interaction between pilots and aircraft from the perspective of flight human-computer interaction interface, and the prerequisite is to analyze the pilot's behavior, in which the safety of the system is an important target of analysis [2]. As shown in Fig. 1, human-caused errors lead to unsafe pilot behavior, which is reflected in safety performance and results in risky human-computer interaction outcomes. Therefore, evaluating pilots' human-caused errors is an important element in improving flight ergonomics and enhancing flight safety.

Pilot safety performance evaluation, quantifying compliance and mission completion under regulations, is pivotal. Advancements in Quick Access Recorders (QAR) technology lately facilitate such assessments, offering abundant operational data for analyzing pilot actions and pinpointing risks [3]. Documents like aircraft manuals and safety management guidelines augment risk-informed performance evaluation. To refine piloting practices and augment training efficacy, an interpretable safety evaluation model is essential. Bayesian Networks, with embedded safety knowledge in node connections and fuzzy mathematics for edge quantification, support this interpretability [4]. By feeding QAR-derived behavioral data into this network, comprehensive pilot safety analysis is achievable. In essence, this work introduces a Fuzzy Bayesian Network-driven approach for pilot safety performance evaluation, rooted in flight error analysis and fueled by QAR data.

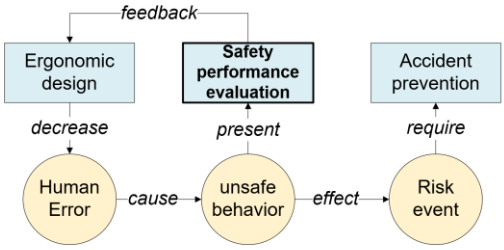

**Fig. 1.** The core concept of research.

## 2 The Framework of Research

This study comprises three sections. First, safety performance evaluation indices are analyzed to pinpoint key pilot error dimensions. This involves extracting evaluation dimensions from standard procedures and defining necessary flight parameters. Next, safety performance indicators are calculated, feeding into a broader flight safety assessment. Calculation relies on flight parameters and human error rules, forming inputs for Bayesian node assessments. Lastly, a comprehensive flight safety scoring method is devised, pinpointing crucial human error aspects. This is achieved via a fuzzy Bayesian-based safety performance evaluation network.

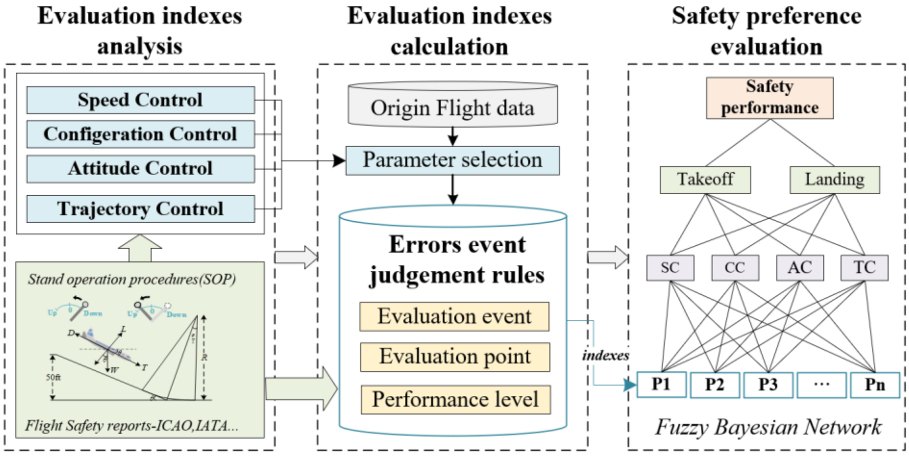

**Fig. 2.** The framework of research.

## 3 Performance Evaluation Indexes Analysis

To enhance flight safety research, nations have adopted data-driven management strategies. The CAAC requires airlines to implement FOQA for safety surveillance, with regulations targeting pilot operations across aircraft types, focusing primarily on flight safety rather than continuous improvement of error identification and correction capabilities. This study, illustrated in Figure 1, builds upon existing FOQA metrics and integrates flight crew SOP [5], categorizing human errors during flight into four: speed, attitude, configuration, and trajectory control errors, each with detailed definitions provided.

(1) Speed control: use airspeed or Mach number control device to ensure that the aircraft in a variety of flight conditions at a constant airspeed or selected airspeed flight, such as the aircraft on the ground in a straight line taxiing speed should be <30kn;

(2) Attitude control: through certain maneuvers to achieve the aircraft attitude angle stabilization and attitude angle control two functions, such as landing roll angle, ground pitch angle control;

(3) Trajectory control: through the manipulation of the aircraft's center of mass along a given trajectory movement of the controllable flight, generally including flight altitude control, downward landing trajectory control, lateral trajectory control, terrain following and terrain avoidance control;

(4) Configuration control: the geometric shape of the aircraft is changed through control to improve the flight performance, such as landing should be controlled to open the leading edge of the slit wing in order to ensure the safety of landing.

The corresponding indicators extracted based on SOP are shown in Table 1.

**Table 1.** Evaluation indexes for pilot safety performance during landing phase.

| First-level indicators | Second-level indicators |
|---|---|
| Speed Control (landing-V) | High Approach Speed(landing-V1) |
| | High touchdown Speed(landing-V2) |
| | Large vertical overload(landing-V3) |
| Attitude Control (landing-A) | Excessive touchdown pitch angle(landing-A1) |
| | Small touchdown angle(landing-A2) |
| Trajectory Control(landing-T) | Glide slope deviation(landing- T1) |
| | Long touchdown distance(landing- T2) |
| Configuration Control(landing-F) | Late selection of landing configuration(landing- F1) |
| | Late landing gear deployment(landing- F2) |
| | Non landing flaps(landing- F3) |

## 4 Performance Evaluation Indexes calculation using flight data

Following the establishment of the pilot safety performance evaluation indicator system, grading the secondary indicators becomes a pivotal step for ensuring smooth progress in subsequent analyses. To this end, the development of a pilot safety performance appraisal rule repository is imperative, enabling the conversion of flight parameters recorded by Quick Access Recorder (QAR) devices into specific rating tiers for these secondary indicators. The construction of this rule repository is grounded in the Advisory Circular issued by the Flight Standards Department of the Civil Aviation Administration of China (CAAC). Safety performance grades for each secondary indicator are categorized into four tiers: SAFE, BLUE, ORANGE, and RED. The resultant Pilot Safety Performance Evaluation Rules are depicted in Table 2.

**Table 2. Pilot safety performance evaluation rules in landing**

| Indexes | Flight data | Evaluation phase | Pilot safety performance level | | | |
|---|---|---|---|---|---|---|
| | | | Safe | Blue | Orange | Red |
| landing-V1 | VA，AAL | 152 m～0 m | $k$＜(VREF+5) kn | (VREF +5) kn＜$k$＜(VREF+10) kn | ＞(VREF+10) kn | — |
| landing-V2 | VA，AAL | Touchdown | $k$＜(VREF+5) kn | (VREF+5)KN＜$k$＜(VREF +10) kn | $k$＞(VREF +10) kn | — |
| landing-T1 | GD，AAL | Under 305 m | $k$＜0.1dot | 0.1 dot＜$k$＜1.5 dot | $k$＞1.5 dot | — |
| landing-F1 | FLAP，SLAP，AAL | With landing configuration | $k$＞1000 ft | 500 ft＜$k$＜1000 ft | $k$＜500 ft | — |
| landing-A1 | PITCH，Main Landing gear | Open Main Landing gear open | $k$＜30% of Tail angle | 30% of Tail angle＜$k$＜40% of Tail angle | $k$＞40% of Tail angle | Tail angle |
| landing-A2 | PITCH，Main Landing gear | Main landing gear touchdown | ＞2.0° | 1.5°＜$k$＜2° | $k$＜1.5° | — |
| landing-T2 | Touchdown distance | 15 m to touchdown | $k$＜700 m | 700 m＜$k$＜750 m | $k$＞750 m | — |
| landing-V3 | VRTG，IVV | Touchdown | $k$＜1.0gn | 1.0gn＜$k$＜1.2gn | 1.2gn＜$k$＜1.4gn | $k$＞1.4gn |
| landing-F2 | Landing gear，AAL | — | — | — | — | $k$＜100 m |
| landing-F3 | Flap，Main Landing gear | — | — | — | — | Non 30or 40 |

# 5 Performance Evaluation Based on Fuzzy Bayesian

Subsequently, A Bayesian network is established for evaluating landing phase pilot safety based on Table 1. Node prior probabilities stem from a specific airline's training squadron data. Conditional probabilities are meticulously estimated by experienced flight experts, integrating domain expertise into the model to ensure more accurate and robust safety performance assessments during landings. As illustrated in Figure 3, the computational findings reveal that during the landing phase, the probabilities stand at 5.84% for SAFE, 22.12% for BLUE, a significant 63.88% for ORANGE, and 8.16% for RED. These results underscore the ongoing necessity for enhanced training to elevate the fleet's safety performance.

Moreover, sensitivity analysis constitutes a pivotal basis for informed decision-making. Leveraging the prior probabilities of base-level performances, posterior probabilities, and conditional probabilities, along with Bayesian network-based sensitivity analysis techniques, permits swift identification of factors that are sensitive to changes in pilot safety performance [6]. This process further quantifies the extent to which each base-level performance influences the overarching pilot safety performance, thereby pinpointing the operational aspects crucial for enhancing safety. By doing so, this analysis contributes to the formulation of targeted interventions aimed at addressing these key determinants and, ultimately, improving flight safety standards.

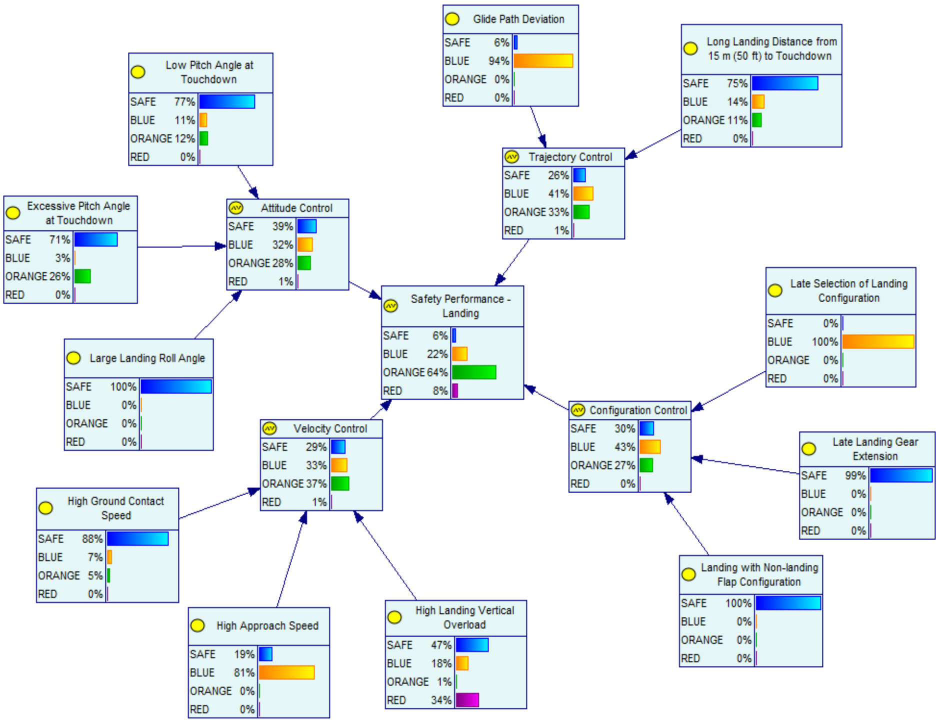

**Fig. 3.** Bayesian network results for evaluating pilot safety performance during landing phase.

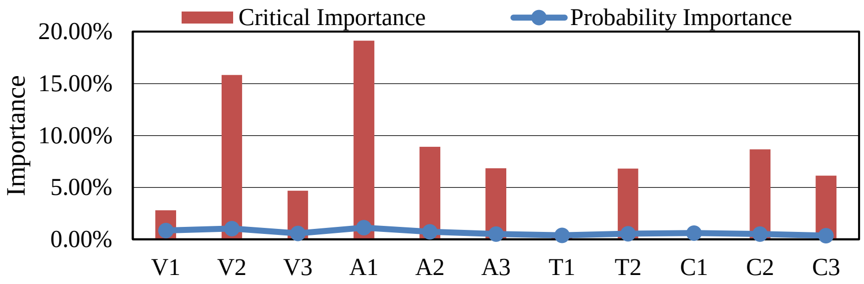

**Fig. 4.** Comparison of Probability and Critical Importance of Basic Events during Landing Stage.

As illustrated in Figure 4, among the elementary events, A1 and V2 exhibit notably higher levels of importance compared to other events, suggesting that enhancements in operational safety pertaining to these aspects hold decisive implications for elevating the overall safety performance during landing. In essence, to augment flight safety performance, prioritized and targeted training should be directed towards controlling the touchdown pitch angle and speed. Enhancing pilot proficiency in these areas promises a substantial boost in safety performance. Furthermore, A2, C2 A3, T2, and C3 all exhibit relatively high probabilities of importance and critical importance. This indicates that improving pilot safety practices concerning these five events can also effectively bolster flight safety performance.

Beyond these key factors, other elements also exert influence on pilot safety perromance, albeit to a lesser degree. Incremental improvements in pilot handling of these additional events can contribute, to some extent, to an uplift in safety performance. Collectively, these findings underscore a multifaceted approach to training, emphasizing both the paramount and supplementary factors for achieving comprehensive advancements in flight safety.

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