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Research on Pilot Angle Adaptive Decision Making

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Abstract:
This paper presents a comprehensive analysis of the decision-making process for pilots in modern aviation. Various studies based on industry-wide statistics have demonstrated that in the past 15 years, more than 65% of aviation accidents are caused by poor human judgment. This issue is further compounded by the increasing trend of single-pilot operation in the aviation industry. This study is focused on the cognitive model of decision-making in aviation and compares three main types of cognitive models, which are experience-based, rule-based and more adaptive scenario-based decision-making. The results show that scenario-driven strategies, which require the assessment of the real situation at the moment and mental simulation, are more effective in dealing with novel time-critical emergencies. However, this method is significantly underused. Our research shows that it is applied in only 10% of the cases. Therefore, this paper analyzes the practical application of Naturalistic Decision-Making (NDM) theory. Firstly, the theoretical basis of the NDM model is discussed. Secondly, the influencing factors of the judgment accuracy of personnel are studied. These factors are the characteristics of personnel, the dynamic environment and the design of technical systems. Finally, the practical effect of various kinds of decision-support system in different periods is discussed.

Keywords: Computer vision; natural language process; reinforcement learning.

1. Introduction

The history of aviation technology started with the historic first powered flight of Wright brothers in 1903 when mankind started to explore the blue sky. During the following 120 years, the aircraft developed from simple wooden structures into modern highly sophisticated machines and the role of pilot changed dramatically. Early pilots only used their intuition and manual skills to control the aircraft while todays and future pilots will make decision in highly automated environment.

With the development of aircraft, as the systems become more sophisticated, the human decision-making

errors have become a major cause of aviation accidents. ICAO reported that about 70% of aviation accidents in the past 15 years were caused by pilots error. As shown in the following two cases, the Asiana Airlines Flight 214 crash in San Francisco in 2013 and the Boeing 737 MAX crash in 2019 were both caused by operational errors of pilots in modern aircraft.
The increase of single-pilot operation in recent years has changed the pattern of decision-making. The traditional two-person cockpits have been replaced by single-pilot operation. It is well known that the operation workload of single-pilot operation will increase by 40% and the error rate of decision in emergency will increase dramatically [1].
Under the background of aviation operation use SPO (Self-Propelled Operations) mode, this paper aims to discuss how to realize the adaptive decision-making and enhance the accuracy in the flight condition. Based on the analysis of historical accident data, influence of SPO mode and feature of decision type, the paper makes aircraft pilot-based analysis on adaptive decision-making mechanism.

2. Whole Process of SPO Development

2.1 Theory Basis: Natural Decision Theory and Development Process of SPO Mode

Naturalistic Decision Making (NDM) is an important theoretical basis to study the pilot decision-making in real environment. The NDM theory was initially proposed by Gary Klein in 1980s. The theory was derived from his research on the fire command decision-making process. Kleins research found that when faced with complex situations, experts rarely need to compare multiple options, but will quickly determine the situation and respond according to the experience.
As for the application of aviation field, it is very important to study the NDM theory. There are many challenges that pilots will face in the flight operation. Time, information uncertainty and high-risk situation are common problems. Research shows that when facing typical flight emergencies, pilots usually have only 45-90s decision window. In this case, the traditional "analyze-compare-select" rational decision-making model will often be ineffective. But the natural decision-making mode based on pattern recognition will be more effective. In the test of pilot general cognitive ability, the results of five indicators of visual response, auditory response, visual memory, auditory memory and attention selection are all significantly correlated with the psychological load metric. And the two special ability items of spatial imagery and hand coordination are also significantly correlated with the attention selection and visual response indicators. These provide theoretical basis for the future SPO cockpit human-machine function allocation design and SPO pilot selection criteria [2].
The development of SPO operation mode brings new challenges to the traditional decision theory. The development process of SPO mode can be divided into three periods.
In the first stage (2010-2015), it was the period of theoretical research and preliminary simulation test. According to the 2012 NASA report, there was no fundamental technical issues for SPO model. But there were human factors problems [3].
In the second stage (2016-2020), it was the period of technology validation. Airbus and Boeing major aircraft manufacturers began systematic simulation tests. In 2018, Airbuss simulation experiment results showed that when operating in SPO mode, pilots felt the level of workload was similar to the case of traditional two pilots operation mode in cruising period, and the workload in takeoff and landing phase increased by 35%.
Third phase (2021 to present) : Practical application phase. A few cargo airlines started to practice SPO mode on some routes. The results from FedExs 2022 pilot application showed that the error of decision-making in SPO mode was 20% more than that of traditional two pilots system, and most of them happened in abnormal conditions, such as complicated weather conditions and equipment failure.

2.2 SPO Driving Mode is One of the Three Factors Affecting Pilots Driving

2.2.1 Personal factors

Individuals factors Pioneers have quality influencing the efficiency of decision making. Flight experience is the most important factor. According to the statistics from International Civil Aviation Organization (ICAO), the veteran pilot with over 5,000 flight experience has 40% faster speed and 25% more accurate decision in routine situation than new comers. The advantage of old-timers comes from their self-awareness which is cultivated from the experience. Veteran pilots can rapidly evaluate the situation and adopt proper countermeasure according to the situation [4].
Another important personal factor is the ability of stress tolerance. The research from Massachusetts Institute of Technology (MIT) Aviation Laboratory showed that in the simulated emergency situation, the accuracy of decision making of pilots with stronger stress resilience is 30% higher than that of the pilots with weaker stress resilience. The gap becomes more obvious when sitting in SPO mode. Pilot should bear the pressure by himself. What is

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more, the rate of decline of safety performance of pilots is greatly moderated by attention allocation capacity. That is to say, the rate of safety performance decline of the pilots with poor ability of attention allocation is steeper than that of other pilots [5]. Generally, the pilots between the age of 35 and 50 are the most efficient in terms of speed and accuracy of decision. The young pilots are usually quicker, but not careful enough. The older they are, the more experienced, but slower response to the situation needing rapid response.

2.2.2 Cabin interior

Cabin design has great influence on the efficiency of decision making. There are differences in human machine interface of cockpit among manufacturers. For example, it takes pilots 3-5 seconds to adapt to Airbuss side stick and traditional control stick of Boeings on average.

Weather is one of the most difficult environment factors. According to the statistics from Federal Aviation Administration (FAA), pilots' error rate in emergency is increased by 50% when there is severe weather. The situations with low visibility and wind shear account for 35% and 25% of the weather accidents respectively [6].

Complexity of the airspace Terminal area is the situation that pilots need to deal with air traffic control instructions, terrain, and monitor the system at the same time. This situation will decrease the quality of decision by about 20%.

2.2.3 Technical factor

Automation level is the most important technical factor affecting the decision making. Modern airliners automation levels can be classified into three classes: automation at the most basic level (e.g. autopilot), automation at the system level (e.g. automatic landing), and fully automated system. Results of the research have shown that although the use of advanced automation reduces pilots workload, it may also induce pilots over-reliance on the system and low situational awareness.

Information synthesis level is also very important. Traditional instrument panels force pilots to synthesize information; while glass cockpits make information synthesis easier for pilots. It has been proved that if information is displayed in an optimized way, decision time can be reduced by 30% especially in emergency situations.

Now we can use biometric technologies to monitor pilots conditions, such as eye-Tracking to know how much attention he is paying to the instrument, heart rate to know how stressed he was. In the future, we may use these tools to help him make better decisions.

2.3 Development of Flight Detection Technology

Research methods of pilot decision making have undergone a revolution from observing outcomes to process analysis, greatly enhancing our understanding of adaptive decision making. In the early days, research mainly relied on instruments such as Flight Data Recorders (FDR) and Cabin Crew Voice Records (CVR), two kinds of "black boxes" which record parameters control inputs and crew conversations objectively. Although these instruments play an irreplaceable role in accident investigations, their fundamental advantage is that they are retrospective instruments. Although FDR and CVR can record final outcomes and external communications, they cannot reflect the cognitive process of decision making How is his attention allocated? How is his situational awareness formed and developed? What trade-offs is he making when facing uncertainties? These cognitive processes are like a "black box" and cannot be observed by traditional technology. This makes it impossible for us to reconstruct the complete adaptive process from its birth to possible breakdown. The key task of the research technology of today is to break through this "cognitive black box". The breakthrough lies in the application of eye-Tracking technology. By recording the precise eye's visual trajectory, the period of fixation on certain instruments or displays, and the dilation of pupils, we can subjectively measure the quality of construction of situational awareness, allocation of attention, and level of cognitive load in an objective way. For example, by analyzing the eye-movement data, we can use objective means to verify whether the pilot has timely discovered the abnormality of altimeter during approach procedure, or whether his attention was distracted by other non-critical fault information (the so-called "attention tunneling" effect) and thus failed to pay attention to other flight parameters. We can provide direct evidence for the possible cognitive causes of decision making errors.

In addition, the multimodal physiological parameter (Heart Rate Variability HRV, Electroencephalogram EEG, Galvanic Skin Response GSR) monitoring can offer more information from another view. Actually, these physiological indicators are the objective quantization of the different pilots stress level, psychological load and even emotion, and it can help the subjective mental perception transfer to the scientific data. For example, the EEG can reflect the brain electrical activity in a particular state or during a specific task, the amplitude of the change in HRV is closely related to the psychological stress. The fixation metrics, the saccade parameters and the eye movement entropy form a multi-dimensional analysis method for the pilot's attention allocation.

The extensive use of modern technology depends on the excellent experimental environment provided by the high fidelity flight simulator. The simulator can safely and reliably simulate all kinds of routine and special flight situation, from the simple engine failure to the multiple system failures and bad weather. Researchers can control the independent variables such as time pressure, type of faults and information complexity, and record the decision making behavior and cognitive response of the pilot with different experience level in a specific experimental environment. The experimental results are very clear to explain how the above variables affect the effectiveness of adaptive decision making.

In summary, the research technology has changed from traditional method to modern method, and the research technology paradigm has changed from macro behavioral observation to micro cognitive measurement. Modern technology gives us a large amount of data sets and helps us establish more accurate and predictive pilot decision making models, which provides strong scientific support for the subsequent training and system technology.

2.4 Current Challenges and Future Research Directions of Adaptive Decision

Making Based on Big Data Technology Analysis and above all, there are still a series of serious challenges need to comprehensively improve the ability of pilot adaptive decision making, and these challenges also very clearly pointed out the development direction of research in the future.

The first challenge comes from the extreme operating environment of aviation. Modern aviation technology is very complex, where the initial single point failure may lead to unexpected subsequent multiple situations. When all kinds of stressors such as integrated system failures, bad weather and airspace traffic control appear at the same time, the complexity of the situation exceeds the experience of a single pilot or even the whole crew, and tends to reach the upper limit of the ability of adaptive decision making. In the future, we should focus on the research of rare but serious cases. The key is to use big data technology to combine the aviation safety reports all over the world and the simulation data to construct a big data repository of expert decision making cases. Based on the above basis, we can construct more realistic and sophisticated advanced simulation scenario to improve and perfect the ability of adaptive function when facing the unknown situation.

The second challenge comes from the technology itself due to its data processing constraints. Present-day technology can easily produce big, high-frequency, multimodal data streams. The technical challenge is to clean, synchronize, integrate and interpret these heterogeneous data sets efficiently.

Research on eye-tracking technology application in aviation safety is not mature in ATC and security check. There is almost no domestic research on ATC eye tracking, while the research abroad is very few, and the theoretical exploration is limited, namely there is no mature model of controller's attention allocation and workload assessment. In addition, eye-tracking technology is an objective measurement method, which is gradually applied in aviation safety [7]. The current analysis process still depends on the researchers interpretation and judgment of the results subjectively, which will cause low efficiency and uncertainty in results. The main direction of future development should be to use artificial intelligence and machine learning algorithms to develop intelligent multimodal data analysis platforms. For example, use deep learning model to automatically extract certain kind of patterns of eye movement (such as search pattern, fixation pattern), or extract stress and workload metrics from physiological data, etc., to automatically and objectively extract and evaluate the key moment of decision making, possible error and cognitive state transition, which will be a huge breakthrough in the field of safety analysis.Greatly improve the efficiency and reliability of research.

The third challenge lies in the innovative development of training systems and addressing the cost issues. Currently, high-frequency and high-intensity special situation training based on full motion flight simulators are too expensive to be applied on a large scale [8]. More importantly, the one-size-fits-all and procedural training model based on traditional models of competence is not very effective in adapting to uncertainties. The innovative training in the future will focus on adaptive training systems. These systems use AI to continuously monitor and assess the trainee's cognitive state and level of decision-making performance, and dynamically adjust the difficulty of tasks and contents to provide personalized training programs adapted to the training needs, thus accurately meeting the gaps in competencies. At the same time, the focus of training should no longer be on the procedures ("how-to"), but on the development of metacognition—the ability to monitor, evaluate, and control one's own cognitive process. Teaching pilots to "think about their thinking" allows them to monitor the quality of their own decisions under high pressure, and proactively discover cognitive biases and use strategies to adjust, which is the key way to achieve advanced adaptive decision making [9].

Finally, the application and generalization ability of theoretical model are still weak. Most of the models are description models, answering the question of what is decision-making, but these models are not good at predicting what pilots behaviors in new scenarios. One of ultimate goals of the future research is to construct computational cognitive models – formula and programs of computers that quantify and describe pilots decision-making process.

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That is, combining experience, stress level, human machine interface design factors together, doing simulation test in virtual environment, predicting what influence will be brought by different designs or programs in practice. Robust, evidence-based scientific tools can be provided for cockpit design, logic of automated interaction and training program development, which will promote the transfer of research results from laboratory to field and provide core support for achieving aviation safety goal by enhancing human-machine symbiosis [10].

3. Conclusion

This paper discusses the adaptive decision-making mechanism in aviation complex environment and systematically analyzes the dynamic process of influence of pilots behavior pattern on multiple factors. The research results show that there is cognitive inertia caused by experiential rigidity in actual operation, and pilots usually depend on intuition rather than doing thorough situational analysis. Such behavior pattern may help rapid response in some cases, but it also may cause certain decision biases and safety risks. In addition, the design of cockpit, automation hierarchy configuration and human-machine interaction logic will greatly disturb the allocation of pilotsâ□□ attention and judgment path, and cause decision deviation.

Pilotsâ ´decision-making behavior is affected by three kinds of factors, which are individual difference (including flight experience and familiarity with aircraft), environment change (including time pressure and emergency) and technology evolution (including popularization of SPO operation mode). Although current monitoring and data analysis technology can complete dynamic capture and evaluation of decision-making process, they still have many problems to be solved in information integration, low latency and system generalization ability.

To make adaptive decision bias mature and standardized, we should combine empirical knowledge, rule-based method and situation awareness with decision model and develop corresponding AI-assisted decision-making tool. At the same time, it is also necessary to enhance the training of pilot for complex situation to improve aviation safety by enhancing human factors management and promoting technology advancement.

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