

Safety Analysis of Aviation Flight-Deck Procedures Using Systemic Accident Model

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Abstract: Analyzing the feasibility of procedures is important for ensuring safety when using systems that feature human operations and highly developed automation. This is certainly the case with flight-deck procedures due to their complexity, which sometimes leads to deviation from standard operation procedures (SOPs) and other serious outcomes (e.g., air crash accidents). To analyze the feasibility of procedures, we adopt the functional resonance analysis method (FRAM) (Hollnagel, 2004) to examine the safety management of flight-deck procedures. However, FRAM is essentially a theoretic method, and there are currently no specific approaches or supportive tools to bridge the gap between theory and practice. In this paper, we propose an adaptation of the cognitive reliability and error analysis method (CREAM) (Hollnagel (1998)) that we call Fuzzy CREAM for systematic and quantitative FRAM analysis. We applied the proposed method to an actual air crash accident that occurred near Cali Airport, Colombia in 1995 and conclude that the accident was due to deviation from SOPs. On the basis of our analysis, we show that FRAM can identify potential hazardous paths that may lead to an accident. We also propose a new method using FRAM for pre-analysis of the safety of designed procedures.

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1. INTRODUCTION

Automation is increasingly being introduced to reduce the workload of humans and improve the accuracy of task performance. At the same time, automation brings about changes to what the operators must do (e.g., change from direct manipulation to the supervision of instruments or task management), causing accidents that cannot be explained by the conventional tenets of accident analysis. In aviation, one of the most typical forms of this accident, "Control Flight Into Terrain" (CFIT), occurs when an aircraft crashes into the terrain but there are no fatalities or damage to the aircraft nor any fatal errors by the crew. This type of accident is thought to be mainly due to discrepancy between the operation of equipment and human cognition or deviation from the standard operation procedures (SOPs). Designing an interface that shows the behavior of equipment in a simple and clear way or that considers which procedures are feasible is key in terms of preventing these accidents.

To analyze this type of accident, Hollnagel (2004) proposed the functional resonance analysis method (FRAM), which is based on a systemic accident model. With FRAM analysis, the potential hazards in a given procedure can be identified. Moreover, from the perspective of resilience engineering, FRAM can identify whether the procedures are resilient against the given disturbances. However, thus far

FRAM has typically functioned as a qualitative method; a systematic way of using FRAM analysis has not yet been established. In this paper, to make the analysis more objective, we propose integrating FRAM and a new method based on the cognitive reliability and error analysis method (CREAM) (Hollnagel (1998)) that we call gFuzzy CREAMh (Hollnagel (1998)). Then, with this integrated method as a basis, we propose a method for evaluating the dynamics of the growing disturbances. Finally, we applied the proposed method to an actual air crash accident that occurred near Cali Airport, Colombia in 1995 and show how the deviation of SOPs started and grew in the cockpit, eventually leading to the fatal accident.

2. FUNCTIONAL RESONANCE ANALYSIS METHOD (FRAM)

The functional resonance analysis method (FRAM) is based on the principle of functional resonance caused by the variability of an operator's performance and the surrounding context. It enables the analysis of deviation from what is expected to be performed (e.g., SOPs). In this method, a procedure is assumed to consist of various functions that have complex dependencies on each other. Hollnagel (2004) identified six aspects of these functions (shown in Table 1) to make such dependencies clear.

Table 1. Six aspects of function

Aspect	Description
Input	Input to the functions, trigger
Output	Outcome of functions
Precondition	Conditions that must be satisfied before functions are carried out
Resource	What is consumed during the process (fuel, energy, labor force...)
Control	What supervises or restricts the function
Time	Time required to accomplish the process

Functions, each consisting of six aspects, are visually represented as hexagons and used to build a network in accordance with the dependencies between the aspects, as shown in Fig. 1.

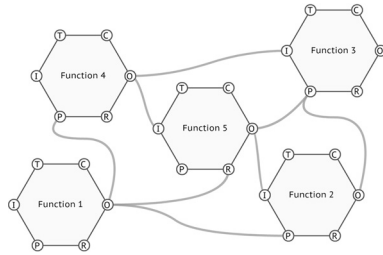


Fig. 1. Visual representation of FRAM

Once the variability in a function is generated, even if its magnitude is small, it will be amplified by the FRAM network, which can sometimes lead to serious outcomes.

This is the basic principle of FRAM analysis, and there has been much research on the best methods to use with it. However, FRAM analysis is qualitative, and no clear approach has yet been established. In this work, to overcome this problem, we introduce Fuzzy CREAM, an advanced cognitive reliability and error analysis method, and propose a novel method integrating FRAM and Fuzzy CREAM.

3. CREAM AND FUZZY CREAM

3.1 Basic Principle of CREAM

Cognitive reliability and error analysis method (CREAM) is the second-generation form of human reliability analysis (HRA) proposed by Hollnagel (1998). Conventionally, in first-generation HRA (e.g., technique for human error rate prediction (THERP)), human error was thought to stem from inherent deficiencies and the fact that humans naturally fail to perform tasks just the same as machines or structures can fail. However, extensive study of HRA revealed that the contextual conditions under which a task is performed have a greater effect on human failure, which led to the development of the second-generation HRA.

In the CREAM method, E. Hollnagel referred to these contextual conditions collectively as the Common Performance Condition (CPC) and defined it to include nine factors: "Adequacy of Organization", "Working Conditions", "Adequacy of Man-Machine Interface", "Availability of Procedures/Plans", "Number of Simultaneous Goals", "Available Time", "Time of Day", "Adequacy of Training and Experience", and "Crew Collaboration Quality". The CPC contains various CPC Levels and CPC

Effects, as shown in Table 2. For example, if the CPC "Working Conditions" in Table 2 is rated as "Advantageous", it has a "Positive" effect on the progress status.

Table 2. Examples of CPC Level and Effect

CPC	Level	Effect
Working Condition	Advantageous	Positive
	Compatible	Not Significant
	Incompatible	Negative

Then, the number of CPCs found to be "Positive" and "Negative" is plotted onto the chart shown in Fig. 2. Depending on the plotted point in Fig. 2, control modes that represent the progress status of given tasks are identified.

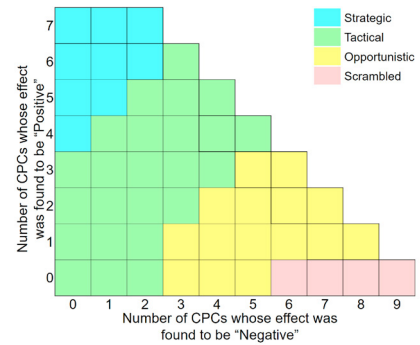


Fig. 2. Relation between CPC effect and control modes.

Also, with respect to each control mode, the intervals of probability of action failure (PAF), by which we mean the probability that the human performance will fail under a certain circumstance, are defined. The correspondence between control modes and the intervals of PAF is shown in Table 3.

Table 3. PAF intervals with respect to control modes

Control Mode	Intervals of probability of action failures
Strategic	$0.5e - 5 < p < 0.01$
Tactical	$0.001 < p < 0.1$
Opportunistic	$0.01 < p < 0.5$
Scrambled	$0.1 < p < 1.0$

However, the evaluation of the CPCs and the identification of control modes are too linguistic, and there is a problem with objectivity. Therefore, quantification of CREAM analysis is required, and various quantitative approaches for CREAM have been developed in recent years. One such approach, Fuzzy CREAM, enables us to evaluate linguistic representations such as "Working Condition is Advantageous" or "Working Condition is Compatible" with continuous quantitative values by introducing fuzzy linguistic variables.

3.2 Fuzzy CREAM

For the quantitative approach, fuzzy logic theory was introduced to modify the original CREAM method. In Fuzzy CREAM, a crisp value of PAF and a control mode are obtained from input variables comprised of CPC scores corresponding to the linguistic values of CPC Levels. Several methods for this have been proposed in the past.

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