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Safety risk analysis in flight operations quality assurance

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Abstract

Flight data recorded by Quick Access Recorder (QAR) is gradually used to analyze pilot's operations quality, especially for the QAR exceedances. In this paper, we use the values of flight parameters to construct the state-space of pilots' operations. A flight is seen as a point in it. Basing on the distributions of normal flights and flights triggering an exceedance, risk analysis is carried out to divide this state-space into dangerous and safety regions. A multi-objective programming is established to analyze the safety risk in pilots' operations and we use Particle Swarm Optimization (PSO) to find the boundaries of regions-of-interest. The feasibility of this method is validated through experiments with real flight data.

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Keywords: Aviation; Safety engineering; Operations; Risk Analysis

1. Introduction

The aviation system is a complex and dynamic system, influenced by human, machine, environment, and many other factors. Study on the aviation system safety engineering^[1] is one of branches of aviation safety management. According to statistics, human errors have been the main causes of flight accidents. There are many researches on this topic. Human Factors Analysis and Classification System^[2] and SHELL model^[3] are very influential. Pilots' physiological and psychological factors have also been studied^[4]. Nowadays, since most of human errors are related to pilot's operations, flight operations quality assurance^[5] is attached much more importance. Quick Access Recorder (QAR) is a device to store flight data, and is gradually been used to analyze pilots' operations, especially the exceedance. Here, an exceedance means the value of a certain flight parameter exceeds its normal range. Most of exceedances are related to flight operations. Basing on QAR data, neural networks are established to analyze causes of exceedance and carry out advance warning of safety risks^[6,7]. However, quantitative analysis of safety risk in flight operations is very limited. There is a pressing need for new methods to evaluate the possibility and severity of safety risk coming from operations effectively and give concrete proposals for pilots' training.

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2. Problem description

During the flight, pilots need to coordinate the control of airplane's speed, heading, roll and pitch, etc. The mismatch in operations may cause an exceedance. The problem is how to find the boundaries of dangerous and safe operation regions. A valuable region should contain a strong majority of one particular class, normal or abnormal, and include at least some pre-specified number of flight samples.

We use some concepts of rough set theory^[8] to illustrate our problem. QAR records can be reworked into a data table, whose columns are labelled by attributes and rows are labelled by objects of interest. Here, the objects are flight samples. We also distinguish two classes of attributes, called condition and decision attributes. The condition attributes represent flight parameters, such as pilot's operations, environmental factors etc. We use the decision attribute to indicate whether an exceedance occurs. Our thinking on this problem is similar to the supervised discretization.

3. Model establishment

The list of symbols appearing in this model is shown below:

N : the sample size of flights;

k : the k_{th} factor related to a certain QAR exceedance, $k=1,2,\dots,K$;

B_k^l : the l_{th} boundary on the k_{th} factor, which are decision variables;

L_k : the maximum number of boundaries of the k_{th} factor, $k=1,2,\dots,K$, which is given by the safety manager;

$max(k)$: the maximum of the k_{th} factor;

$min(k)$: the minimum of the k_{th} factor;

θ_1 : the threshold of high-risk region. If the ratio of QAR exceedance is above or equal to θ_1 , this region is a high-risk one. It is given by the safety manager;

θ_2 : the threshold of low-risk region. If the ratio of QAR exceedance is below θ_2 , this region is a low-risk one. It is given by the safety manager;

$m(B_k^l)$: the number of high-risk regions according to a certain partition;

$n(B_k^l)$: the number of low-risk regions according to a certain partition;

$M_i(B_k^l)$: the number of flights in the i_{th} high-risk region, $i=1,\dots,m$;

$N_j(B_k^l)$: the number of flights in the j_{th} low-risk region, $j=1,\dots,n$;

$S_i(B_k^l)$: the number of normal flights in the i_{th} high-risk region, $i=1,\dots,m$;

$D_j(B_k^l)$: the number of QAR exceedances in the j_{th} low-risk region, $j=1,\dots,n$;

$p_i(B_k^l)$: the misclassification rate of the i_{th} high-risk region, $p_i(B_k^l) = S_i(B_k^l)/M_i(B_k^l)$, $i=1,\dots,m$;

$q_j(B_k^l)$: the misclassification rate of the j_{th} low-risk region, $q_j(B_k^l) = D_j(B_k^l)/N_j(B_k^l)$, $j=1,\dots,n$.

The model is established to find out the boundaries of dangerous operations and safe operations.

$$(MOP) \quad \min \left(\sum_{i=1}^m \frac{M_i(B_k^l)}{N} \times (p_i(B_k^l))^\alpha, \sum_{j=1}^n \frac{N_j(B_k^l)}{N} \times (q_j(B_k^l))^\beta, \frac{m(B_k^l) + n(B_k^l)}{N} \right)^T \quad (1)$$

$$s.t. \quad min(k) < B_k^l < max(k) \quad \forall l \leq L \quad (2)$$

The first objective aims to minimize the misclassification rates of high-risk regions. The second objective aims to minimize the misclassification rates of low-risk regions. We are interested in regions with lower misclassification rates and more flight samples. So the ratio of sample size of a certain region to the total sample size of flights is used as the weight. Here, α and β are used to control the change rates of regions' misclassification rates. The third

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