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SAFETY RISK ASSESSMENT SYSTEM FOR HUMAN-MACHINE INTERACTION

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Abstract
Safety risk assessment is of significant importance in management. Timely and binding hazard identification and risk assessment makes great contribution to the prevention of accidents. Aiming at the human-machine interaction behavior risk assessment, the interaction behavior risk assessment process is provided. The hazard of interaction behavior is identified using event tree analysis, and the risk assessment model is developed based on human-in-the-loop fault tree analysis, and risk level is determined using risk matrix based on severity and probability. Finally, a safety risk assessment system for human-machine interaction is developed.

Introduction
Safety risk assessment is of significant importance in aviation safety management. Timely and binding hazard identification and risk assessment makes great contribution to the prevention of accidents [1,2,3]. Many scholars have studied the methods of safety risk assessment. Wen-Kuei Lee developed a quantitative model for assessing aviation safety risk factors as a means of increasing the effectiveness of safety risk management system by integrating the fuzzy linguistic scale method, failure mode, effects and criticality analysis principle, and as low as reasonably practicable approach [4]. Milan Janic presented a methodology for assessment risk and safety in civil aviation based on factors analysis of aviation accidents [5]. John J. Hickey describes the continued airworthiness assessment methodologies to the identification, prioritization and resolution of unsafe conditions within the power plant and auxiliary power unit installations of transport category [6]. However, most of the risk assessment methods mentioned above are associated with the systems, equipment and components, and it is assumed that the flight crew could carry out the task efficiently and little attention is paid to the risk of human-machine interaction behavior in cockpit [7,8]. Human-machine interaction behavior is the action or reaction of flight crew and machines in cockpit under specified circumstances. Inappropriate behaviors may lead to a catastrophic accident or the risk exceeding an unacceptable level.
In this paper, aiming at the human-machine interaction behavior risk, the interaction behavior risk assessment process is provided in accordance with the general process of risk assessment, the hazard of interaction behavior is identified using event tree analysis, the risk assessment model is developed based on human-in-the-loop fault tree analysis, risk level could be determined using risk matrix based on severity and probability, and a safety risk assessment system for human-machine interaction is developed.

Interaction behavior risk analysis
The process of risk analysis
Safety risk is mainly related to the frequency of occurrence and the associated level of hazard of an event. In order to assess the safety risk of human-machine interaction behavior, the process is illustrated in Figure. 1, which mainly contains definition of the objective of safety risk assessment, data and information input on human-machine interaction behavior, identification the hazard of interaction behavior, estimation of the consequence and probability of hazard, and determination of the safety risk level.
1. Definition of the objective. In order to assess the safety risk, the objective should be defined at first. When defining the objective, the configuration and boundary conditions of the human machine system should be illuminated, and the types of the consequence and severity should be declared.
2. Input data and information collection. Data and information are important input for risk assessment. The data and information used for risk assessment of human-machine interaction behavior can be obtained from the statistics of accident or accident proneness, the experience of operators or the domain experts, and the technical reports related.
3. Hazard identification. Using the data and information collected, hazard identification is to determine the event chain that may lead to hazard. In this stage, the hazard have little influence to safety of the human-machine system need to be exclude, and the similar hazards can be integrated and analyzed together or in groups.

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4. Estimation of the consequence and probability. The consequence severity is categorized according to the influence of the hazard to personal safety. The probability is calculated based on the correlation of interaction behaviors and the logical relationships.

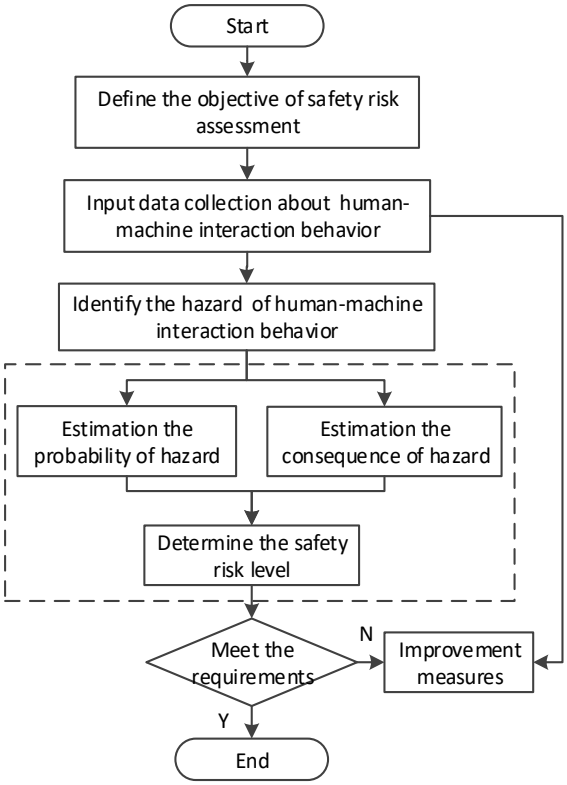

Figure 1 The process of human-machine interaction risk assessment

Hazard identification

Event tree is an inductive analytical diagram in which an event is analyzed using Boolean logic to examine a chronological series of subsequent events or consequences. Event tree analysis is a logical evaluative process which works by tracing forward in time or forwards through a causal chain to model risk.

When an initial event is given, the intermediate events and final results could be analyzed. If there are m intermediate events and two states for each event, then the number for possible consequences is 2^m. The steps for hazard identification based on event tree are as follows:

Step 1: Determine the initial hazard events that may result from human-machine interactions. This process should combine with the experiences of pilots and experts in the field.

Step 2: Find out the intermediate events, the states of each event and the order.

Step 3: Analyze the consequences based on the sequences and states of intermediate events. The number of states is not limited to two, and sometimes an event may have multi-states.

Step 4: Determine the consequence of initial event, which is the input for quantitative analysis and assessment of safety risk.

Risk quantitative evaluation

Fault tree analysis is a useful approach to analyze the safety of a system[9]. It helps the designers detect the weakness of the system, however, human is not in the loop when developing the fault tree and human factors are not considered most of the time. In this section, risk quantitative assessment approach is proposed based on HIL-fault tree analysis, which is an expansion of fault tree, and the human-machine interaction behaviors are considered. With human-in-the-loop fault tree analysis, the potential reasons for the hazard caused by inappropriate human-machine interaction behaviors could be determined and the probability of the top event could be calculated. Related human behavior is taken as an intermediate event or bottom event. Figure. 2 shows typical relationships that may lead to a hazard event based on human-in-the-loop fault tree analysis. Using this method, the logical relationship of an accident could be clarified and human-machine interaction behavior risk is identified.

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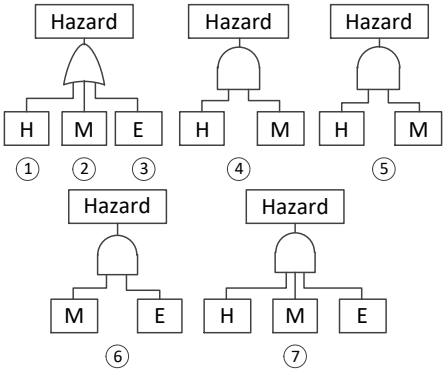

Figure 2 Typical relationships

Risk quantitative assessment based on human-in-the-loop fault tree mainly contains the parts of solving the minimal cut sets, calculating the probability of top event and the importance of bottom events.

Assuming T is the top event of human-in-the-loop fault tree, x_1, x_2, ... , x_n are n independent bottom events, denoting

$$x_i = \begin{cases} 1, & x_i \text{ occurs} \\ 0, & x_i \text{ not occurs} \end{cases} \tag{1}$$

$$\Phi = \begin{cases} 1, & T \text{ occurs} \\ 0, & T \text{ not occurs} \end{cases} \tag{2}$$

then the top event T is depended on the states of the bottom events, which could be expressed as

$$\Phi = \Phi(\mathbf{X}) = \Phi(x_1, x_2, \cdots, x_n) \tag{3}$$

and $\Phi(\mathbf{X})$ is called structure function of human-in-the-loop fault tree.

Assuming p_i is the probability for bottom event x_i occurs, denoting $\mathbf{p}=(p_1,p_2,\ldots,p_n)$, then

$$\Psi(\mathbf{p}) = \Psi(p_1, p_2, \cdots, p_n) \tag{4}$$

which is the probability composition function of human-in-the-loop fault tree.

If a set of $\mathbf{X}$ makes $\Phi(\mathbf{X}) = 1$, then the bottom events, the values of which are 1, make up a cut set, and the minimum number of bottom events that lead to the occurrence of top event make up a minimal cut set. With minimal cut sets and the probability of each bottom event, the total probability of top event T could be calculated.

Assuming C_i (i=1,2,…,n) is the ith minimal cut set, and the probability of bottom event x_{i1}, x_{i2}, ... , x_{ik} in C_i are $p(x_{i1})$, $p(x_{i2})$, ... , $p(x_{ik})$ respectively, the probability of C_i is

$$P(C_i) = P(\bigcap_{j=1}^{k} x_{ij}) = \prod_{j=1}^{k} p(x_{ij}) \tag{5}$$

The total probability of top event T is

$$P(T) = P(\bigcup_{i=1}^{n} C_i) \approx \sum_{i=1}^{n} P(C_i) - \sum_{i<j=2}^{n} P(C_i C_j) + \sum_{i<j<l=3}^{n} P(C_i C_j C_l) \tag{6}$$

The importance of each bottom event $I_{\mathbf{p}_0}(i)$ could be calculated by (7)

$$I_{\mathbf{p}_0}(i) = \left. \frac{\partial \Psi(\mathbf{p})}{\partial p(x_i)} \right|_{\mathbf{p}=\mathbf{p}_0} \tag{7}$$

In order to determine the risk level, the risk matrix is employed, which is made up of the hazard probability categories and hazard severity categories. The hazard probability categories are divided into probable, occasional, remote and improbable. The hazard severity categories are divided into catastrophic, hazardous, major and minor. The risk level, which is divided into low, medium and high, is determined in term of the probability and severity. The input for risk level analysis is from event tree analysis and human-in-the-loop fault tree analysis.

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Assessment system development

The assessment system contains data import module, hazard identification module, and risk level estimation module. The system predefined and stored a coupled of the objectives for assessment in the database. Data import module receives the input about the risk assessment of human-machine interaction behavior on different task stages. The event trees and human-in-the-loop fault trees are also pre-established. With the dynamic input data on different task stages, the hazard could be identified and the risk level could be matched automatically. The system framework is shown in Figure. 3 and the main interface is shown in Figure. 4.

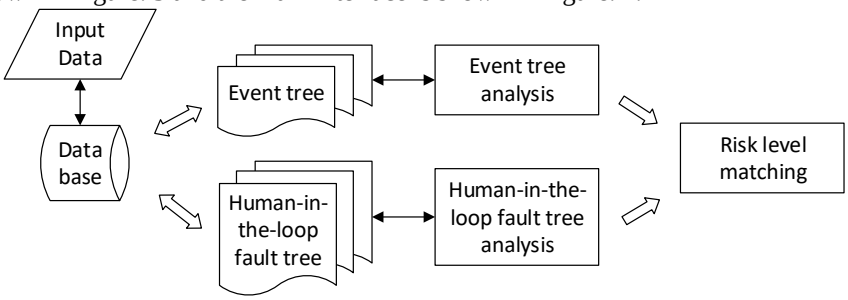
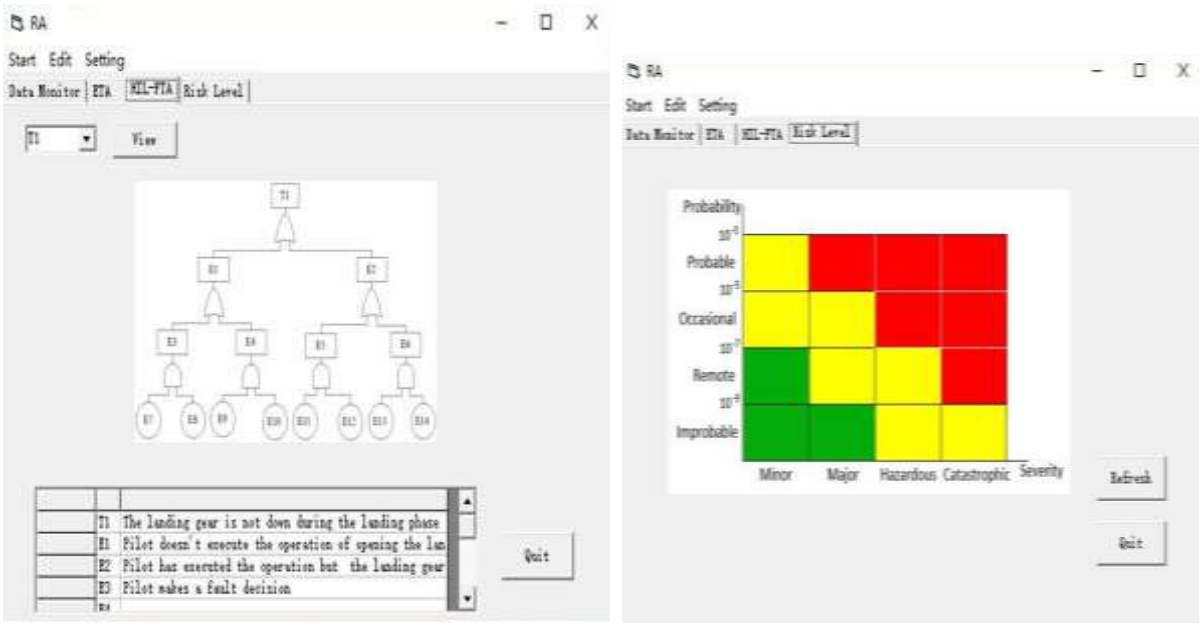


Figure. 3 System framework of assessment system



(a) human-in-the-loop fault tree analysis (b) Safety risk level output

Figure. 4 The main interface of the assessment system

Conclusions

Aiming at the human-machine interaction behavior risk assessment, the interaction behavior risk assessment process is provided. The hazard of interaction behavior is identified using event tree analysis, and the risk assessment model is developed based on human-in-the-loop fault tree analysis, and risk level is determined using risk matrix based on severity and probability. Finally, a safety risk assessment system for human-machine interaction is developed.

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