Fault Tree Establishment of Flight Conflict Based on the HAZOP Method

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Abstract. Aiming at the issues of subjectivity, coverage and ambiguity, this paper presents a systematic approach to constructing fault trees of flight conflict at airport based on HAZOP. First, the necessary deviation events are determined by associating the HAZOP guide words with the ATC parameters of terminal area, the causes and results of the deviation are analyzed in order to determine the paternity of the effectiveness of the proposed approach, and then the modeling process of the airport where two planes flight conflict happened in the United States is presented. This method can establish fault tree normatively, and provide a scientific and rational way to identify the inherent or potential risks within the airport.

Introduction

Hazard and Operability (HAZOP) analysis can help the technical designer find dangerous factors earlier and improve technical process safety, and it can also identify the potential hazards and operating problems, clarify the formation and propagation of potential accidents, assess the consequences of accidents, and propose measures to reduce the risk of the proposal[1]. Among the existing safety management technologies and system analysis methods, HAZOP method is a important one with the characteristics of its "innovative thinking by guide words" ,"collective wisdom" and "scientific and systematic analysis to the accident scenario" . It has acquired a wide range of applications in current international chemical process safety management technologies and methods.

With the rapid development of the aviation industry, the application of HAZOP analysis method has been further extended to the aerospace sector in recent years, and to ATM by NATS (National Air Traffic Services). By 2013, the number of HAZOP analysis projects has reached tens of millions all over the world, and it has been widely used in risk assessment in European and American countries. Nevertheless, the application of HAZOP method started late in air traffic control in our country[2].So this paper will combine HAZOP with fault tree method and analyze the flight conflict scenario between approach aircrafts and departure aircrafts over the airport. Not only can we succeed in introducing HAZOP method into the ATC, but also solve the problems like redundancy in the establishment of FTs,which can be reliable basis for decision-makers.

The Presentation of HAZOP and Fault Tree Analysis Methods

As shown in Figure 1, HAZOP analysis method based on fault tree is established over the airport. General procedure of HAZOP analysis is in the left part of Figure 1.
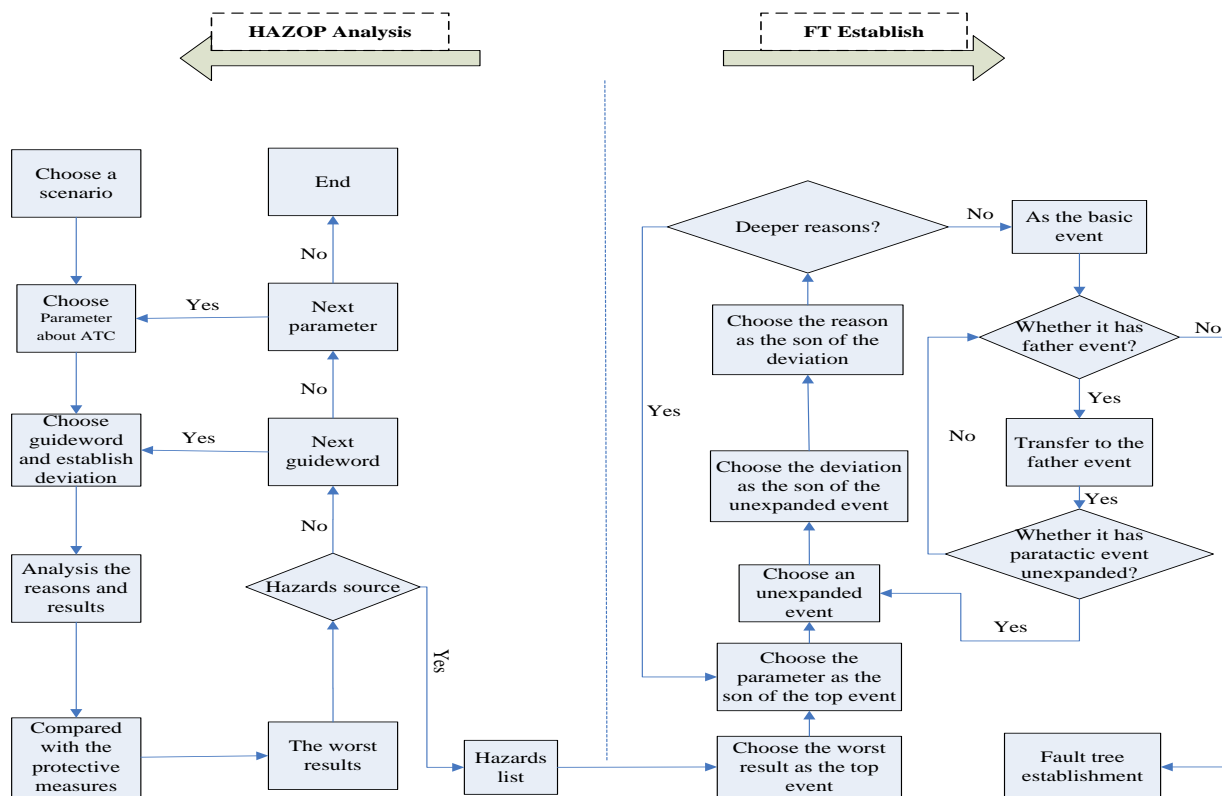
Fig.1 Flow chart of building fault tree with HAZOP analysis

Step 1: Determine the scenario.

Make sure that the purpose, object and scope of the scenario are as clearly as possible.

Step 2: Select ATC parameters.

A flight program will be divided into many process nodes. One parameter is element or characteristic in the design of each node. Parameters must be selected to describe the characteristics of the scenario.

Step 3: Select guidewords and establish deviations.

Deviation is the combination of guidewords and parameters, and can be generally expressed as follows:" guidewords + parameter = deviation", which means combining ATC parameters with guidewords to build the structure and determine the significant deviation. For example, " None + flow = no flow", representing that there is no plane flew overhead in the scenario. Using the guidewords to describe the problems can ensure the unity of HAZOP method and the systematization of the analysis.

Step 4: Generate hazards list and establish FTs.

Do HAZOP analysis according to the flow chart in the left part of Figure 1. After traversing all the guidewords and parameters, choose a meaningful deviation, and then generate hazards list. Establish FTs taking the worst result as the top event.

Step 5:Find out the basic events that influence the top event most, and adopt the relevant preventive measures.

HAZOP is qualitative analysis, while the quantitative calculations can be made by FTA to determine the probability of accident. We acquire the deviation and hazards list with HAZOP method, and then make in-depth accident analysis with FTA, which can be a complete process of accident scenario analysis.

Practical example

Taking the flight conflict in Anchorage, America as an example. Shortly after local time 12:00 at midnight in May 21,2010, a Boeing 747 plane belonging to Cargolux Airlines International flew from Anchorage to O′Hare International Airport in Chicago and two crew members were on board.

Meanwhile, a A319 plane belonging to American Airlines were ready for landing, flew from Phonenix to Anchorage in Alaska and 138 passengers were on board. The A319 plane had to pull up and go around at a low altitude because of wind shear. In the course of the operation, the vertical interval between two aircrafts was only 100 feet and the horizontal interval was only 0.3 nautical miles[3].

We know that this is a case of flight confict occurred during the approach and departure. Our purpose is to identify the causes and the key factors of the accident so that we can formulat appropriate measures to avoid the occurrence of similar case. After determining the scenario, we would choose ATC parameters from four aspects(including human, machine, environment and management), which are instruction, handover, transmission and descend. According to the views of experts like controllers, flight commanders, navigators, weatherman, we make a practical significant deviation by combining guidewords with ATC parameters, and traverse all the deviations related to flight conflict. Finally, a hazards list of the risk scanarios is obtained as shown in Table 1[4][5].

Table 1 The hazards list(Portion)

Number	Parameter	Guidewords	Deviation	Reason	The worst result
H1	Handover	None	Forget to handover	1 The pilot did not ask forwardly 2 Human error from controller 3 Communication equipment faults	Flight conflict、Collision accident
H2		Early	Handover earlier	There were too many flights in approach area.	Flight conflict
H3		Late	Handover later	Controllers ignored it because of overload	Flight conflict
T1	Transmission	None	No transmmion	1 The pilot chose the error frequency channel. 2 Communication failure crossing navigation station.	Flight conflict
T2		As Well As	Interference and noise	1 The effects from another electronic equipments. 2 Turn on/off communication button	Flight conflict
T3		Other Than	False-alarm from TCAS	Height indicator is broken	Flight conflict、Divert attention from flying

Establishment of Fault Tree

The determination of the top event plays a key role on the FTA. We would take the worst result just like flight conflict as the top event based on the hazards list as Table 1, then establish the FT according to the logic process of the interpretation[6][7]. Deviation is chosen as the intermediate event, the results as new top event and causes as new basic event, and we can acquire the fault tree in Figure 2 following the steps in the right part of Figure 1.
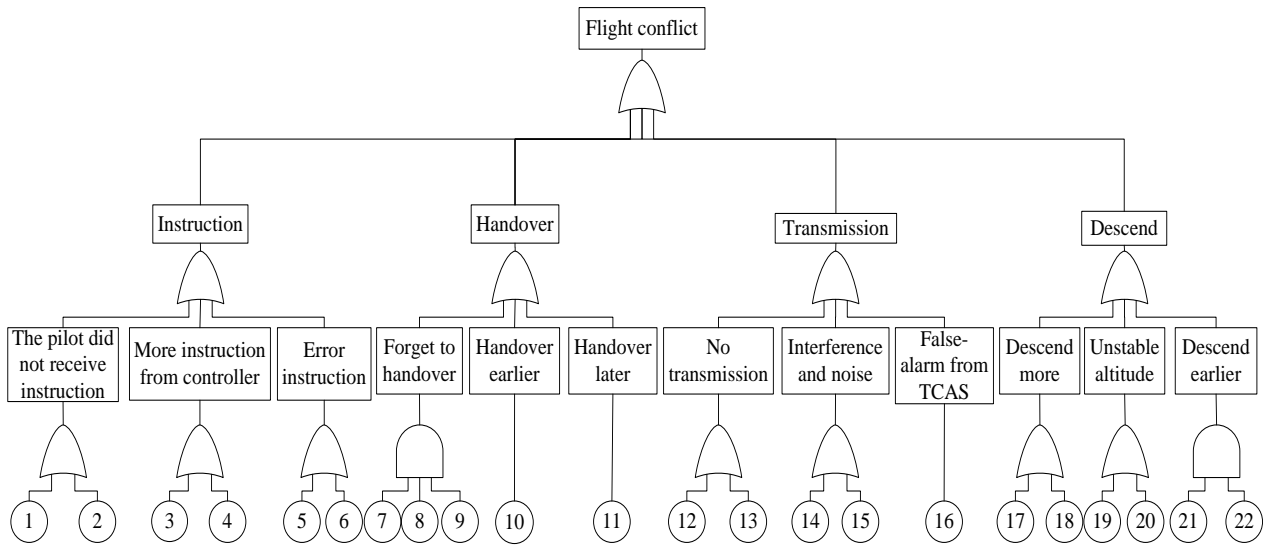
Fig. 2 Fault tree of flight conflict

The basic events of the flight conflict are shown in Table 2[8].

Table 2 Fundamental events of fault tree

Number	Basic events	Number	Basic events
1	Wireless channel is busy	12	The pilot chose the error frequency channel
2	The controller is busy doing anything else	13	Communication failure crossing navigation station
3	Expression is not clear as the controller's scarce capacity	14	The effects from another electronic equipments
4	The flight is in emergency	15	Turn on/off communication button
5	The flights has the similar callsign	16	Height indicator is broken
6	The tower controller can't divide his attention reasonably as workload	17	Measuring error
7	The pilot doesn't ask forwardly	18	Responder model C displays error altitude
8	The human error from controller	19	Upper wind、Turbulence、wind shear
9	Communication equipment faults	20	Wake flows
10	The pilot switch the transmission channel earlier	21	Operation error from pilots
11	The approach controller ignores it as workload	22	Instruction error from controllers

Fault tree Quantitative Analysis

The structure importance should be analyzed in order to determine the influence of the basic events to the top event. The calculation of that of the basic events is in type (1) [6].

$$I_\Psi(i) = \frac{1}{K} \sum_{j=1}^{m} \frac{1}{R_j} \qquad (1)$$

The K in type(1) is the number of the minimum cut sets in the fault tree, the m is the number of the minimum cut sets that contain the ith basic event. The R_j is the number of the jth minimum cut sets that contain the ith basic event.

We can get the structure importance of basic events in Table 3. The result shows that the single-events are the most important influence factors. Because their number is big, we would do more precise quantitative analysis as followed.

Table3 Structure importance of basic events   Table4 Occurrence probability of basic events

Basic event	Structure importance	Basic event	Structure importance
X_1	0.0526	X_{12}	0.0526
X_2	0.0526	X_{13}	0.0526
X_3	0.0526	X_{14}	0.0526
X_4	0.0526	X_{15}	0.0526
X_5	0.0526	X_{16}	0.0526
X_6	0.0526	X_{17}	0.0526
X_7	0.0175	X_{18}	0.0526
X_8	0.0175	X_{19}	0.0526
X_9	0.0175	X_{20}	0.0526
X_{10}	0.0526	X_{21}	0.0263
X_{11}	0.0526	X_{22}	0.0263

Basic event	Probability $/d^{-1}$	Basic event	Probability $/d^{-1}$
X_1	0.02200	X_{12}	0.02700
X_2	0.00300	X_{13}	0.00900
X_3	0.05500	X_{14}	0.00200
X_4	0.00400	X_{15}	0.00500
X_5	0.00300	X_{16}	0.01200
X_6	0.05800	X_{17}	0.00300
X_7	0.03200	X_{18}	0.01400
X_8	0.06100	X_{19}	0.02500
X_9	0.00400	X_{20}	0.01400
X_{10}	0.02500	X_{21}	0. 04700
X_{11}	0.04500	X_{22}	0.00400

According to the FT, we can get the Q which is the probability of the top event.

$$Q = 1 - \prod_{i=1}^{19}(1 - P_{Ei}) \qquad (2)$$

P_{Ei} stand for the probability of the *ith* minimum cut sets.

We can determine the probability of the basic events as Table 4 by studying the survey analysis of flight conflicts from 1994 to2014 in reference[3], and then get $I_{P(i)}$ which is the probability importance coefficient of the basic event as shown in Table 5 by solving simultaneous type(2)and type(3).

$$I_{P(i)} = \frac{\partial Q}{\partial q_i} \qquad (3)$$

Table 5 Probability importance of occurrence of basic events

Basic event	Coefficient of probability	Basic event	Coefficient of probability
X_1	$7.375379*10^{-9}$	X_{12}	$6. 197708*10^{-9}$
X_2	0.99642535	X_{13}	$1.195053*10^{-10}$
X_3	0.99599683	X_{14}	$6.917708*10^{-10}$
X_4	$8.365369*10^{-9}$	X_{15}	$4.182685*10^{-9}$
X_5	$7.967019*10^{-10}$	X_{16}	$5.967018*10^{-10}$
X_6	0.99599683	X_{17}	$7.195053*10^{-10}$
X_7	$5.975264*10^{-10}$	X_{18}	$1.195053*10^{-10}$
X_8	0.99671455	X_{19}	$7.967018*10^{-10}$
X_9	$7.060781*10^{-10}$	X_{20}	$5. 519103*10^{-10}$
X_{10}	$1.190553*10^{-10}$	X_{21}	$6. 779018*10^{-9}$
X_{11}	0.99649514	X_{22}	$5. 911053*10^{-9}$

Analyzing the results shown in Table5, we can draw the following conclusions:

(1) The probability importance of the basic events like X_2、 X_3、 X_6、 X_8、 X_{11} is much higher than others, and the influence of the change of the top event is larger. The result is consistent with the final investigation report released by NTSB(National Transportation Safety Board)in America.

(2)To avoid the similar flight conflict, we should find the safety loopholes and solve them in time, such as shortening time to reduce the controller's workload, and strengthening the pilots study of basic flight rules.

Conclusions

In this paper, the HAZOP method is introduced into the field of air traffic control. The way to apply the method to the hazard list, to find the potential security risks and to provide a reliable basis for decision makers are described at length. Problems have been solved that when boundaries of many top events are not clear, there being much overlap and duplication among FTs; that some events being missed because of subjectivity; that the vague of key points if FT is too big or too complex as a result of the ambiguity of top events. The HAZOP can be used for reference in flight conflict analysis of terminal area.

Acknowledgement

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