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Research on Risk Assessment based on Bayesian Network

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ABSTRACT

The purpose of this study is to achieve the risk assessment by using the Bayesian network. Provides a possible new method in airline risk assessment. Airline risk assessment system is an interrelated index system. The risk assessment index system is established by collecting the reliability data, maintainability data, management data and safety data from airlines. The weight of index is determined by using the analytic hierarchy process and the qualitative index are quantified by using fuzzy comprehensive evaluation. The airline risk assessment model is based on the Bayesian network. The findings of this article identify a number of useful scenarios for future airline safety risk management applications and considerations. Research limitations/implications: It is imperative to emphasize that the concept of this article solely sheds light on risk assessment of Bayesian network. Practical implications: Implications of risk assessment for airline may result in enhancing airline safety management level and reducing operating costs. Further implications could possibly be extended to various of civil aviation operations. Social implications: The risk assessment method can be applied to other complicated systems. Originality/value: The qualitative index are quantified by using fuzzy comprehensive evaluation. The airline risk assessment model based on the Bayesian Network (BN) using GeNIe software. In this way, it can take full advantages of the two methods and raise the effect of integration.

Key words: Analytic hierarchy process, fuzzy comprehensive, Bayesian network, GeNIe, risk assessment

INTRODUCTION

Civil aviation is an industry with features of high-tech, high-risk and intensive capital. Safety is an essential basis for airline survival and development. Risk assessment is one of the most significant parts of the management of airline. The effect of the assignment influences the profit of the company directly. Factors which affect the airline safety are complex and variable. It is necessary to explore a scientific and objective method to assessment the risk of airline.

Pearl (1993) proposed Bayesian network to solve the uncertainty problem. Bayesian network method is a technology that combines all kinds of evidence, expert experience and testing and operation information. It has a very strong description ability. It not only can be used for prediction but also for diagnosis. The reason why we using the Bayesian network to risk assessment field lies in that the Bayesian network has its distinct predominance: (1) Synthesize a priori information and posterior information; (2) Suitable for dealing with incomplete data sets; (3) Easy to find the causal relationships between the data; (4) High efficiency reasoning algorithm and mature software.

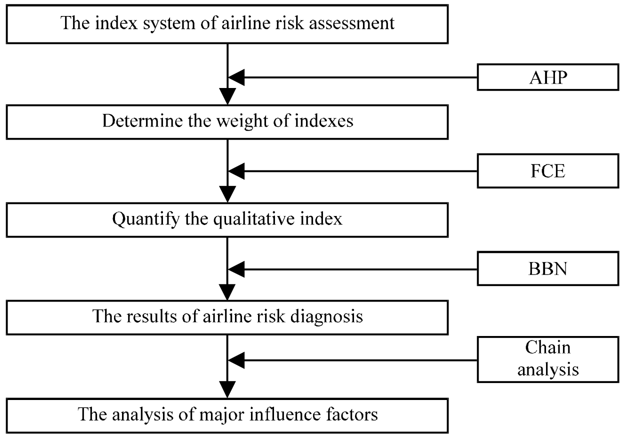

Fig. 1: Airlines risk assessment flow chart

In this study, on the basis of the theory of MMEM system, an airlines risk assessment index system is established by a research on civil aviation rules and standards. The qualitative indexes are quantified by using fuzzy comprehensive method. The risk assessment model is established by using the Bayesian networks software-GeNIe. Then complete the inference of probability calculation. Find out the factors that influence airline safety condition by comparing the decline in posterior probability of the root node. The results of this study have practical significance in improving the use of Bayesian network method in the field of airline risk assessment (Fig. 1).

INDEX SYSTEM OF AIRLINE RISK ASSESSMENT

MMEM is developed from the traditional people-machine-environment theory. The establishment of index system is on the basis of MMEM theory. By collecting the airlines reliability data, maintainability data, management data and safety data, separate the qualitative index from the quantitative index. Index system is shown in Fig. 2.

Among them, the U_1, U_2, U_3 subsystem of the index is a quantitative index, U_4 and U_5 subsystem of the index is a qualitative index.

Plane technology state (U_1): The plane technology state includes the failure rate of unit report (U_{11}), SDR (U_{12}), repeated defect (U_{13}), irregular flights thousand times rate (U_{14}) and fault keeping situation (U_{15}).

Maintenance quality (U_2): Maintenance quality includes general maintenance mistake (U_{21}), serious maintenance mistake (U_{22}), incident million rate (U_{23}) and maintenance fault report rate (U_{24}).

Environmental effect (U_3): Environmental effect includes working site (U_{31}), operating time (U_{32}), materials management (U_{33}), weather effect (U_{34}), utilization efficiency of days (U_{35}). Taking aircraft AOG, namely the non-planned repair parking rates measured in air materials management to affect the quality of locomotive repair.

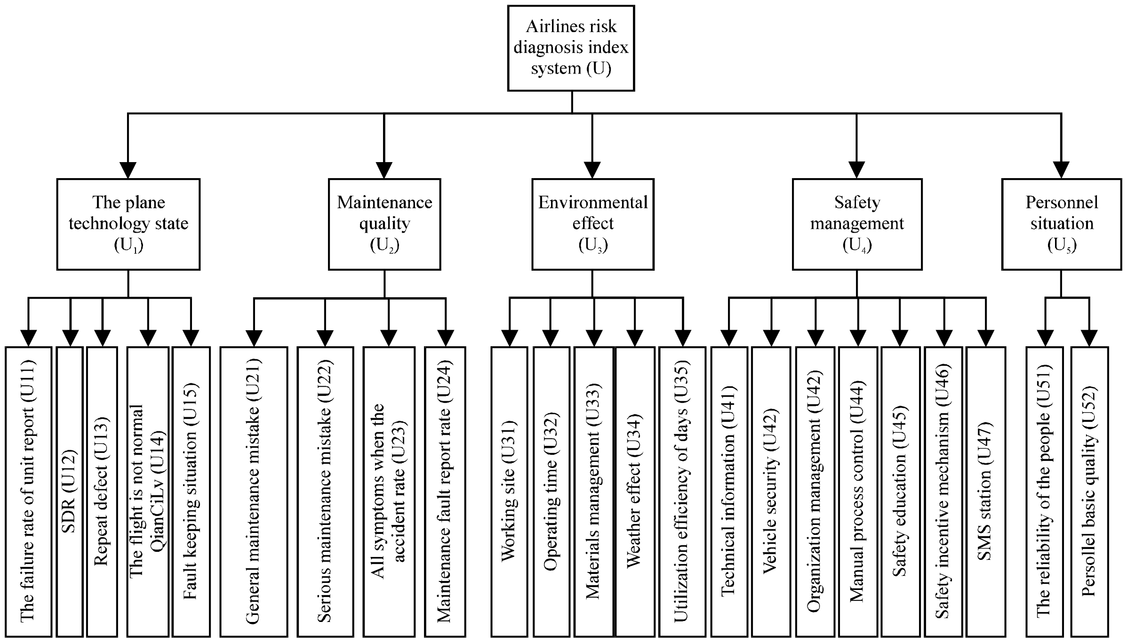

Fig. 2: Airlines risk assessment index system

Safety management (U_4): Safety management includes technical information (U)$_{41}$ vehicle security (U_{42}), organizational management (U_{43}), manual process control (U_{44}), safety education (U_{45}), safety incentive mechanism (U_{46}) and SMS situation (U_{47}).

Personnel situation (U_5): Personnel situation including the reliability of the people (U_{51}) and personnel basic quality (U_{52}).

APPLICATION OF FCE METHOD TO QUANTIFY THE QUALITATIVE INDEXES

On U_4 and U_5 subsystem are qualitative indexes, using the fuzzy comprehensive assessment method for the quantitative. Fuzzy comprehensive assessment method is a method which is based on fuzzy comprehensive assessment method. It has clear and systematic characteristic which can be used to solve the fuzzy and difficult problem of quantifying. Fuzzy comprehensive assessment method consists of three elements: The factor set, the assessment set and single factor evaluation. The main computing steps are as follows:

Step 1: Establishment of factor set and weight set: Factor set, according to Fig. 2, gets weight by AHP. Analytic hierarchy process (Analytic Hierarchy Process, AHP for short) is to put the data, expert opinion and analysis judgement method combined. It can not only ensure the system model and the rationality but also make full use of expert experience. Using AHP to compute the weights associated with the steps detailed in the literature (Doguc and Ramirez-Marquez, 2009)

Step 2: Establish evaluation set: In this study, to determine the evaluation level, the evaluation level set V defined as four grade:

$$V = \{v_1, v_2, v_3, v_4\} = \{\text{Excellent, Normal, Medium, Bad}\}$$

The comparison table of evaluation result and grade is shown in Table 1.

Table 1: Comparison table of evaluation result and grade

Estimation grade	Estimation result	Median
Excellent	$100\geq u_i\geq 90$	95
Normal	$90\geq u_i\geq 75$	82
Medium	$75\geq u_i\geq 60$	67
Bad	$60\geq u_i\geq 0$	30

Step 3: **The determination of membership:** After determining the sets of factors, the weight and the evaluation, the evaluation results of single factors are used to determine the membership of the evaluation. The article adopts the peer review statistics that is, it should look for experts (general requirement has 20) who are familiar with all levels index and the indexes are implied of single factor evaluation and the normalized processing in the form of questionnaire survey

Step 4: The fuzzy comprehensive evaluation set and step 5 calculation of anti-blurring process reference literature (Doguc and Ramirez-Marquez, 2009)

RISK ASSESSMENT MODEL BASED ON BAYESIAN NETWORK

The use of BN assessment of risk priority is to build a Bayesian network model firstly. The main task of the Bayesian network modelling Khakzad *et al*. (2011) is to determine the topology of the network and the conditional probability distribution for each node in the network. Model topology is based on the index system manually, then divided the grade of the security situation on the impact of various factors based on expert's opinions and finally combined with research which is collected by airlines operating data by parameter learning method to obtain the conditional probability table of each node.

Bayesian network topology model: Based on the analysis of airline risk assessment index system shown in Fig. 2, the relationship between the layers of the index to its upper index is the exchange relationship in the Bayesian network of local connections, this exchange expresses by the parent node point to the child node has directed edges to represent an index from the two indicators point to the corresponding final convergence to a total target of U. As it is analysis above, build an ssessment model of airline risk Bayesian network topology shown in Fig. 3 (the cross-sectional self-GeNIe interface).

Conditional probability table: Select the data obtained from the airline in January 2009-December 2010 as training samples. Taking into the situation of the lack of data collected from the airlines and the non-correspond time, this article uses the EM algorithm Jiye *et al*. (2009) to patch missing value of the sample and then uses GeNIe software to provide parameters learning function to obtain the conditional probability table for each node. Determine the root node of the conditional probability is obtained by statistics airlines collect sample data in the corresponding state of the incident frequency.

At the same time, calculate the alert value and get the corresponding interval division of what the each root node level belongs to. Alert value is used to measure the reliability indicators whether the indexes are overrun limit, determined by historical data. In this article, the standard deviation is used to calculate the alert value.

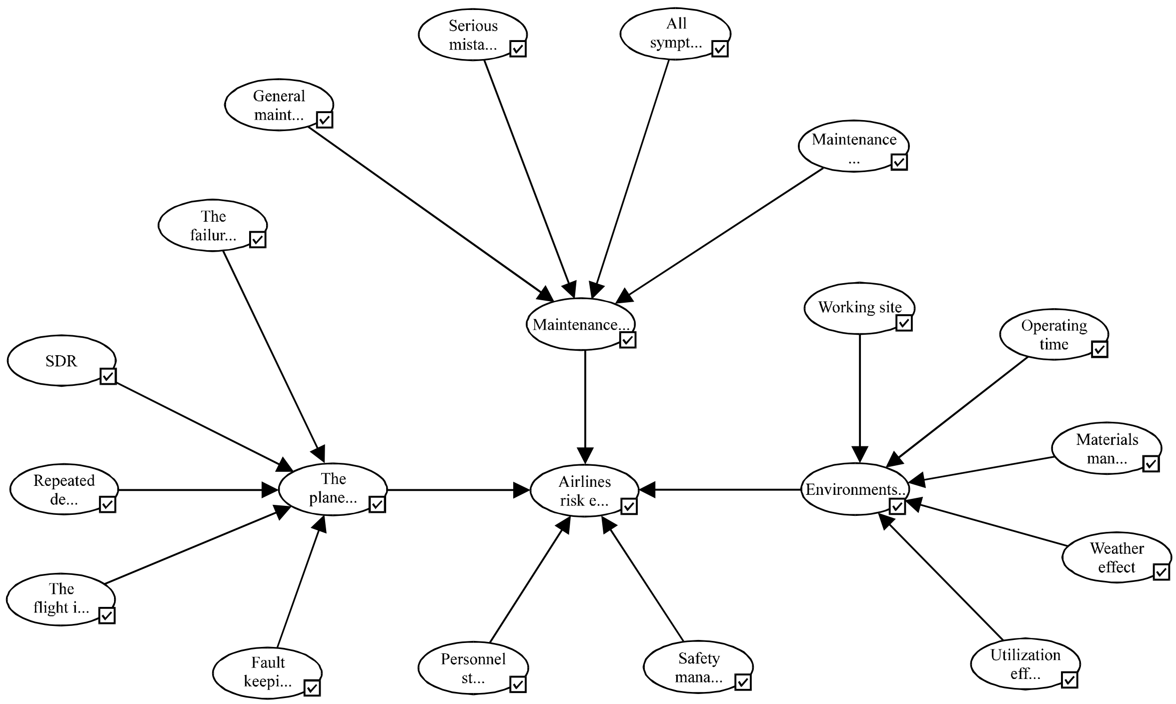

Fig. 3: Bayesian network topology structure of airline risk assessment model

Standard deviation equation:

$$\sigma = \sqrt{\frac{\sum X^2 - \frac{(\sum X)^2}{N}}{N-1}} \tag{1}$$

X = Index month ratio
N = The number of months

Alert value calculation equation:

$$UCL = \overline{X} + K\sigma \tag{2}$$

In which:

$$\overline{X} = \sum X/N \tag{3}$$

The value of K set by the reliability engineer, with the airline experts discussion, this article, when $X \le \overline{X} + \sigma$ (K = 1), Situation for good, when $\overline{X} + \sigma < X \le \overline{X} + 1.5\sigma$ (K = 1.5), Situation for medium, when $X > \overline{X} + 1.5\sigma$, Situation for bad. (As space is limited, the detailed about each node classification is described in Annex 1).

CASE STUDY

Based on the FCE method of qualitative index quantification.

Data acquisition: Organize a total of 20 airline maintenance staff and experts in the form of a questionnaire on indicators of the safety management subsystem (U4) single factor evaluation and the frequency of the number of normalized (i.e., part of the four levels)assume that the security management subsystem membership matrix as follows:

$$\tilde{R}_{U_4} = \begin{bmatrix} 0.25 & 0.5 & 0.15 & 0.1 \\ 0.3 & 0.45 & 0.2 & 0.05 \\ 0.15 & 0.4 & 0.25 & 0.2 \\ 0.1 & 0.3 & 0.4 & 0.2 \\ 0.05 & 0.2 & 0.65 & 0.1 \\ 0.15 & 0.45 & 0.3 & 0.1 \\ 0.25 & 0.4 & 0.35 & 0 \end{bmatrix} \quad (4)$$

Security management subsystem weights obtained by AHP set as follows:

$$\tilde{A}_{U_4} = [0.0325 \quad 0.0203 \quad 0.4100 \quad 0.2560 \quad 0.1473 \quad 0.0836 \quad 0.0503] \quad (5)$$

Determine the evaluation level: Use MATLAB matrix operations to obtain the fuzzy comprehensive evaluation set shown as follows:

$$\tilde{B}_{U_4} = \tilde{A}_{U_4}\tilde{R}_{U_4} = [0.1338 \quad 0.3534 \quad 0.3523 \quad 0.1606] \quad (6)$$

Anti-fuzzy center of gravity method:

$$M = \frac{\sum_{i=1}^{n} b(u_i)\times u_i}{\sum_{i=1}^{n} b(u_i)} = \frac{0.1338\times 95 + 0.3534\times 82 + 0.3523\times 67 + 0.1606\times 30}{0.1338 + 0.3534 + 0.3523 + 0.1606} = 70.10 \quad (7)$$

In contrast to the Table 1, in this evaluation, the airline safety management system for medium evaluation grades.

Based on BN airlines risk assessment model: For safety management and personnel condition node, these two subsystem use fuzzy comprehensive evaluation method to get the excellent scale, normal scale, medium scale and bad scale. Their prior probability is obtained by the frequency in January 2009 to December 2010. The completed Bayesian network structure and the structure of each node of conditional probability in the establishment of the table as shown in Fig. 4 shows the GeNIe such cut interface).

Airline risk assessment based on BBN: For the subsystem of U4 and U5, their prior probability are determinated by analytic hierarchy process which is using FCE methods to get excellent, normal, medium, bad opinion rating. Finally, the finished Bayesian network comprehensive evaluation model and the contingent probability of its node are shown in the Fig. 4 (the figure cut from the GeNIe interface).

Then, evaluate the risk profile of the airline in January 2011 on the basis of this assessment model. Update the marginal probability of the root node. The result is shown in Fig. 5.

At this time, airline risk assessment node (U) of good probability is 75% as before. Aircraft technology condition (U1) of good probability decreased from 41-39%. Maintenance quality of good probability increased from 39-41%. Environment influence of Good probability decreased from 77-75%. The condition of the probability of the safety management and the personnel situation remained the same. We can get the airline risk state in February to September 2011 by the same method.

Determinate the major influence factors by link-relative analysis: Firstly, do chain analysis of the good probability of the airline risk assessment node (U) January to September 2011, shown in Fig. 6. The good probability of U node reached a high point on February and then decreased steadily. It is obvious to see that the overall trend of airline risk assessment is increasing.

Secondly, analysis the chain ratio of each sub systems and the situation changes is shown as Fig. 7.

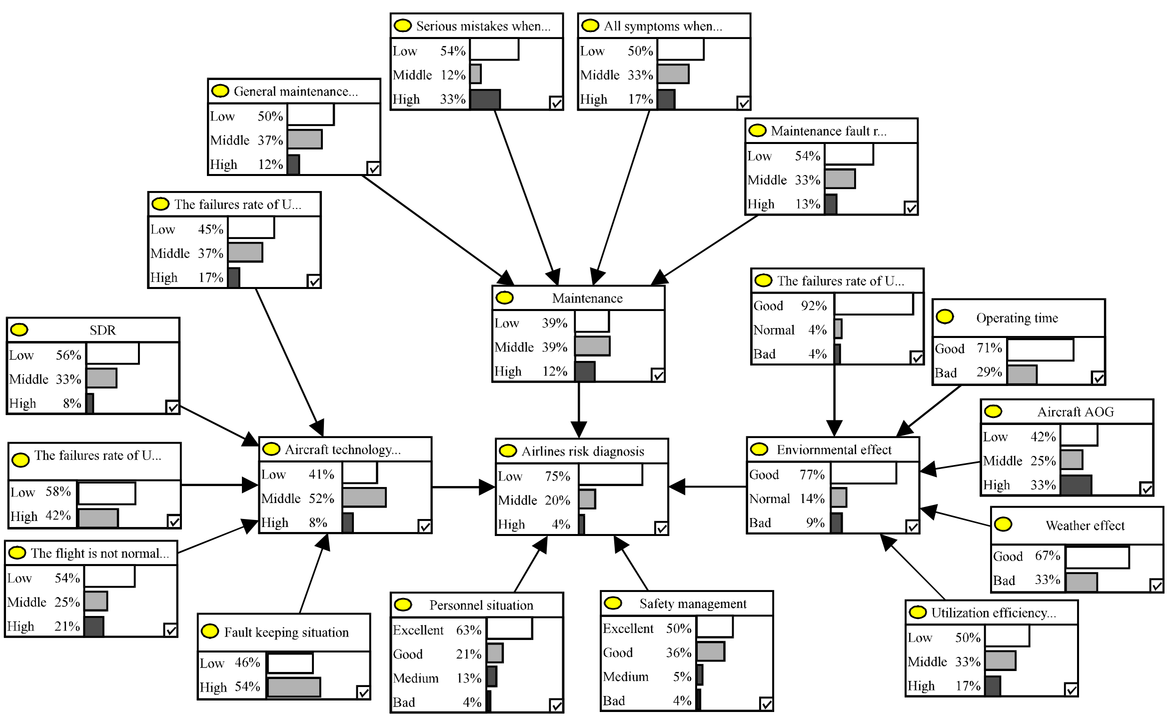

Fig. 4: Airline risk assessment model

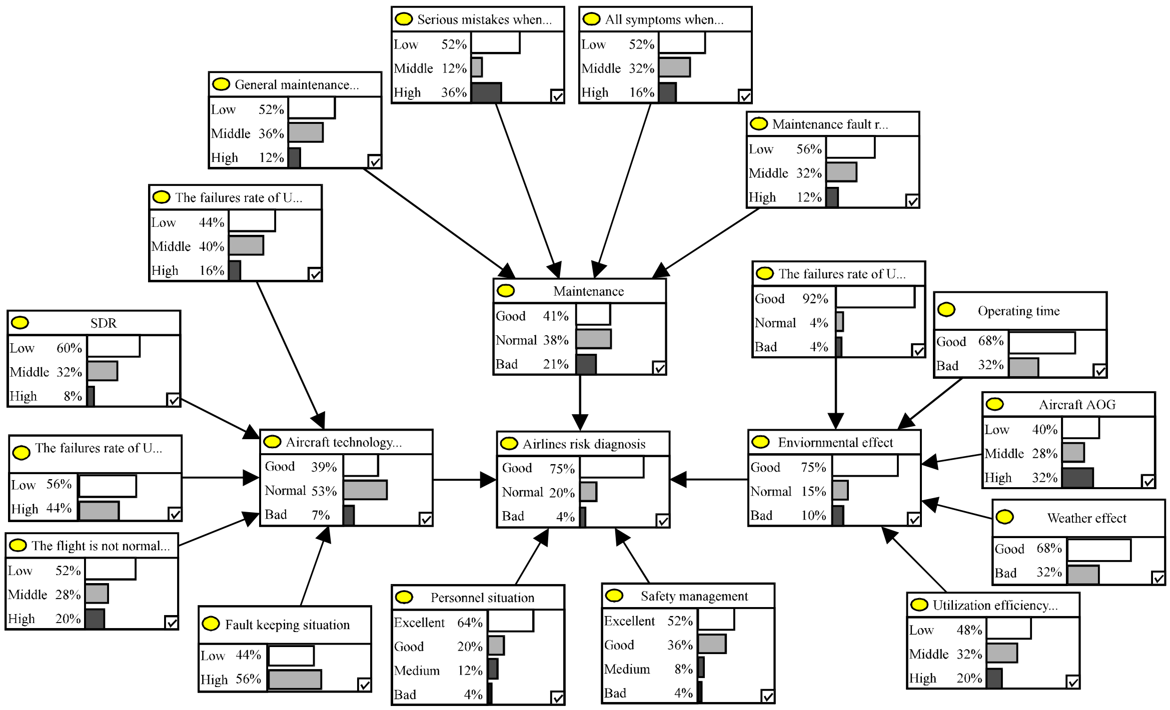

Fig. 5: Airlines risk probability in January 2011

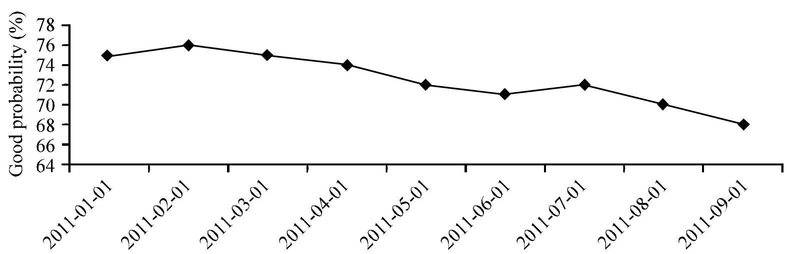

Fig. 6: Chain analysis

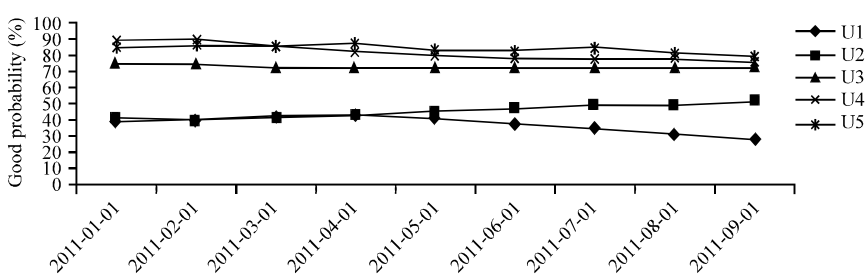

Fig. 7: Subsystem chain analysis diagram

From Fig. 7, the situation of U2, U3, U4 and U5 subsystems remained the same. However, there is a decline trend of the good probability of U1 sub system from May 2011, seeing that the upward trend of the risk is due to the aircraft technology. Finally, considering of the relevant data of the aircraft technology, obtained on the basis of each node level division on comparison (according to Annex 1), as shown in Table 2.

Table 2: 2011 May-September aircraft technology state data table

Time	U_{11}	U_{12}	U_{13}	U_{14}	U_{15}
2011.5	0.37 (H)	44 (M)	77 (H)	3.34 (L)	481 (H)
2011.6	0.53 (H)	48 (H)	91 (H)	4.70 (M)	452 (H)
2011.7	0.50 (H)	55 (H)	103 (H)	4.38 (M)	494 (H)
2011.8	0.70 (H)	49 (H)	64 (H)	4.23 (M)	489 (H)
2011.9	0.56 (H)	51 (H)	42 (H)	4.51 (M)	402 (H)

H: High, M: Middle and L: Low

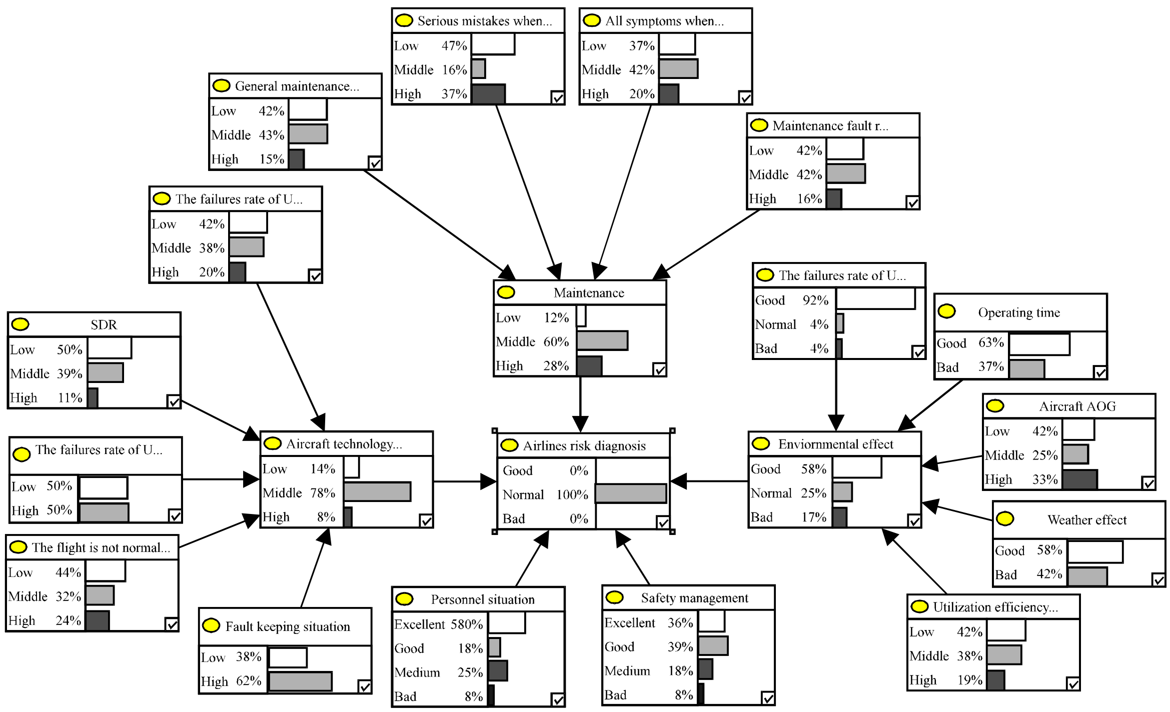

Fig. 8: Results figure

According to the Table 2, H: High, M: Middle, L: Low. It is obviously to see that the upward trend of the airline is due to the high side of the failure rate of unit report, SDR, repeated defect and fault keeping situation. The results of the assessment reflect the disorderly conduct of the servicemen about the work link like post flight check, daily maintenance, the plane release. Airline needs to do production safety inspection for the maintenance department and correct irregularities in time.

Risk diagnosis: Kept in airline maintenance quality risk is normal for example, diagnosis the formation of risk. As shown in Fig. 8 (the figure cut from the GeNIe interface) is shown, input all the evidence, then update the entire network and find the root node state of good posterior probability generally decreased. The index has dropped more than 10% personnel, safety management, accident symptom million rate, maintenance report failure rate and irregular flights a thousand times rate. Their decline as shown in Table 3.

In the case of the lack of other evidence, it can regard as the five factors caused the airline increased risk. In order to find the reasons, when the U14, U23 and U5 are known in this month,

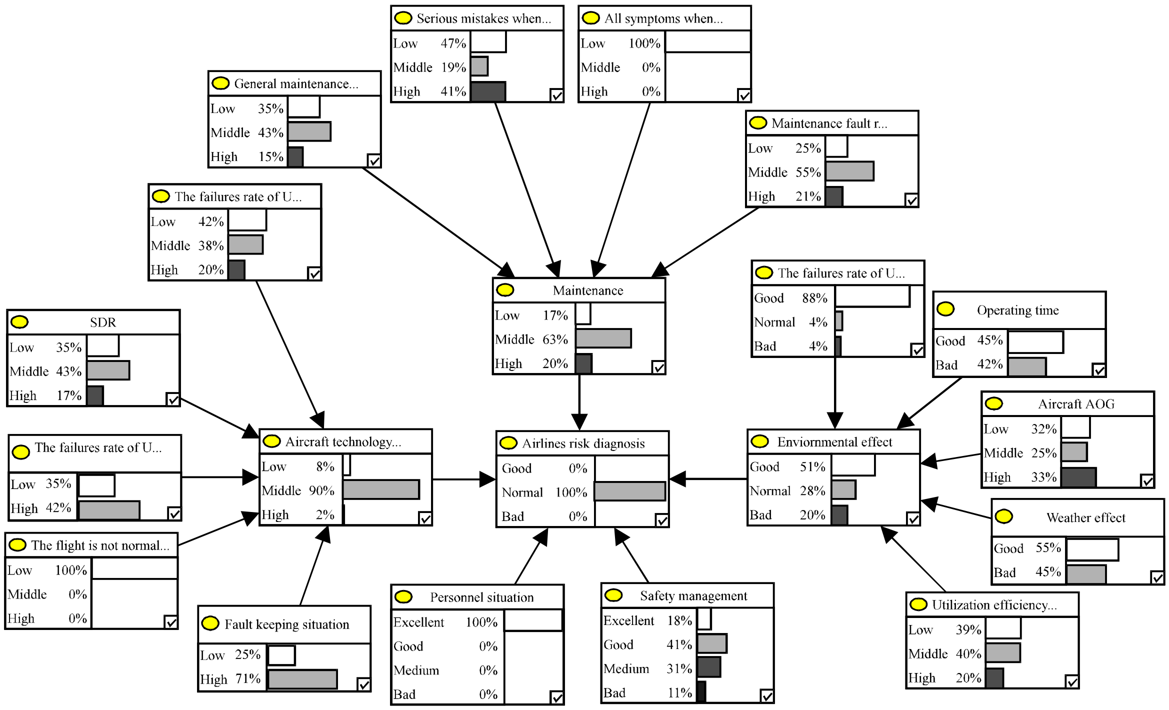

Fig. 9: Rate of the posterior probability

Table 3: Probability table

Index	U14 (%)	U23 (%)	U24 (%)	U4 (%)	U5 (%)
Prior probability	54	50	54	88	84
Posterior probability	44	38	42	75	68

these situation is good. Then set the U14 and U23 rate to 100% for Low state, set U5 to 100% for Excellent state, after the update computation results as shown in Fig. 9 (the figure cut from the GeNIe interface).

At this time, the locomotive report failure rate of Low probability from 42 to 25%, the safety management for excellent and good probability and from 75 to 59%, we can further determine the reasons for the decline is due to the maintenance report failure rate and safety management.

CONCLUSION

This study established a comprehensive index system based on the airline risk assessment. Use AHP to determine the weights and fuzzy comprehensive to evaluate qualitative indexes. Get the probability value of the risk factor by the Bayesian network. By comparing the change of the probability, determine the main factors influencing the risk. The outcomes of this study are important for developing operable theory and methods of airline safety risk management.

Application examples show that this study makes the safety and quality management more specifically and standardization of the airlines maintenance, promote the improvement of the airline's aircraft maintenance and safety management level. The risk assessment method can also be applied to other complicated systems.

FURTHER WORK

More data need to be collected to refine the estimates. Design and implementation of airline engineering maintenance safety evaluation system, use Netica-J API software JAVA class library completed comprehensive assessment based on Bayesian networks.

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NOMENCLATURE

BN = Bayesian network
AHP = Analytic Hierarchy Process
FCE = Fuzzy comprehensive Evaluation
MMEM = Man Machine Environment Management
SDR = Service Difficulty Reports
SMS = Safety Management System
AOG = Aircraft On Ground

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