THE EMPLOYMENT OF ARTIFICIAL INTELLIGENCE FOR ANALYZING AIR ACCIDENTS

F. M. Zhang and E. Z. Su
Management Engineering Department
Air Force College of Engineering
Xi'an, China

Abstract

In this paper, the possibility and necessity of developing the computer-aided system for analyzing aviation accident causes with the expert system (ES) in the artificial intelligence (AI) are discussed firstly. The paper also presents the design thought and its structure of the aviation accident analysis-expert system (3A-ES) recently developed by the author. Then, the bidirectional knowledge representation (BKR) method in the domain of aviation accident analysis, the model of interactive automatic knowledge acquisition, and control strategies and reasoning mechanism in the process of accident analysis are intensively discussed.

I. Introduction

With the development of aviation science and technology, the components and structure of an aircraft become more and more complex. This, in addition with the management and human factors, makes it hard to ensure the reliability and safety in the process of aircraft operations. Aviation accident often happens because of component failures or improper maintenance, operation or command and so on, which results in the enormous economic loses and social effect. After the accident takes place, the true causes and the person responsible should be found out so that preventive measures and technical improvements can be taken to prevent it from happening again. However, the variety of accident factors makes it very difficult to analyze the accident.

The analyzing of an accident depends, to some degree, on the knowledge and experience of the investigators. The Chinese goverment and its flight safety management department, while applying various kinds of technical means to get the accident causation, pay much attention to the role of accident analysis expert. An expert should have not only rich theoretical knowledge, but also wealthy experience on accident analysis which is gradually accumulated throughout his life. But it is not quite easy to train such an expert. It will take quite a long time and he has to be well-experienced in practical accident analysis. Furthermore, an expert will retire up to a certain age. Once he retires, the knowledge and experience which he owns will go away with him. Therefore, a kind of technology is urgently needed to solve this problem. The AI, one of the three great scientific and technological achievements in this century, especially its ES, is very suitable to aid analyzing the aviation accidents.

The ES is a computer program system that can pose and answer questions relating to information borrowed from human expert and stored in the system's knowledge base (KB), which can simulate expert's mode of thinking to solve the real problems which can be often dealt with by an expert based on lots of specialistic knowledge and experience of this domain. Since it is invented, many achievements have been achieved in ES theory and technology. Combining with multitudinous applied domains, many practical ESes have been developed. Whether a domain is suitable for developing an ES depends on: an expert who can be cooperated with; a problem which can not be solved by traditional method of program design; a domain knowledge which can be represented in a language. The aviation accident analysis is such an applied domain which is very suitable to develop an ES.

The purposes of developing this system are (1) to aid an accident investigator to find out the causes in order to take some relevant measures to prevent the similar accidents from happening again and instruct the design of an aircraft so that the safety of an aircraft can be maintained; (2) to raise the accuracy and automation of accident analyzing; and (3) to inherit the rich knowledge of an accident analysis expert in order to help to undertake more and more complicated accident investigation, and also to train the younger accident analysers.

Ⅱ. Overall Structure of 3A-ES

The 3A-ES software system is developed by the ES technology of AI. It gives a computer the rich knowledge in aviation accident domain and wealthy experience of a domain expert. The computer will infer with them to judge the real causes of an aviation accident. Its working principle can be shown by Fig. 1. In this figure, we can see that, to finish such a work, the system should possess two abilities: how to formalize the domain knowledge and put it into the computer; how to analyze an accident based on such knowledge. That is to say, the system must consist of a knowledge base (KB) and a reasoning machine (RM).

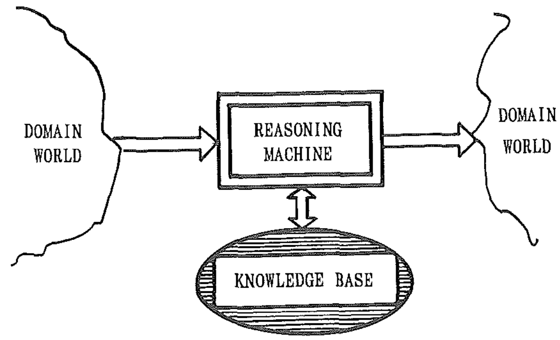

Figure 1. Basic Structure of Expert System

2.1 The Components and Structure of the System

The 3A-ES is an applied system which includes global database, knowledge acquisition, man-machine interface, interpretation and other functional modules, besides the KB and the RM. Its structure is shown as Fig. 2.

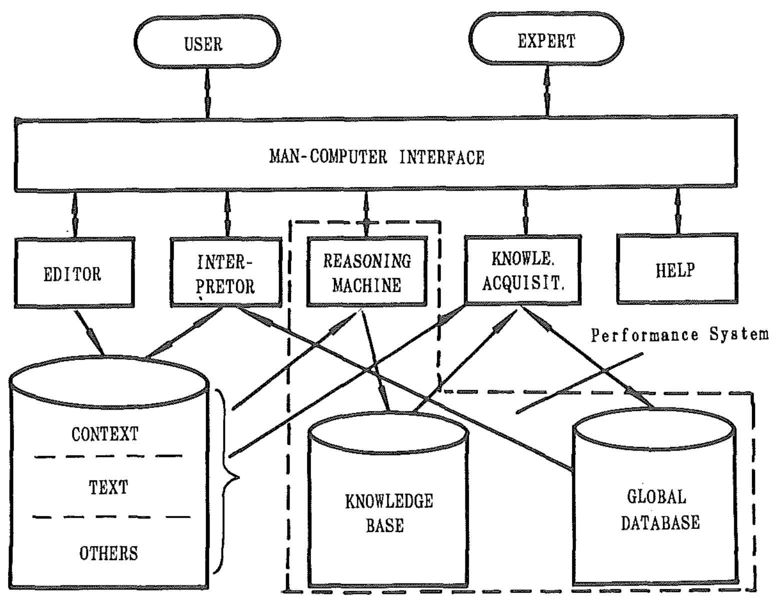

Figure 2. The Structure of the 3A-ES

Knowledge Base: a storage to store the knowledge which is wanted in aviation accident analyzing. The special knowledge in the KB could be obtained from the domain of avivtion accident analysis, and is mainly represented by the form of production rule (PR).

Reasoning Machine: in charge of analyzing the causes of aviation accidents with the knowledge in KB. It is mainly in charge of selection and execution of rules.

Global Database: to store the input information and the immediately-produced intermediate information needed in the operation of this system, including the description of accidents, records of analyzing accidents, intermediate results after inference, and som other information.

Knowledge Acquisition (KA): in charge of formalization of knowledge in the domain of accident analysis in natural state, i.e., to transform it from external form into internal form which can be processed directly by a computer. This system employs the combination method of learning from typical example and domain experts.

Man-Machine Interface: an interface of man-machine conversation to realize the interactional communication each other. It employs the window technology to talk with each other in Chinese.

Interpretation Program: in charge of understanding and answering various questions asked in Chinese by the user. It is an important component to enhance transparency of this system.

Besides those above, in order to manipulate and maintain the system, other functional modules are also built up, such as the text editor and HELP.

In Fig. 2, the system within the frame of the dotted lines is called as performance system. It is composed of the global database, knowledge base and reasoning machine which are closely related to the analyzing of aviation accidents causes. The components out of the frame of the dotted lines are the environment in which performance system exists and develops, and can indirectly assist analyzing the accidents.

2.2 Working Principle

Two kinds of works are mainly carried out by 3A-ES: to obtain knowledge from the domain of accident analysis, and to take out the necessary knowledge in the KB to analyze the accidents which really happen. The following is a brief introduction of its working principle.

This thesis employs interactive auto-knowledge acquisition to obtain a lot of domain knowledge. Its principle is, at first, to describe aviation accident causes in accident reports or in the expert's mind, with the external form of KR; and then, to store the aviation accident causes into the text base as texts. According to steps such as text conceptualization, description of relationship between facts, rule generation and rule refinement, the system acquirs PRs from texts for analyzing accidents and stores them in KB. It is shown as Fig. 3.

The accident investigator inputs the accident information which has been known by the terminal, and transforms the information into the internal form by means of interpretational program (discussed later), and stores it in the global database. Basing on the control strategies of the system, the Reasoning Machine selects from knowledge base the rules which can be applied to the present problems, and executes the rules, including the match of premise, inaccurate computing and so on. Such a process will be repeated till a conclusion is obtained or a failure is told. In accident analysis, man and computer work interactively. An organic man-computer co-existence system is formed for analyzing the accident causes altogather.

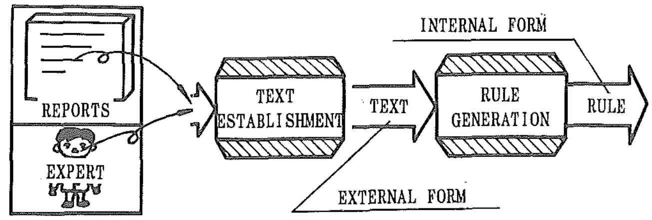

Figure 3. Knowledge Acquisition

Ⅲ. Establishing Knowledge Base

The KR and KA are the two main problems in establishing KB in the domain of aviation accident analysis.

3.1 Knowledge Representation

The knowledge in the domain is usually described in natural language which is not suitable to be processed by the computer. Therefore, it is needed to use a proper data structure to represent the domain knowledge which is described by natural language. In order to help the computer automatically accomplish the formalized transfermation of knowledge, a kind of knowledge representation approach is presented, i.e., BKR, facing both to the domain expert and the system itself.

3.1.1 Domain-Oriented Knowledge Representation

By domain-oriented is meant a certain data structure fit for describing natural language. It consists of the contexts and the texts.

By context is meant a huge process applied by the domain expert in the accident investigation describe the types of the prospective investigations. Its BNF is:

context ::= <statement>/<phrase>

```
statement≡::(<verb><object>)
```

such as, 'to investigate the accident site', 'to investigate the witness', 'to investigate the aircraft track' and so on, all of which are contexts talked about in this system.

Text refers to the system's abstract description of the typical accident causes, based on the basic knowledge on accident domain. Its establishment is due to the instruction of the domain expert and the natural language conversation. It is a set consisting of a series of facts and the relatonships between the facts. It is represented as

```
text≡:: ( < fact><relation><fact>) ♀
fact≡:: (<object><attrib.><value>)
relation≡::<AND relation>|<OR relation>|
                <CAUSALITY relation>
AND relation≡::<AND>|<&>
OR relation≡::<OR>|</>
CAUSALITY relation≡::<IF [premise]
                   THEN <[conclusion]>|
              <[premise]-->[conclusion]>
premise≡::<condition>|<condition1 AND
                 ... AND conditionN>
conclusion≡::<object><attrib.><value>
condition≡::<object><attrib.><value>
object≡::<event>|<conception>|
                <process>|<thing>|...
attrib.≡::<switch attrib.>|
             <physical attrib.>|
   degree attrib.>|<dispersed attrib.>
value≡::<symbol>|
        <numeric character><digit>|...
```

3.1.2 System-Oriented Knowledge Representation

By system-oriented is meant a data structure fit for processing in computer. It has mainly two forms--node tree and production rules.

A node is the conclusion described by the causality relationship in texts. A node tree is a tree which represents the internal relationship between nodes. A node tree can be used to describe accident chain, i. e., logical relationship between the causes of accidents. Fig.4 is a part of a node tree of engine stopcocking accidents.

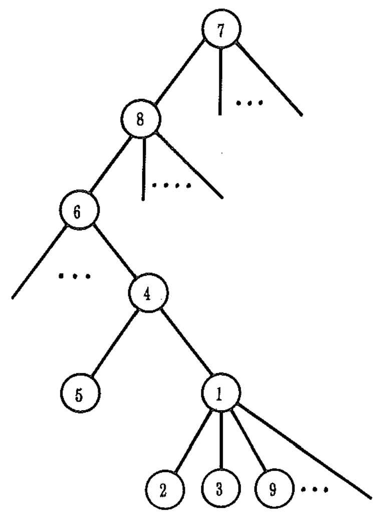

Figure 4. A Part of a Node Tree of Engine Stopcocking Accidents.

In the tree, each node represents:

Node Number	Object	Attrib.	value
1	engine	poor stopcocking	true
2	compressor's ninth-plate	crack	true
3	servo piston	position	right
4	engine	engine statement at collision landing	small speed
5	engine	rich stopcocking	true
6	power equipment of aircraft	work statement	failure
7	aircraft	yes/no accident	yes
8	aircraft	accident cause	mechnical fault
9	load-bearing cirlce	crack	true

TABLE 1 NODES' OBJECT-ATTRIB.-VALUE

A node tree is built up by the system, with the instruction of the domain expert, mainly for the purpose of rule generation.

The production rule of this system takes its BNF as

production knowledge≡:: (<production rule>) ♀
production rule≡:: (<rule number>
<IF [primise] THEN [conclusion]>
<certainty of rule>)
rule number≡::<natural number>
premise≡::<condition>|<condition 1
AND ... AND condition N>
conclusion≡:: (<object><attr.><value>)
condition≡::<object><attr.><value>
object≡::<event>|<conception>|
<process>|<thing>|...
attr.≡::<switch attr.>|<physical attr.>|
<degree attr.>|<dispersed attr.>
value≡::<symbol>|<numeric character>
<digit>|...

In 3A-ES, all knowledge is represented as the rule form mentioned above.

3.2 Knowledge Acquisition

The specialized knowledge acquisition is a subsystem of the 3A-ES system. It is built up as shown in Fig. 5. Its establishment consists of the two stages as text establishment and rule generation.

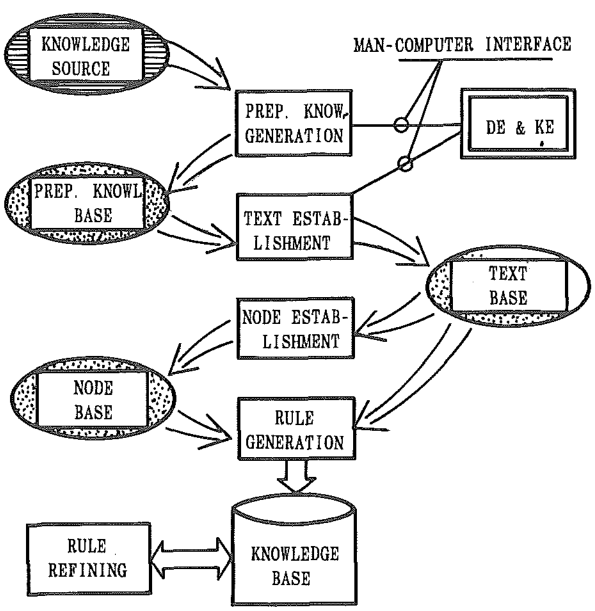

Figure 5 Knowledge Acquisition Flow Giagram

3.2.1 TextEstablishment

Text is a set consisting of a series of facts and the relationships between facts. To build up a text of an accident record, the descriptions of the facts which are stated about in the record and of the relationship between the facts should be contained. After the above processes, an abstract structure is obtained, and stored in the form of the text.

1. Fact Description

The facts in texts can be obtained through illustrating the different contexts in the typical accident record. When a typical accident record is described, a context to be talked about is drawn from the context list, and then is illustrated. That is, the value of each attr. of all the objects in this context should be made clear. When all the contexts are illustrated, all the facts in the typical accident record will be generated. The deep-first searching technology is used in illustrating context. (Fig. 6).

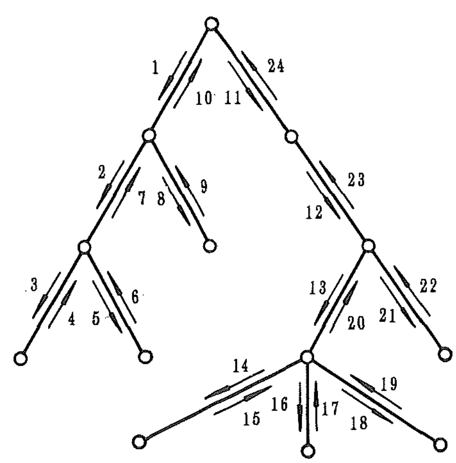

Figure 6. Deep-First Searching

2. Fact Relationship Description

It is believed by the modern accident experts that few accidents are caused by only one cause. Generally, they are caused by an accident chain composed of a series of events. When any event in the chain takes place, it will lead to an accident. Each fact in the accident chain is an accident cause. But among all the causes there is one or more main causes (or basic causes), and also one or more relational causes (or accident factors). All the main causes and relational causes must be found out so that in the accident investigating record the relationship between the accident conclusion and the various causes can be made very clear. And it is very easy for the domain expert to describe the three relationships--AND relationship, OR relationship and CAUSALITY relationship, by means of the node tree set up in accordance with the accident chain. In describing the relationships, the domain expert plays a major role, whereas knowledge acquisition a minor one. For example, the acquisition process of the CAUSALITY relationship is shown as follows

3. Conclusion Acquisition

From all the facts in a text, all the final conclusions of this accident are chosen. Suppose a domain expert chooses N final conclusion, then each conclusion is represented by Ci (i=1, 2, . . . , N).

From all the facts contained in the context relating to Ci, an intermediate conclusion which causes Ci is selected till there is no final conclusion.

Take the intermediate conclusion as a final conclusion, and repeat the above processes till all the causes of the accidents are found out.

4. Premise Acquisition

Find out all the contexts (set A) relating to conclusion Ci;
Get all the facts (set B) in each context in set A.
Select from B all the facts which form a causality with C , and take them as premises (set D) of conclusion Ci. The domain expert will further make it clear whether it is AND relation or OR relation.

5. Causality Certainty Degree

Basing on his own experience, the domain expert gives certainty degree P of the causality relationship, the scale of which is:

P ∈ {absolute possible, very possible, possible, not possible}.

3.2.2 Rule Generation

The terminal purpose of knowledge acquisition is to produce a node tree as complete as possible, with rules useful for each node correspondingly. The flow diagram of rule generation is shown as in Fig. 7.

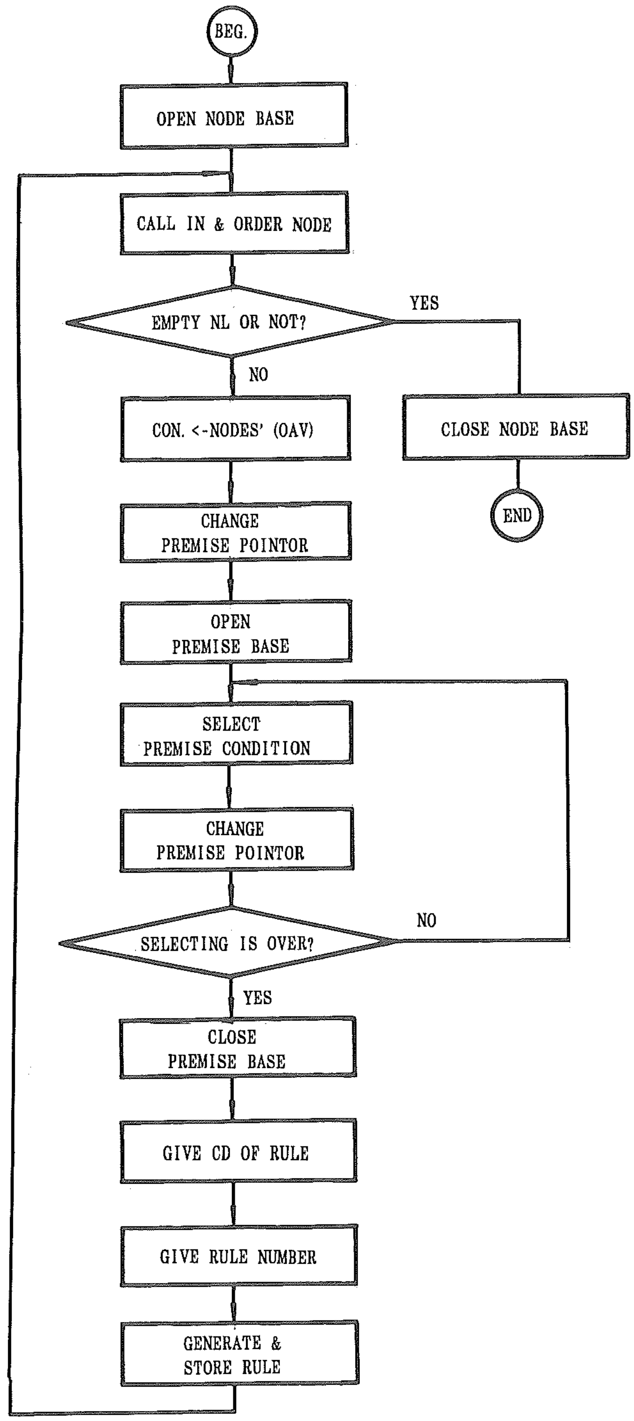

Figure 7. The Flow Diagram of Rule Generation

As to the method for establishing node tree, consult reference [15] [16].

3.3 3A-ES Bases

Generally there are mainly 6 bases in 3A-ES, the relationships of which are shown as in the following TABLE 2:

Preparing KB	context base object base natural language pattern base	set up by a knowledge engineer for building up the text base and the node base
	text base	built up mainly by the domain expert for rule generation.
perfomance KB	node base rule base	automatically-built up by the KA for accidents analyzing.

TABLE 2 3A-ES'S BASES

Ⅳ. Reasoning Machine of 3A-ES

The reasoning algorithm of 3A-ES is composed of two models as control strategies and inaccurate inference.

4.1 Algorithm of Contrōl Strategies

In -3A-ES, the control strategies of forward-first and backward-second presented by the author are used. Its algorithm is:

1) Open the node base , and take out the top node from the node base in accordance with the relationships described by the node tree, and then store it in OPEN list.

2) Illustrate the first node N in OPEN list, and show it in 'Node Window', and then delete it from OPEN list.

3) Call rule set(S) in relation to node N in memory.

.Take out all the facts contained in rule set S(fact in O-A-V form)

.Open 'Natural Language Pattern Base', to execute the natural language generation program, and generate the natural language form of rules

.Show rule set S rules in 'Reasoning Window' by page

4) Match the premise (represented by P) of all the rules in rule set S with all the facts in the global database.

.Turn to (5) if there is no relevant fact to this condition in the global database

Match if there is a relevant fact to this condition in the global database, and carry on matching until this condition from P is deleted

.Go on executing the above- mentioned process till there is matching premise in P. and then return to (6)

5) Seek for the relevant facts to this condition from user.

.Show the possible value of this condition in 'Selection Window' to let the user select answers.

.Give up the selection and answer 'UNKNOWN' if the user is not clear about it.

.Return to (4).

6) Rule Execution

.Order the matching degrees of rule premises and execute the rules one by one till the certainty degree of rule conclusion is obtained:

Answer the handling of 'UNKNOWN' defaultly.

Calculate out the certainty degree of the premise.

Calculate out the certainty degree of the conclusion.

Put the conclusions in the order of the certainty degrees from the big to the small. If the certainty of the conclusion is above the dividing value V, then show the conclusions in the 'Conclusion Window' according to the order, and store them into the OPEN list.

.Classify and store the relational information in rule executing into the global database.

7) Take out the first node N from the OPEN list into 'Node Window', and delete it from OPEN list

8) Repeat steps 3), 4), 5), 6).

9) Decide whether the conclusion is acceptible in accordance with the extent of the certainty degree. If not, then apply the background algorithm to return to the other node of this level.

10) Enlarge the node in accordance with the node tree, and put it in the front of the "OPEN" list. If there is no node to be enlarged, then the answer to the question is obtained. Algorithm ends.

11) Return to step 7).

4.2 Inaccurate Reasoning Model

1. Evidence Composition

Suppose E is composed by N evidence, i.e., $E=\wedge Ei$, $i=1, 2, \ldots, N$. and the linguistic value of each evidence Ei is V(Ei), the certainty degree of Ei is represented by CD(Ei), then the compositive certainty degree of the N evidence can be calculated as follows

$$CD(E)=1-2d/\sqrt{n}, \quad CD(E)\in[0,1] \tag{1}$$

where,

$$d=[\sum(1-V(Ei))^2]^{1/2} \tag{2}$$

If the relationship between the N evidences is logic union one, i.e., $E=\vee Ei$, $i=1, 2, \ldots, N$, then a rule conclusion is reasoned out from N evidences. In other words, a same conclusion can be reasoned out from N different rules. Under this condition, the certainty degree of the conclusion H is computed as follows

$$CD(H)=CD1(H)+CD2(H)-CD1(H)\cdot CD2(H) \tag{3}$$

This formular can only be applied to the computing of two evidences. As to the computing of more than two evidences, it can be done with this formular repeatedly, until all the evidences are computed.

2. Certainity Degree Computing in Rule Execution

PR form in this system can be represented as

IF P THEN C [CD(C, P)]

where,

P -- permise;

C -- conclusion;

CD(C, P) -- certainty degree of rule, $CD(C,P)\in[0,1]$.

After the execution of the rule, the certainty degree of the conclusion C can be computed as follows

$$CD(C)=CD(P)\cdot CD(C,P), \tag{4}$$

or

$$CD(C)=\min\{CD(P), CD(C,P)\}, \tag{5}$$

or

$$CD(C)=\min\{1, 1-CD(P)+CD(C,P)\}. \tag{6}$$

where,

CD(P) -- certainty degree of premise

CD(C) -- certainty degree of conclusion

V. Conclusion

Owing to the wide use of the advanced technology in aviation field, the future analysis of aviation accidents will become more and more complex than that of the present. Therefore, it is a developing tendency on accident analysis to study and develop various artificial intelligence systems to aid analyze the aviation accidents. Basing on recent years' studying on this topic, the author presents in this thesis Bidirectional Knowledge Representation, Knowledge Acquisition Technology in Accident Analysis, Control Strategies and Inaccurate Reasoning Models, which have been proven useful in accident analysis. Moreover, 3A-ES system has been developed with C language in SCC-386 micro-computer. At present, the knowledge on analyzing aviation accidents caused by engine faults has been built up which has arrived at the expected goal. In the times to come, we will focus our attention on the perfecting of this system and the acquiring of other accident knowledge so that the performance of this system can be raised and put into application.

Acknowledgments

We are greatly indebted to Miss Yang Wenchin from Xi'an Foreign Languages Institute and Mr. Zhao Yongsheng from our college for their helpful comments and supports.

References

1. C.A.Roberts, Ph.D.PE, "Aircraft Accident Investigation - a Potential Applications Area for Artificial Intelligence Concepts", FSF Flight Safety Digest, JAN. 1986.
2. R.S.Michalski, J.G.Carbonell and T.M. Mitchell, "Machine Learning, an Artificial Intelligence Approach".
3. G.R.Yost and A.Newell, "A Problem Space Approach to Expert System Specification", the Proceedings of the Tenth IJCAI89.
4. A.Apt and L.Olsen, "Expert System and Fuzzy Systems", Constantin Virgil Negoita,

Constantin Virgil Negoita, Hunter college, City University of New York, 1985
5. J.McDermott, 'R1: A rule- based configurer of computer system', AI vol. 19:1, 1982.
6. B. Hayer-Roth, 'A Blackboard Architecture for control', Addison Wesley Publishing Company, 1984.
7. L. A. Zadeh, 'Fuzzy Logic and Its Application for Approximate Reasoning', Proceedings IFIP Congress 74, 1974.
8. L.A.Zadeh, 'Semantic inference from fuzzy premise', IEEE 76 CHIII-4C, 1976.
9. K. Adlassnining, 'Fuzzy Sets Thoery in Medical Diagnosis, IEEE Trans. on SMC, VOL. 16, 1986.
10. J.J.Buckey, ' A Fuzzy Expert System', Fuzzy Sets & syst., Vol. 20, 1986.
11. R.L.Flowers & A. Kanoel, 'Possibilisbic Search Trees', Fuzzy Sets & syst., Vol. 9, 1985.
12. J.R.Hong, 'A Theory and Implementation of Production Rule Discovery', Proceedings of NJI-ACTAI'91, 1991.
13. Y.H.Wu & S.L.Wang, 'A Framework of Inducing Rules from Examples', Proceedings of CJCAI'90, 1990.
14. X.Y.Tu, 'Methodology for Design of Large Expert System', Proceedings of CJCAI'90, 1990.
15. F.M.Zhang & A.M.Liu, ' The Study and Implementation of the Knowledge Acquisition System in 3A-ES', 1991.
16. F.M.Zhang & Q.G.Xie, ' The Study and Implementation of the Reasoning Machine in 3A-ES', 1991.