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# Rocket Safety Control Intelligent Decision System

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## Abstract

*Various unpredictable faults often occur when the rocket is on mission. It is very important that the safety control decision is made in time and effectively according to judging and analyzing the fly parameters. The expert system for rocket safety control based on uncertain reasoning is proposed according to the characteristics of parameters. At first the reasoning control strategy is studied on, which provides the method for resolving the conflicts and the search. Then a novel uncertain reasoning model is put forward, and the knowledge's uncertain representation and processing, the uncertain match algorithm and the certainty factor deliver method are expressed. Simulation experiments show that this system can acquire the craft launching information quickly and accurately, and can determine its sphere of influence, which effectively makes decision for the safety control officer.*

**Keywords:** *intelligent decision; safety control; reasoning strategy; uncertain reasoning; uncertain analysis*

## 1. Introduction

With the rapid development of the spacecraft industry, the rocket has become the focus of attention of the countries in the world. However, the rocket launching is a complex task. There are many troubles in the process of the rocket launching. For example, when point of fall will exceed the allowable range of placement and endanger the ground safety, the safety control officer can control the rocket and blow it up by the termination of the rocket flight power. If the officer can't accurately control it, consequence is very serious. Therefore the rocket safety control has become the most important problem in the world [1-2].

The rocket safety control system (Rocket Safety Control System, hereinafter referred to as RSCS) by ground safety system and rocket safety system [3]. Among them, the ground control system mainly observes the rocket flight status and judges its status, and sends out the corresponding alarm or destruct command. Rocket control system accepts the destruct command send by ground system, and ignites the explosive device through analysis. The rocket safety control expert system is proposed according to the characteristics of the two control systems. It is very important that the safety control decision is made for the control officer in time and effectively according to real-time diagnosis based on the rocket flight condition [4-5].

In the rocket flight safety control problems, there is a lot of priori knowledge and rule about the rocket flight characteristics. In view of the deterministic safety knowledge, the traditional rocket safety control system can conclude the safety decision scheme by the simple logic judgment and reasoning. This method often produces the false alarm, which leads to safety control experts to make the wrong decision. According to the characteristics of the rocket safety control knowledge and the deficiency of the existing system, and the use of the intelligent decision

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technology and the reasoning technology in artificial intelligence, and following the safety decision knowledge, the rocket safety control system based on intelligent decision is proposed and the uncertainty reasoning model is constructed. A comparative analysis of two control system show that the intelligent decision-making system can observe more accurately on the launching condition, and can acquire the craft launching information quickly, which can make control decision effectively

## 2. Safety Control System

The rocket safety control decision is the computer decision support system in trajectory data processing and safety control decision in one. The reasoning process is that point of fall is calculated according to the highest reliability of a trajectory, and the values calculated are compared with previously stored in the computer's theory data. IF the deviation value is in the range of error, the rocket flight is normal. If the actual parameter value reaches or exceeds the range of error, the safety control decision is made to judge whether the rocket is in the fault state of insecurity by the knowledge base, and as the same time the alarm signal is sent by the launch command and control center. If the conclusion has reach to the allow destruction line and point of fall has entered the boundary line protection zones, the destruct command is given. If the actual parameter value reaches to the necessary destruction line, the destruct command is send out immediately. In addition to the safety control from the ground, the rocket self-destruction system will compare the actual parameters of each instantaneous value with the provisions of the pre input value. When the actual parameters exceed the allowable value, the astronauts separated from the rocket at first, and then the insurance is terminated, and at last time-delay device is connect, so that the ground safety system selects the destruct time or placement. Within the scheduled delay time, even if the ground system can't send out destruct command, the destruct device can be automatically started to blow up the rocket if the delay time has arrived.

According to this process, the frame structure of the control system as shown in Figure 1. The frame structure is mainly composed of four parts of orbit selection, point of fall calculation, safety control knowledge base and safety control decision. The orbit selection, point of fall calculation and selection are the part of the rocket data processing; the safety control knowledge base and decision are the part of safety control decision.

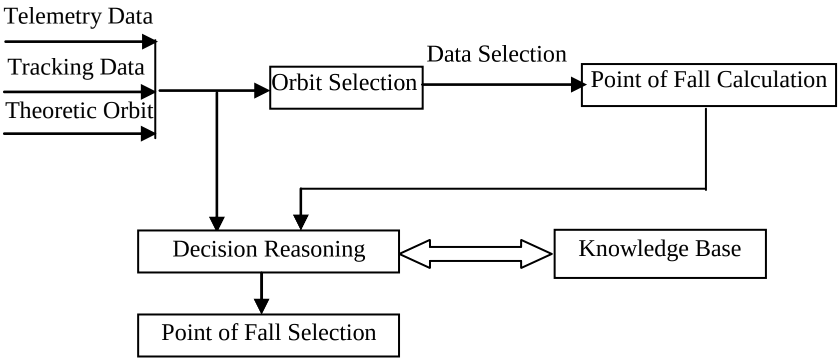

**Figure 1. Frame Structure of Safety Control**

### 2.1. Orbit Selection

Firstly, according to the future knowledge of the characteristics of the craft orbit, the orbit data measured (the telemetry data and tracking data) are compared with theoretical the orbit data are currently stored, and the reliability of the orbit data are judged and the error measurement orbit data are deleted. Then a craft orbit of the highest measurement accuracy is selected based on all reliability orbits for point of fall calculation and safety judgment [6]. The theoretical orbit data values are obtained by the interpolation algorithm. The telemetry data and tracking data can be obtained from the call module.

### 2.2. Point of Fall Calculation and Selection

Point of fall calculation is to instantaneous calculating the state of the rocket in flight, which is the rocket falling on the ground position if it failure. The input data for calculation are the data measured by the measuring equipment, which are the parameters in the launching coordinate system for the point of fall calculation of the orbit after the calculation of the computer. They include the location parameters: $X_k$, $Y_k$, $Z_k$ and the velocity parameters: $v_{xk}$, $v_{yk}$, $v_{zk}$. The output data are the orbit of any observed point velocity value, speed angle, yaw angle, height, latitude and longitude, local sub placement, placement, the latitude and longitude range along the projected range, range of yaw and so on.

The orbit selection, point of fall calculation and selection are the part of the rocket data processing, which provides the basic data for the safety control decision.

### 2.3. Safety Control Knowledge Base

The safety control knowledge base is the foundation of work safety decision system in order to describe all kinds of knowledge and rules of rocket safety control system. It consists of the control parameters, atomic facts and rule knowledge base [3]. This organizational structure not only simplifies the knowledge base, to facilitate the organization and management of knowledge in the knowledge base, but also avoid cross knowledge, to ensure the consistency and completeness of knowledge.

### 2.4. Safety Control Decision

The safety control decision reasoning forms by knowledge reasoning of qualitative and uncertain reasoning model. The control system adopts the decision-making reasoning network based on uncertain knowledge representation. In the process of the safety control decision reasoning, according to the characteristics of safety control knowledge, reasoning machine is reasoning through the forward reasoning mechanism and the depth first search strategy, and finally the rocket safety control system based on intelligent decision is given.

## 3. Knowledge Classification

In RSCS, the control knowledge given by the experts are complex and are influence by many factors. If the security knowledge without distinction of expressed, on the one hand it adds to the complexity of knowledge representation, on the other hand it also brings difficulties to the knowledge reasoning. To solve this problem, the control knowledge is classified. It is divided into the safety control parameter (referred to as the control parameter), atomic facts and rules knowledge base.

### 3.1. Control Parameter

The control parameters are mainly describing the parameters used in the rocket safety control system. They can be divided into three categories: tracking trajectory, telemetering trajectory, telemetering pressure parameters. The tracking trajectory and telemetering trajectory include placement, speed, angle, inclination angle, range and so on; the telemetry pressure parameters include pitch angle deviation, rolling angle deviation, yaw angle deviation, level one pressure 1, level one pressure 2, level one pressure 3, level one pressure 4, level two pressure and so on. Only placement, speed and range parameters are used to blow up and alarm at the same time; the other parameters are used only to alarm and not to blow up.

At each sampling period, the control parameters are formed as the decision basis for the safety control system. In specific implementation, because parameters provide is not complete (only flying position and velocity data), and there are no pipeline data, which have increased the difficulty for the complete test. In the realization of the system, a randomly generated control parameter method had to be adopted.

### 3.2. Atomic Facts

The atomic fact the main description of each state variable is continuous multi-point cross-border information. They are represented by $S_i$（Y, $V_k$, 20, Z）. Its meaning is telemetry(Y) orbit velocity ($V_k$) for 20 consecutive points beyond destruction line (Z), which are represented as a premise or conclusion in rule in knowledge base. Atomic facts are used as the intermediate variable to facilitate the safety judgment reasoning.

### 3.3. Rules Knowledge Base

Rule knowledge bases mainly describe the rule knowledge of rocket safety control system, which are composed of a plurality of atomic facts and are represented by production. Expressed in the following form:

IF $S_1$（Y, $L_c$, 20, Z）AND $S_3$（Y, $V_k$, 20, Z）
THEN $S_y$

In this production, the preconditions of $S_1$ and $S_3$, the conclusion $S_y$ are represented by $S_i$, which are atomic facts. If a rule has more than two preconditions, we can introduce intermediate variables, and then the rules are divided into two for storage. If a rule has less than two preconditions, we can the number 999 or other code to represent the second precondition for invalid. Through this method, the second precondition is invalid. At this time a rule has only one precondition.

## 4. Inference Control Strategy

The reasoning process is a process of thought, which is the process of solving the problem. The quality problem solving not only depends on the methods of solving problem, but also depends on the strategies of solving problem, which is reasoning control strategy. Reasoning control strategy includes reasoning, the conflict resolution strategies and search strategy [7-9].

In RSCS, according to the characteristics of various parameters and rules, there are three working areas to represent all kinds of knowledge. They are as follows. The first is parameters area with different values of different parameters of the recording time. The second is rule elements area used to describe the condition or the conclusion of the rules. Then third is the rules area (dynamic database), by using the method of production rule expression, which stores intermediate facts and reasoning conclusion. According to the structural characteristics of the three working area, the forward reasoning of object-oriented is put forward. That is deduced from the known facts to the conclusion direction, until the launch of the correct conclusion. General process as follows: according to the change of the dynamic database, inference control module activates timely and matches the knowledge in the knowledge base, and modifies and updates the information in the database to reasoning step by step (forward reasoning). The rules of the knowledge base are called dynamic and real-time. According to the present situation of the dynamic knowledge and the knowledge of knowledge base, problem solving is completed by searching and matching. Thus multiple feedback and synthetic judgment are carried out, to improve the system's flexibility and adaptability and decision-making ability [10-12]. The reasoning process is shown in Figure 2.

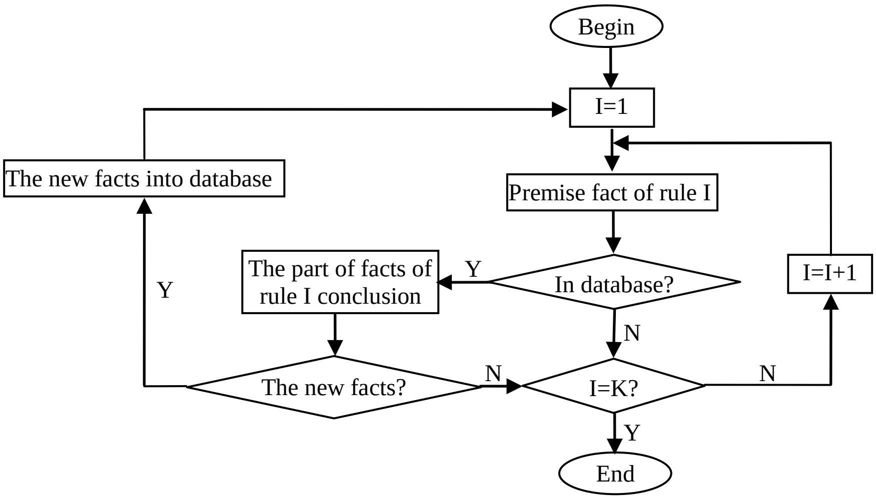

**Figure 2. The Flows Char of Reasoning**

In the process of reasoning, the system matches the known facts with the knowledge continuously, and then it is possible there are a number of knowledge preconditions are met. So these knowledge are all matched, the formation of the conflict. Conflict resolution strategy is the main content of the specific choice of which rule execution. In RSCES, the system uses uncertain knowledge representation method based on production. It gives each rule a confidence CF (Certainty Factor) by the knowledge expert, for all meet the matching requirements of rules, according to the confidence of size, the rule matching priority is determined.

Search is a fundamental problem in artificial intelligence, is a part of the reasoning inseparable, and is directly related to the performance and operation efficiency of the expert system. According to special of the rules in RSCES, the system mainly uses the breadth-first search, which is generally not the same as the breadth-first search. It is from the bottom layer by layer, before the search for any node on a layer, all the nodes in this layer must searched.

## 5. Uncertainty Reasoning Model

### 5.1. Second-order Headings

In RSCES, the control knowledge is often cannot measure by the accurate data, or cannot be described accurately. For the uncertain fuzzy knowledge representation and processing, there are many methods. This paper uses the uncertainty knowledge representation method based on production[13]. The representation is as follows:

R: IF $E_1(\omega_1)$ AND $E_2(\omega_2)$ AND … AND $E_n(\omega_n)$

THEN H (CF(H, E), λ)

$E_i(i=1,2,\cdots,n)$ is the prerequisite for rules, H is the conclusion; $\omega_i( i=1,2,\cdots,n )$ is the weights of the prerequisite for rules $E_i(i=1,2,\cdots,n)$, $\sum\omega_i=1$ ; CF(H, E)( $0<CF(H, E)\leq 1$ ) is the rules reliability; λ ( $0<\lambda\leq 1$ ) is the threshold value of the rules activated, only when the prerequisite E reliability CF(E) reaches or exceeds the limit, also known as $CF(E)\geq\lambda$ , the corresponding rules will be activated. The above expressions more conform to the logical reasoning way of thinking [14]. For example:

IF (tracking point of fall Continuous alarm over 60 times) (1.0)

Then（external alarm）(0.8, 0.7)

Representation of the rule element as follows.

IF $S_{20}$ (1.0) THEN $S_w$(0.8,  0.7)；

The system not only gives the prerequisite reliability CF (E), the rules reliability CF (H, E), and the conclusion reliability CF (H, e), but also gives the evidence reliability CF (e), the conditional reliability CF (E, e), the results reliability CF (h) and the hypotheses reliability CF (H). The CF (E) and CF (H) are given based on the expert experience, which generally are given directly by the domain expert in the fuzzy rule. According to the uncertainty knowledge representation, the uncertainty reasoning model RSCES is put forward. The model is shown in Figure 3.

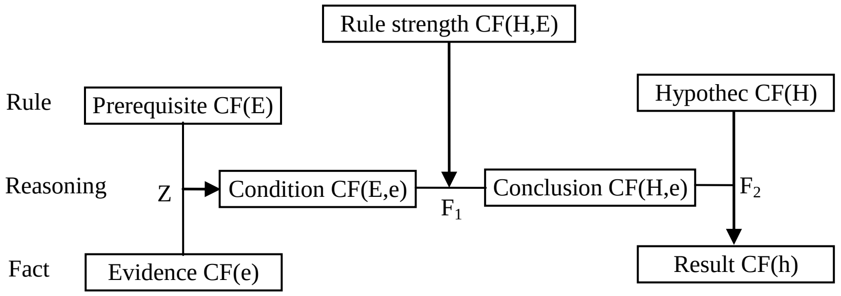

**Figure 3. Model of Uncertainty Reasoning**

### 5.2. Uncertainty Knowledge Processing

The values of rules reliability CF are given directly by the domain expert in the fuzzy rule, but the different experts may have more values to the same rules. Such as n experts give n CF, according to the ascending order, $CF_1 < CF_2 ... < CF_N$. Here, $CF_1$ is positive influenced by $CF_2$, and $CF_2$ is negative influenced by $CF_1$, which is positive influenced by $CF_3$. And so on, formula for the influence value is as follows.

$$S = \begin{cases} d/2 & (d \le 0.5) \\ (1-d)/2 & (d > 0.5) \end{cases}$$

Here, d is the absolute value of difference of the adjacent CF. CF total influence value S is CF positive effects $S_+$ minus its negative $S_-$, also known as $S= S_+ + S_-$. The value of the modified CF ' is the original CF and S, formula is as follows:

$$CF' = CF + S_{总}$$

Considering the value of reliability CF ' , CF can be obtained after a group of coordination. Then according to the reliability value after coordination, the values of rules ultimate reliability CF is figured out and formula is as follows:

$$CF = \left( \sum_{i=1}^{n} CF_i' \right) / N$$

This reliability value obtained is considered the various expert opinions, and the reasoning results more close to the actual situation and more has the characteristics of the human thinking [15-16].

### 5.3. Uncertainty Matching Algorithm

The so-called matching (Sometimes called pattern matching) is to compare and coupling of two knowledge model, to check whether the two knowledge structure is identical or similar. According to the similarity degree of two pattern matching, matching can be divided into certainty matching and uncertainty matching. The certainty matching refers to two models completely consistent, also known as a perfect matching or an exact matching. Uncertainty matching refers to two mode is not completely consistent. But on the whole, the degree of approximation is in the specified limits [17-18]. The uncertainty matching of the rules are discussed as follows.

In RSCES, the method is given by the initial evidence given to introduce the corresponding conclusion. At first, the production rules that match the evidence are selected from the knowledge base. Then the conclusion is gradually deduced by using these rules. The facts in the database come from two aspects. One is the initial evidence provided by the system, another is the intermediate evidence obtained by inference rules.

Here, the uncertainty knowledge representation is shown as 5.1. The uncertainties of the prerequisite $E_1$, $E_2$... $E_n$ is CF ($E_1$), CF ($E_2$)... CF ($E_n$); the corresponding evidence are $e_1$, $e_2$... $e_n$; the uncertainties of them are CF ($e_1$), CF ($e_2$)... CF ($e_n$). Matching algorithm is as follows.

(1) Calculating the distance $d_i$ between each prerequisite and the corresponding evidence:

$$d_i(E, \ e) = \{[CF(E_i) - CF(e_i)] \vee 0\} \times \omega_i,$$

$$i = 1,2,\cdots,n$$

(2) Calculating the maximum value $d_{max}$(E, e) of $d_i$:

$$d_{\max}(E, \ e) = \vee d_i, \qquad i = 1,2,\cdots,n$$

(3) Calculating the matching degree by the following formula:

$$m(E, \ e) = 1 - d_{\max}(E, \ e)$$

(4) When $m(E, \ e) > \lambda$, the evidence and the rule are matching, and then a rule instance is obtained. Otherwise not matching, the condition is not enabled, then to produce the backtracking, and on other rules matching.

### 5.4. And / Or Tree Reliability Calculating

The reliability theory of uncertainty reasoning process is very suitable for an and / or tree decision network. The “and” node represents a rule inference, some evidence “and” for the rule premise corresponds to several branches of “and” node. The “or” node represents multiple rules for the same reasoning. If the fact reliability is given, each intermediate node and the conclusion reliability are calculated from the bottom to top according to the rules reliability. The method can be summarized as follows:

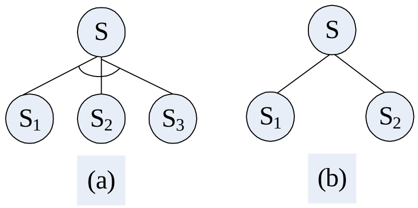

Figure 4. Computing Reliability of ‘and’, ’or’ Node

(1) “And” node reliability

As shown in Figure 4 (a), the formula for the node S reliability is as follows:

$$CF(S, \ e) = CF(S, \ S_1 \cap S_2 \cap S_3) \cdot CF(S_1 \cap S_2 \cap S_3, \ e)$$

Because nodes S1, S2, S3 are logical “and”, the above formula is as follows:

$$CF(S_1 \cap S_2 \cap S_3, \ e) = \omega_1 \times CF(S_1, \ e_1) + \omega_2 \times CF(S_2, \ e_2) + \omega_3 \times CF(S_3, \ e_3)$$

If the rules reliability is expressed by R, that is

$$R = CF(S, \ S_1 \cap S_2 \cap S_3)$$

Then

$$CF(S,\ e)=R\times[\omega_1\times CF(S_1,\ e_1)+\omega_2\times CF(S_2,\ e_2)+\omega_3\times CF(S_3,\ e_3)]$$

(2) “Or” node reliability

As shown in Figure 4 (b), if the two rules reliability is expressed by $R_1$, $R_2$, and the conclusion reliability formulas to the following formula:

$$CF(S,\ e_1)=CF(S,\ S_1)\times CF(S_1,\ e_1)=R_1\times CF(S_1,\ e_1)$$

$$CF(S,\ e_2)=CF(S,\ S_2)\times CF(S_2,\ e_2)=R_2\times CF(S_2,\ e_2)$$

In the formula, CF (S, $e_1$), CF (S, $e_2$) are calculated by the chain of reasoning $e_1\to S_1\to S$, $e_2\to S_2\to S$. Because $e=e_1\cup e_2$, the formula for the node S reliability is as

$$CF(S,e)=CF(S,e_1\cup e_2)=\begin{cases} CF(S,e_1)+CF(S,e_2)-CF(S,e_1)\times CF(S,e_2), & CF(S,e_1)\geq 0, CF(S,e_2)\geq 0\\ \dfrac{CF(S,e_1)+CF(S,e_2)}{1-\min[CF(S,e_1),CF(S,e_2)]}, & CF(S,e_1)\times CF(S,e_1)<0\\ CF(S,e_1)+CF(S,e_2)+CF(S,e_1)\times CF(S,e_2), & CF(S,e_1)<0, CF(S,e_2)<0 \end{cases}$$

follows:

### 5.5. Examples of Application

The decision rules of the system as an example, the uncertain reasoning are explained as follows. With the following a set of rules:

$R_1$：IF $S_1$(0.5) AND $S_3$(0.5)
THEN $S_{w1}$(0.8, 0.6) CF($S_{w1}$)=0.8
$R_2$：IF $Sw_1$(1.0)
THEN $S_w$(0.8, 0.7) CF($S_w$)=0.9
$R_3$：IF $S_{20}$ (1.0)
THEN $S_w$(0.8, 0.7) CF($S_w$)=0.9
$R_4$：IF $S_7$(0.75) AND $S_9$(0.25)
THEN $S_y$(0.9, 0.6) CF($S_y$)=0.9
$R_5$：IF $S_w$(0.5) AND $S_y$(0.5)
THEN $S_z$(0.9, 0.7) CF($S_z$)=0.9

In the above all rules, $R_i$, $\omega_i$ respectively express all rules reliability (the rule strength) and all rules condition weight. If

CF($e_1$)=CF($e_3$)=CF($e_7$)=0.8, CF($e_9$)=CF($e_{20}$)=1,

According to the analysis of the parameters, all of evidence reliability is:

CF($e_1$)=1, CF($e_3$)=0.5, CF($e_7$)=0.8, CF($e_9$)=-0.8, CF($e_{20}$)=1。

According to the above rules, the evidence and conclusion form as shown in figure 5 of the decision network.

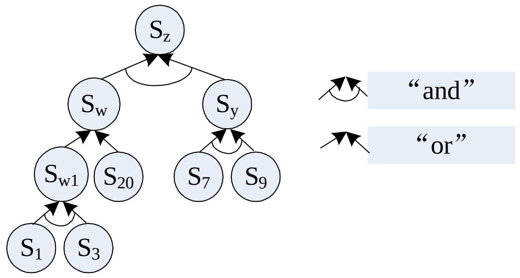

Figure 5. Decision-making Network

(1) Calculating the matching degree

$$d_{S_1}(S, e) = \{[CF(S_1) - CF(e_1)] \vee 0\} \times \omega_{S_1} = [(1-1) \vee 0] \times 0.5 = 0$$

Similarly, the other distance $d_i$ can be calculated.

$$d_{S3}(S, e) = 0.25, \quad d_{S7}(S,e) = 0.15, \quad d_{S9}(S,e) = 0.45, \quad d_{S20}(S,e) = 0$$

(2) Judging rules activated or not

$$m_1(S, e) = 1 - d_{1\max}(S, e) = 1 - \max(d_{S_1}, d_{S_3}) = 1 - 0.25 = 0.75 > 0.6,$$

Rule $R_1$ can be activated;

Similarly, the other matching degree can be calculated.

$m_3(S, e) = 1 > 0.7$, Rule $R_3$ can be activated;

$m_4(S, e) = 0.55 < 0.6$, Rule $R_4$ can't be activated;

Because rule $R_4$ can't be activated, rule $R_5$ can't be activated. Whether the judgment rule $R_2$ can be activated by the following analysis.

(3) Calculating node $S_1$ reliability by the condition reliability

$$CF(S_1, e_1) = CF(S_1) \times CF(e_1) = 1 \times 1 = 1$$

Similarly, node $S_3$ and node $S_{20}$ reliability can be calculated.

$$CF(S_3, e_3) = 0.5, CF(S_{20}, e_{20}) = 1$$

(4) According to the decision network, bottom-up, the other nodes reliability is calculated as follows:

$$CF(S_{w1}, e_{w1}) = CF(S_{w1}, S_1 \cap S_3) \times CF(S_1 \cap S_3, e_{w1})$$

$$= R_1 \times \left[\omega_{S_1} \times CF(S_1, e_1) + \omega_{S_3} \times CF(S_3, e_3)\right]$$

$$= 0.8 \times (0.5 \times 1 + 0.5 \times 0.5) = 0.6$$

Because $CF(S_{w1}, e_{w1}) = CF(S_{w1}) \times CF(e_{w1})$,

Then

$$CF(e_{w1}) = \frac{CF(S_{w1}, e_{w1})}{CF(S_{w1})} = \frac{0.6}{0.8} = 0.75$$

$$d_{S_{w1}}(S, e) = \{[CF(S_{w1}) - CF(e_{w1})] \vee 0\} \times \omega_{S_{w1}} = [(0.8 - 0.75) \vee 0] \times 1.0 = 0.05$$

$m_2(S, e) = 1 - 0.05 = 0.95 > 0.7$, Rule $R_2$ can be activated;

By the and / or tree reliability calculating, "or" node reliability can be calculated as follows.

$$CF(S_w, e_{w1}) = CF(S_w, S_{w1}) \times CF(S_{w1}, e_{w1}) = R_2 \times CF(S_{w1}, e_{w1}) = 0.8 \times 0.6 = 0.48$$

Similarly,

$$CF(S_w, e_{20}) = CF(S_w, S_{20}) \times CF(S_{20}, e_{20}) = R_3 \times CF(S_{20}, e_{20}) = 0.8 \times 1 = 0.8$$

Because of $e = e_{w1} \cup e_{20}$, by the parallel rule model, node $S_w$ reliability can be calculated as follows.

$$CF(S_w, e) = CF(S_w, e_{w1} \cup e_{20})$$

$$= CF(S_w, e_{w1}) + CF(S_w, e_{20}) - CF(S_w, e_{w1}) CF(S_w, e_{20})$$

$$= 0.48 + 0.8 - 0.48 \times 0.8 = 0.896$$

Then, by the result reliability, $CF(S_w)$ can be calculated.

$$CF(s_w) = CF(S_w, e) \times CF(S_w) = 0.896 \times 0.9 = 0.8064$$

So, the final result is $S_w$, also is the external alarm, and its reliability is 0.8064.

## 6. Conclusions

According to the characteristics of the decision rules and decision procedure, the reasoning control strategy is studied. Following the knowledge representation based on the reliability, a novel uncertain reasoning algorithm and the corresponding reasoning model is proposed. Simulation experiments show that this system can acquire the craft launching information quickly and accurately, which greatly improves the reliability and authenticity of safety control decision for rocket aviation, and can control the rocket aviating state effectively.

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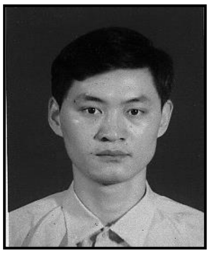

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