GO-Bayes Method for System Modeling and Safety Analysis

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Abstract—Safety analysis ensuring the normal operation of an engineering system is important. The existing safety analysis methods are limited to relatively simple fact description and statistical induction level. Besides, many of them enjoy poor generality, and fail to achieve comprehensive safety evaluation given a system structure and collected information. This work describes a new safety analysis method, called a GO-Bayes algorithm. It combines structural modeling of the GO method and probabilistic reasoning of the Bayes method. It can be widely used in system analysis. The work takes a metro vehicle braking system as an example to verify its usefulness and accuracy. Visual implementation by Extendsim software shows its feasibility and advantages in comparison with the Fault Tree Analysis (FTA) method.

Keywords: **Safety analysis, GO-Bayes method, and Reliability**

I. INTRODUCTION

Safety evaluation technologies were originated in the 1930s. In the 1960s, the needs from the US military field's engineering system safety theory and applications promoted their rapid development[1]. As people's awareness of safety continues to grow and system safety engineering becomes a mature discipline, a system safety engineering approach is gradually extended to aviation, nuclear industry, petroleum, chemical, and manufacturing areas. Researchers have proposed new theories and methods, such as safety checklist[2], safety analysis[3] and evaluation methods[4], event trees[5], fault trees[6] and risk assessment techniques[7-8], mode evaluation, six-stage safety and other risk index evaluation method, artificial neural networks and other technologies.

The GO method has commonly been used since 1980s [9]. Several improved methods for quantitative analysis are proposed in signal processing[10]. This work intends to improve the GO algorithm based on Bayes reasoning[11-13] and names the new method as a GO-Bayes algorithm. It has the following innovative characteristics:

First, the structural modular reliability analysis of the GO method is applied to analyze the operational status of a safety analysis assessment system; Second, the Bayes probability theory is used in a safe state probability parameter extraction process to each basic unit of the model; Third, the Bayes inference is integrated into the system GO graph model, reversing fault reasoning analysis and evaluation, thereby achieving simpler quantitative analysis. The proposed GO-Bayes method combines the structural modeling of the GO method and probabilistic reasoning of the Bayes method[14], which can be used in situations where one has a large amount of system fault information. Its use can help one prevent and diagnose faults in a timely fashion, thus ensuring the safe operation of an entire system.

II. GO-BAYES METHOD

The proposed GO-Bayes method is system-unit-component failures oriented. It combines basic unit models and logic analysis models according to a flow chart to establish the analysis model, in accordance with certain rules to calculate reliability parameters. Besides we adopt Bayes methods to deduce system failure and solve inverse probability, in order to achieve a comprehensive system safety evaluation. The GO-Bayes method's operators are shown in Figure 1.

A. Modeling method

The GO-Bayes method inherits graph modeling ideas, e.g., schematic diagrams, flow charts and other drawings. First, we summarize the basic model elements, and explain the unit algorithm. Second, we build a system model according to a system structure and data flows among its units. We use system modeling algorithms to process raw input data and then obtain system outputs according to the working mechanism and fault conditions.

B. Bayes theory based on information fusion

Information fusion research based on the Bayes theory is mainly used for system internal self-monitor and self-test information. The information (hereinafter collectively referred to as detection information) plays a strong role in system operation safety analysis. The GO-Bayes method is based on the description and information of each component and subsystem, and the model is systematically analyzed. Fault information related to the system reliability and safety is integrated for system reliability analysis.

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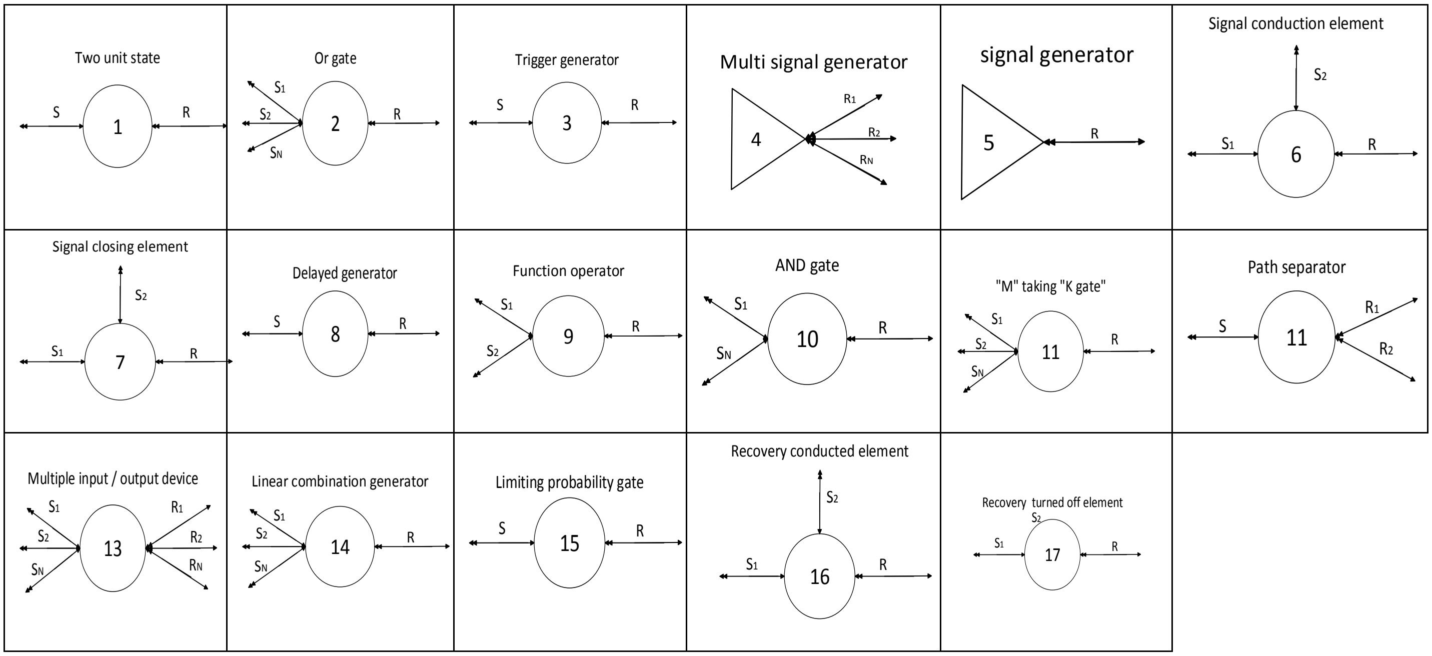

Figure 1. The operators used in the GO-Bayes method

C. *Probabilistic Inference based on GO-Bayes*

System probabilistic safety evaluation can be realized in two ways. First, from components to systems, based on the probability parameters of component parts, we solve probability parameters of a system, such as normal work probability and failure probability. Second, from the system to the components, based on known system state information and component probability parameters, we reason a system's various safety status probabilities, i.e., "inverse probability".

III. *INTRODUCTION TO UNIT MODEL*

When a basic unit is described, its probability data follows the following principles [15-16]. We use the following notation: S is the data unit subscript, like R_s, F_s and P_s; I is the input data subscript, like R_I, F_I and P_I; and O is the output data subscript, like R_o , F_o and P_o.

A. *Signal generating unit*

A signal generating unit means an input to a system, external event or signal independent of the system. It can represent a generator, power, environmental impact and human factors. It has two states, normal or faulty. Its safety probability parameter comprises, Unreliability $F(1)$, inverse probability $P(1)$. Its single arrow output indicates an unreliability output, double arrow indicates an inverse probability input, satisfying:

$$F_O(1) = F_S(1) \tag{1}$$

$$P_S(1) = P_I(1) \tag{2}$$

Figure 2 means a signal generating unit model, and Figure 3 means a signal generator unit.

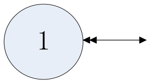

Figure 2. A signal generating unit model

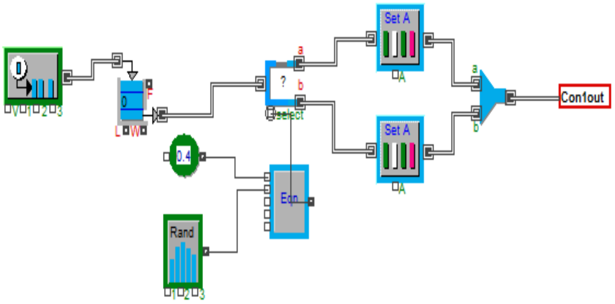

Figure 3. A Signal generator unit

B. *Two state unit*

As shown in Figures 4-5, a two-state unit is the most common unit, whose two states are normal and faulty ones. It has input and output data, and can represent resistors, switches, and valves. Its unreliability value is calculated based on the reliability theory,

$$F_O(2) = 1 - [1 - F_S(2)][1 - F_I(2)] \tag{3}$$

Two-state unit output failure results from either input fault or its own fault. They form a series logical relationship with the inverse probability

$$P_S(2) = \frac{F_S(2)P_I(2)}{F_O(2)} \tag{4}$$

$$P_O(2) = \frac{F_I(2)P_I(2)}{F_O(2)} \tag{5}$$

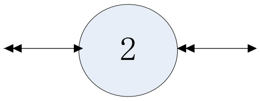

Figure 4. A Two-state unit model

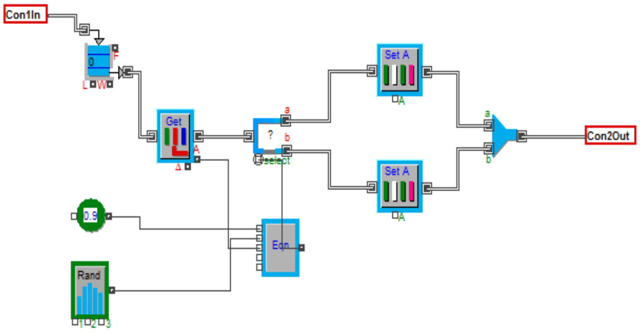

Figure 5. A two-state unit

C. *Conditional control unit*

A conditional control unit, as shown in Figures 6-7, requires two inputs, the working status input, with a subscript label 1, and the control state input, with a subscript label 2. Its output represents their safety status. A conditional control unit may represent relay and mechanical control valves and so on. Its probability parameter calculation rules as follows:

$$F_O(3) = 1 - [1 - F_{I1}(3)][1 - F_{I2}(3)][1 - F_S(3)] \tag{6}$$

$$P_S(3) = \frac{F_S(3)P_I(3)}{F_O(3)} \tag{7}$$

$$P_{O1}(3) = \frac{F_{I1}(3)P_I(3)}{F_O(3)} \tag{8}$$

$$P_{O2}(3) = \frac{F_{I2}(3)P_I(3)}{F_O(3)} \tag{9}$$

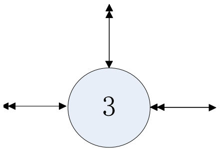

Figure 6. A Conditional control unit model

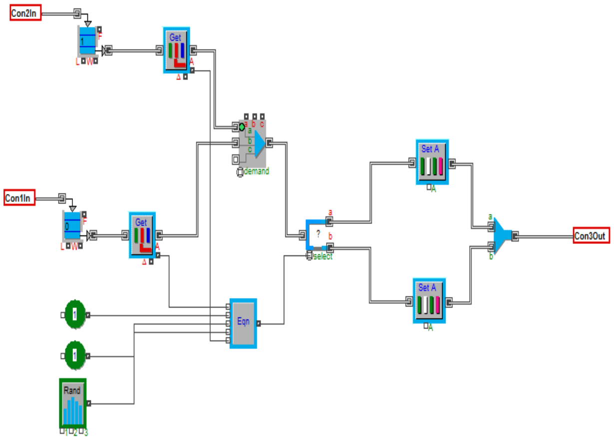

Figure 7. A Conditional control unit

D. *AND gate*

An AND gate unit is shown in Figures 8-9. It can rely on several reliability input data items (with subscript labels being 1, 2, 3, …, n), to compute one reliability output. It yields an output only when multiple inputs simultaneously are available. It does not have its own data. It does not stand for an internal system component, but is used to connect different units. Its reverser fault data is expressed as an input and multiple output. Obviously, an AND gate unit represents a parallel logical relationship. Its probability parameters can be computed:

$$F_O(4) = F_{I1}(4)F_{I2}(4)...F_{In}(4) \tag{10}$$

$$P_{O1}(4) = P_I(4) \tag{11}$$

$$P_{O2}(4) = P_I(4) \tag{12}$$

$$P_{On}(4) = P_I(4) \tag{13}$$

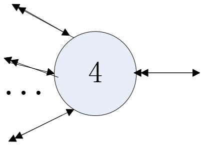

Figure 8. An AND gate unit model

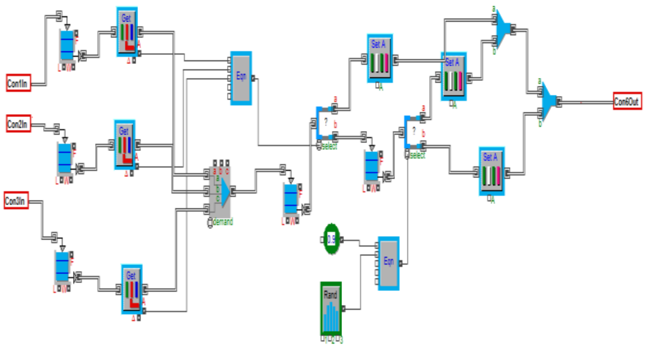

Figure 9. An AND gate unit

E. OR gate

An OR gate unit relies on several reliability input data (with a subscript label 1, 2, 3,…, n), to compute reliability output data, as shown in Figures 10-11. When one of the multiple inputs occurs, it can yield an output. It does not have its own data, and stand for no internal system component, but can be used to connect multiple units. Its reverser fault data is expressed as an input and multiple outputs. Probability parameters are calculated as follows:

$$F_O(5) = 1 - [1 - F_{I1}(5)][1 - F_{I2}(5)]...[1 - F_{In}(5)] \quad (14)$$

$$P_{O1}(5) = \frac{F_{I1}(5)P_I(5)}{F_O(5)} \quad (15)$$

$$P_{O2}(5) = \frac{F_{I2}(5)P_I(5)}{F_O(5)} \quad (16)$$

$$P_{On}(5) = \frac{F_{In}(5)P_I(5)}{F_O(5)} \quad (17)$$

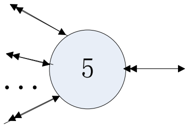

Figure 10.An OR gate unit model

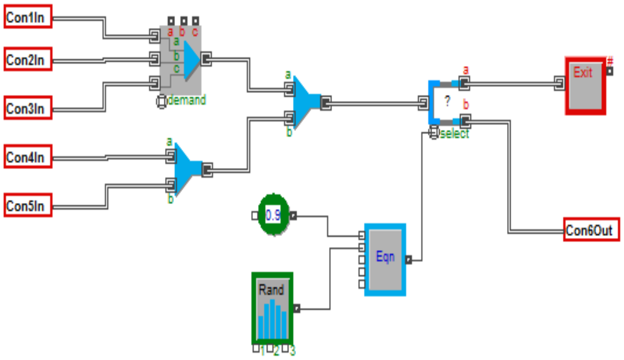

Figure 11. An OR gate unit

F. Voting gate

A voting gate unit as shown in Figures 12-13 has several reliability input data items (with a subscript label 1, 2, 3, …, n), and one output. It produces an output only when more than k inputs are present at the same time. It does not have its own data, and stands for no internal system component, but it can be used to connect multiple units. Its reverse fault data is expressed as an input and multiple outputs. It represents a parallel and series logical relationship. It can be divided into a combination of AND gate units and OR gate units. For example taking 2 from 4 has C_4^2=6 options, two AND gate units connect to one OR gate unit, meaning that two or more input failures lead to system output failure.

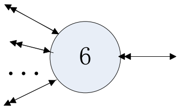

Figure 12. A Voting gate unit model

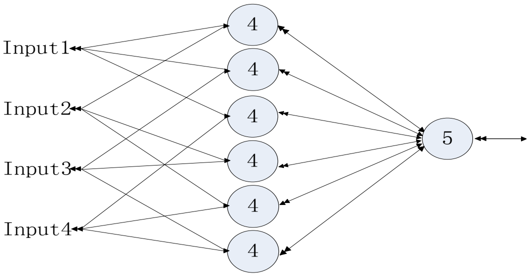

Figure 13. A 4-input series-parallel voting gate model

Its probability parameters can be derived from those for AND gate and OR gate units. We derive an algorithm for a GO-Bayes basic voting model.

Take 2 from 4 as an example in Figure 13. It can be divided into a combination of 6 AND gate units and 1 OR gate unit.

Assuming that the probabilities of inputs 1-4 are $R_{I1}(6)=x_1$, $R_{I2}(6)=x_2$, $R_{I3}(6)=x_3$, $R_{I4}(6)=x_4$, we can derive the probability formula for the 2/4 voting gate $F_o(6)$,

$$\begin{aligned} F_o(6) = 1 - &[1-(1-x_1)\cdot(1-x_2)]\cdot[1-(1-x_1)\cdot(1-x_3)]\cdot \\ &[1-(1-x_1)\cdot(1-x_4)]\cdot[1-(1-x_2)\cdot(1-x_3)]\cdot \\ &[1-(1-x_2)\cdot(1-x_4)]\cdot[1-(1-x_3)\cdot(1-x_4)] \end{aligned} \quad (18)$$

thus

$$\begin{aligned} F_o(6) = 1 - (&x_1\cdot x_2\cdot x_3 + x_1\cdot x_2\cdot x_4 + x_1\cdot x_3\cdot x_4 + \\ &x_2\cdot x_3\cdot x_4 - 3x_1\cdot x_2\cdot x_3\cdot x_4) \end{aligned} \quad (19)$$

Since the jointly signal has no effect on the calculation of the reverse probability, according to the reverse probability formula of an AND gate unit (label 4) and OR gate unit (label 5), we can derive the following reverse probability of the gate:

$$P_I(1\cdot 2) = \frac{F_I(1\cdot 2)P_I(6)}{F_O(6)} = \frac{(1-x_1)\cdot(1-x_2)\cdot P_I(6)}{F_O(6)} \quad (20)$$

$$P_I(1\cdot 3) = \frac{F_I(1\cdot 3)P_I(6)}{F_O(6)} = \frac{(1-x_1)\cdot(1-x_3)\cdot P_I(6)}{F_O(6)} \quad (21)$$

$$P_I(1\cdot 4) = \frac{F_I(1\cdot 4)P_I(6)}{F_O(6)} = \frac{(1-x_1)\cdot(1-x_4)\cdot P_I(6)}{F_O(6)} \quad (22)$$

$$P_I(2\cdot 3) = \frac{F_I(2\cdot 3)P_I(6)}{F_O(6)} = \frac{(1-x_2)\cdot(1-x_3)\cdot P_I(6)}{F_O(6)} \quad (23)$$

$$P_I(2\cdot 4)=\frac{F_I(2\cdot 4)P_I(6)}{F_O(6)}=\frac{(1-x_2)\cdot(1-x_4)\cdot P_I(6)}{F_O(6)} \tag{24}$$

$$P_I(3\cdot 4)=\frac{F_I(3\cdot 4)P_I(6)}{F_O(6)}=\frac{(1-x_3)\cdot(1-x_4)\cdot P_I(6)}{F_O(6)} \tag{25}$$

$$P_{I1}(6)=\frac{F_{I1}(6)}{(1-x_1)\cdot(1-x_2)}\cdot\frac{(1-x_1)\cdot(1-x_2)\cdot P_I(6)}{F_O(6)}=\frac{F_{I1}(6)\cdot P_I(6)}{F_O(6)} \tag{26}$$

$$P_{I2}(6)=\frac{F_{I2}(6)}{(1-x_1)\cdot(1-x_2)}\cdot\frac{(1-x_1)\cdot(1-x_2)\cdot P_I(6)}{F_O(6)}=\frac{F_{I2}(6)\cdot P_I(6)}{F_O(6)} \tag{27}$$

$$P_{I3}(6)=\frac{F_{I3}(6)}{(1-x_1)\cdot(1-x_3)}\cdot\frac{(1-x_1)\cdot(1-x_3)\cdot P_I(6)}{F_O(6)}=\frac{F_{I3}(6)\cdot P_I(6)}{F_O(6)} \tag{28}$$

$$P_{I4}(6)=\frac{F_{I4}(6)}{(1-x_1)\cdot(1-x_4)}\cdot\frac{(1-x_1)\cdot(1-x_4)\cdot P_I(6)}{F_O(6)}=\frac{F_{I4}(6)\cdot P_I(6)}{F_O(6)} \tag{29}$$

Then we get a 2/4 vote gate algorithm. We can obtain the similar results for other voting gates.

IV. *SAFETY ANALYSIS OF VISUAL UNIT METRO VEHICLES BRAKING SYSTEM*

We now show how to use the proposed GO-Bayes method to analyze an urban rail transit vehicle air braking part.

A. Basic composition of air braking

Air braking portion of a braking system's basic components include air compressor and filtration device (as shown in A5 of Figure 14), total duct, air spring devices and pneumatic part (beginning with L in Figure 14), parking braking device (B7), braking control section (B13), braking airline (beginning with B), foundation brakes (beginning with C), and electronic anti-skid devices (beginning with G).

We build the visual system for an urban metro vehicle braking system as shown in Figure 14.

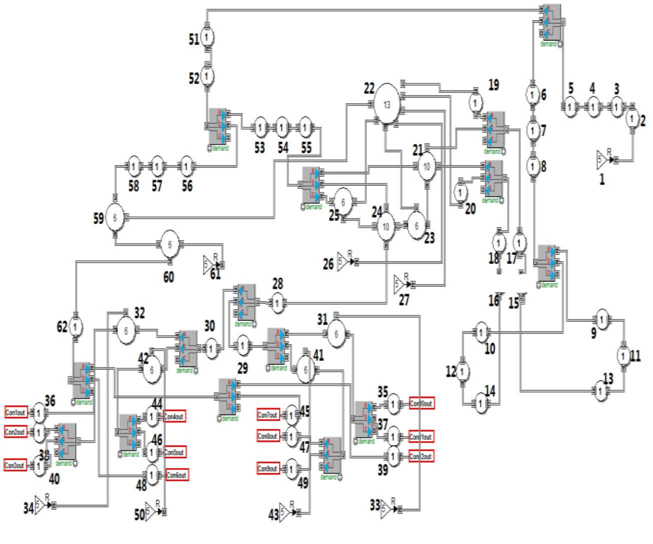

Figure 14. Visual system of an urban metro vehicle braking system

B. GO-Bayes modeling method for a braking system

The braking system has a complex structure and many components. In order to display and analyze it fully, this work uses a hierarchical modeling method by dividing the braking system into two layers. Its first layer has six functional sections as shown in Figure 15.

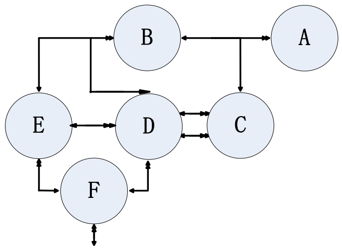

Figure 15. First layer structure model of a braking system

In Figure 15, node A represents an air supply device, B the line along which braking air passes through, C the air spring suspension, D the braking control device, E parking braking control, and F the foundation braking.

In the second layer of the model structure as shown in Figure 16, since the number of components is big, we label them according to the labels in the first parts and the position in the device. Numbers on the left of the dash represents unit types, and those on the right side correspond to the system unit.

(1) An air supply device is shown in Figure 16 and Table 1.

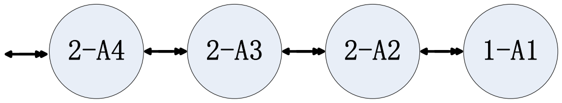

Figure 16. Structure model of an air supply device

TABLE 1 Units in an air supply device model

Code	Corresponding component
1-A1	Drive motor
2-A2	Air compressor
2-A3	Drying tower
2-A4	total air cylinder

(2) A braking air route is given in Figure 17 and Table 2.

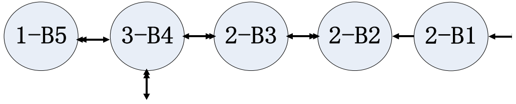

Figure 17. Braking air route structure model

TABLE 2 Components in a braking air route structure model

Code	Corresponding component
2-B1	Total air duct
2-B2	Cut-off valve
2-B3	Safety valve
3-B4	Braking reservoir cylinder
1-B5	Exhaust valve

(3) An air spring suspension device is shown in Figure 18 and Table 3.

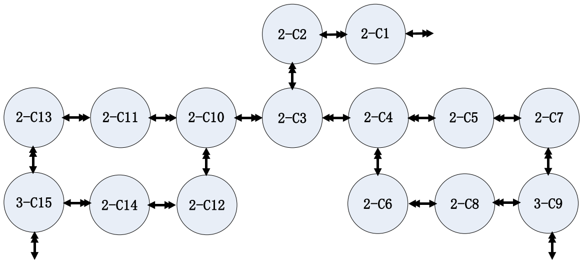

Figure 18. Structure model of an air spring suspension device

TABLE 3 Components in an air spring suspension device model

Code	Corresponding component
2-C1	Cut-off valve
2-C2	Filter
2-C3	Air spring cylinder
2-C4	Cut-off valve
2-C5	Left height valve
2-C6	Right height valve
2-C7	Air spring
2-C8	Air spring
3-C9	Pressure valve
2-C10	Cut-off valve
2-C11	Left height valve
2-C12	Right height valve
2-C13	Air spring
2-C14	Air spring
3-C15	Pressure valve

(4) A braking control device inner has its structure and components shows in Figure 19 and Table 4.

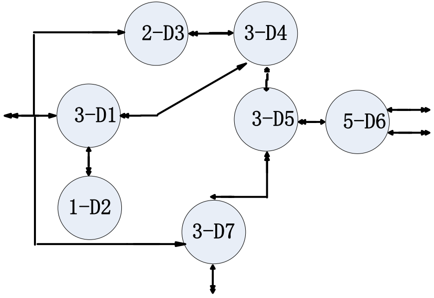

Figure 19. Structure model of a braking control system

TABLE 4 Components in a braking control system model

Code	Corresponding component
3-D1	Analog converter
1-D2	ECU code
2-D3	Emergency solenoid valve
3-D4	Pressure Switch
3-D5	Weighing valve
5-D6	OR gate
3-D7	Relay valve

(5) A parking braking device has its structure and components in Figure 20 and Table 5.

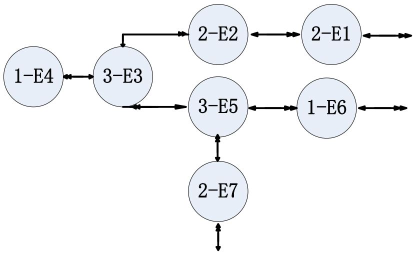

Figure 20. Structure model of a parking braking device

TABLE 5 Components in a braking device model

Code	Corresponding component
2-E1	Cut off valve
2-E2	Pressure Switch
3-E3	Parking braking solenoid valve
1-E4	Parking braking code
3-E5	Pulse valve
1-E6	Two-way valve
2-E7	Check

(6) A Foundation Braking is given in Figure 21 and Table 6.

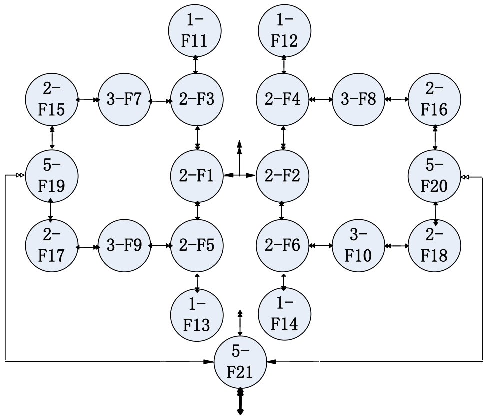

Figure 21.Structure model of a foundation braking device

TABLE 6. Components in a foundation braking device model

Code	Corresponding component
2-F1	Cut off valve
2-F2	Cut off valve
3-F3	Slip solenoid valve
3-F4	Slip solenoid valve
3-F5	Slip solenoid valve
3-F6	Slip solenoid valve
2-F7	Braking air reservoir
2-F8	Braking air reservoir
2-F9	Braking air reservoir
2-F10	Braking air reservoir
1-F11	Speed Sensor
1-F12	Speed Sensor
1-F13	Speed Sensor
1-F14	Speed Sensor
2-F15	Slipper
2-F16	Slipper
2-F17	Slipper
2-F18	Slipper
5-F19	Or gate
5-F20	Or gate
5-F21	Or gate

Another feature of the hierarchical model is that each of its modules can be individually analyzed. During the entire system analysis procedure, the correlations among modules have to be paid attention to.

C. Calculation of probability indicators

Safety probability indicators are computed based on the GO-Bayes model of the braking system. First, obtain the fault parameters for each component by statistically analyzing historical operating cumulative data of the system. Component fault rate is the total number of the system failures divided by the total number of components, and then divided by the time duration. Secondly, we can calculate the component fault probability and normal work probability at time *k* according to the correlations among failure rate indices.

(1) Original data

Component failure rate data for each component comes mainly from the historical operation statistics. Assume steady-state operation 100h as shown in Table 7,

TABLE 7 Initial data of components in the model

Code	Failure Rate(10E-06/h)	Fault Rate
1-A1	3	2.9996E-04
2-A2	4.5	4.4990E-04
2-A3	6	5.9982E-04
2-A4	0.5	4.9999E-05
2-B1	1	9.9995E-05
2-B2	1.2	1.1999E-04
2-B3	2.5	2.4997E-04
3-B4	0.7	6.9998E-05
1-B5	8	7.9968E-04
2-C1	3	2.9996E-04
2-C2	1	9.9995E-05
2-C3	0.5	4.9999E-05
2-C4	3	2.9996E-04
2-C5	10	9.9950E-04
2-C6	10	9.9950E-04
2-C7	1.5	1.4999E-04
2-C8	1.5	1.4999E-04
3-C9	5	4.9988E-04
2-C10	3	2.9996E-04
2-C11	10	9.9950E-04
2-C12	10	9.9950E-04
2-C13	1.5	1.4999E-04
2-C14	1.5	1.4999E-04
3-C15	5	4.9988E-04
3-D1	2	1.9998E-04
1-D2	42	4.1912E-03
2-D3	9	8.9960E-04
3-D4	4	3.9992E-04
3-D5	0.8	7.9997E-05
3-D7	2	1.9998E-04
2-E1	3	2.9996E-04
2-E2	4	3.9992E-04
3-E3	3.5	3.4994E-04
1-E4	1	9.9995E-05
3-E5	3	2.9996E-04
1-E6	7	6.9976E-04
2-E7	1.2	1.1999E-04
2-F1	3	2.9996E-04
2-F2	3	2.9996E-04
3-F3	3.5	3.4994E-04
3-F4	3.5	3.4994E-04
3-F5	3.5	3.4994E-04
3-F6	3.5	3.4994E-04
2-F7	1	9.9995E-05
2-F8	1	9.9995E-05
2-F9	1	9.9995E-05
2-F10	1	9.9995E-05
1-F11	15	1.4989E-03
1-F12	15	1.4989E-03
1-F13	15	1.4989E-03
1-F14	15	1.4989E-03
2-F15	9	8.9960E-04
2-F16	9	8.9960E-04
2-F17	9	8.9960E-04
2-F18	9	8.9960E-04

(2) Calculation results

Based on the above model structure, we calculate the reliability and unreliability of each component's output, and then reverse reasoning to obtain each component's input probabilities. We can obtain the system output reliability that is 9.7079E-01, unreliability is 2.9205E-02. In Table 8, the inverse probability of the following components is relatively larger. That is to say, (1-D2, 1.4351E-01), (2-D3, 3.0803E-02), (1-F11, 1-F12, 1-F13, 1-F14, 5.1322E-02), (2-F15, 2-F16, 2-F17, 2-F18, 3.0803E-02) indicate the component fault will most likely lead to system fault. Hence, we have to focus on tracking them.

TABLE 8 Safety analysis results of braking system

Code	Output unreliability（Cumulative probability of fault）	Output reliability（Normal work probability）	Component input inverse Probability	Component inverse Probability
1-A1	2.9996E-04	9.9970E-01	1.0271E-02	1.0271E-02
2-A2	7.4972E-04	9.9925E-01	2.5671E-02	1.5405E-02
2-A3	1.3491E-03	9.9865E-01	4.6194E-02	2.0538E-02
2-A4	1.3990E-03	9.9860E-01	4.7903E-02	1.7120E-03
2-B1	1.4989E-03	9.9850E-01	5.1322E-02	3.4239E-03
2-B2	1.6187E-03	9.9838E-01	5.5425E-02	4.1086E-03
2-B3	1.8683E-03	9.9813E-01	6.3970E-02	8.5591E-03
3-B4	2.7362E-03	9.9726E-01	9.3691E-02	2.3968E-03
1-B5	7.9968E-04	9.9920E-01	2.7382E-02	2.7382E-02
2-C1	1.6986E-03	9.9830E-01	5.8160E-02	1.0271E-02
2-C2	1.7984E-03	9.9820E-01	6.1578E-02	3.4239E-03
2-C3	1.8483E-03	9.9815E-01	6.3287E-02	1.7120E-03
2-C4	2.1477E-03	9.9785E-01	7.3538E-02	1.0271E-02
2-C5	3.1450E-03	9.9685E-01	1.0769E-01	3.4224E-02
2-C6	3.1450E-03	9.9685E-01	1.0769E-01	3.4224E-02
2-C7, 2-C8	4.1414E-03	9.9586E-01	1.4180E-01	5.1357E-03

3-C9	4.9378E-03	9.9506E-01	1.6907E-01	1.7116E-02
2-C10	2.1477E-03	9.9785E-01	7.3538E-02	1.0271E-02
2-C11, 2-C12	3.1450E-03	9.9685E-01	1.0769E-01	3.4224E-02
2-C13, 2-C14	4.1414E-03	9.9586E-01	1.4180E-01	5.1357E-03
3-C15	4.9378E-03	9.9506E-01	1.6907E-01	1.7116E-02
3-D1	7.1146E-03	9.9289E-01	2.4361E-01	6.8474E-03
1-D2	4.1912E-03	9.9581E-01	1.4351E-01	1.4351E-01
2-D3	3.6334E-03	9.9637E-01	1.2441E-01	3.0803E-02
3-D4	8.0078E-03	9.9199E-01	2.7419E-01	1.3694E-02
3-D5	1.5056E-02	9.8494E-01	5.1551E-01	2.7391E-03
5-D6	6.6279E-03	9.9337E-01	2.2694E-01	0
3-D7	1.5252E-02	9.8475E-01	5.2226E-01	6.8474E-03
2-E1	3.0354E-03	9.9696E-01	1.0393E-01	1.0271E-02
2-E2	3.4341E-03	9.9657E-01	1.1759E-01	1.3694E-02
3-E3	3.8824E-03	9.9612E-01	1.3294E-01	1.1982E-02
1-E4	9.9995E-05	9.9990E-01	3.4239E-03	3.4239E-03
3-E5	1.7367E-02	9.8263E-01	5.9467E-01	1.0271E-02
1-E6	1.5942E-02	9.8406E-01	5.4585E-01	2.3960E-02
2-E7	1.7485E-02	9.8251E-01	5.9871E-01	4.1086E-03
2-F1,2-F2	1.7780E-02	9.8222E-01	6.0880E-01	1.0271E-02
3-F3, 3-F4, 3-F5, 3-F6	1.9595E-02	9.8040E-01	6.7096E-01	1.1982E-02
2-F7, 2-F8, 2-F9, 2-F10	1.9693E-02	9.8031E-01	6.7432E-01	3.4239E-03
1-F11, 1-F12, 1-F13, 1-F14	1.4989E-03	9.9850E-01	5.1322E-02	5.1322E-02
2-F15, 2-F16, 2-F17, 2-F18	2.0575E-02	9.7942E-01	7.0451E-01	3.0803E-02
5-F19	2.3363E-02	9.7664E-01	7.9996E-01	0
5-F20	2.3363E-02	9.7664E-01	7.9996E-01	0
5-F21	2.9205E-02	9.7079E-01	1.0000E+00	0

D. Experimental Analysis

We can conclude from the above safety analysis:

(1) When a system shows abnormal conditions, we have to obtain real-time inverse probability through the fault backward reasoning method. The inverse probability of components (3-B4, 1.3070E-02), (1-B5, 1.4932E-01), (3-D1, 3.7340E-02), (1-D2, 7.8258E-01), and (1-F11, 4.7087E-01) is significantly larger than the others', which shows that these parts may be abnormal. We should thus focus on tracking them. In addition by using the system diagram model to analyze 3-B4, 1-B5, 3-D1, and 1-D2, which are working parts connected together, the abnormal output of 3-D1 indicates that the failure possibility of these four components is very large, and the failure possibility of (1-D2, 7.8258E-01) is the highest. It represents Electronic Control Unit instruction, error rate of which is higher, because it has many electronic circuit components. While (1-F11, 4.7087E-01) is an independent failure, in fact, it represents the speed sensor with a self-resetting function. Its false detection occurs frequently. If an abnormal event is detected when its probability of failure is less than 1/2, we should check and maintain them.

(2) Traditional fault probability calculation depends on the forward deduction of historic data. By contrast, the GO-Bayes method provides structural models of a system and inverse reasoning probability. The models' output and inverse probability reflect more accurately the system's reliability than traditional fault probability. Figure 22 is a metro train's braking system based on FTA. Table 9 shows GO-Bayes' advantage compared with FTA.

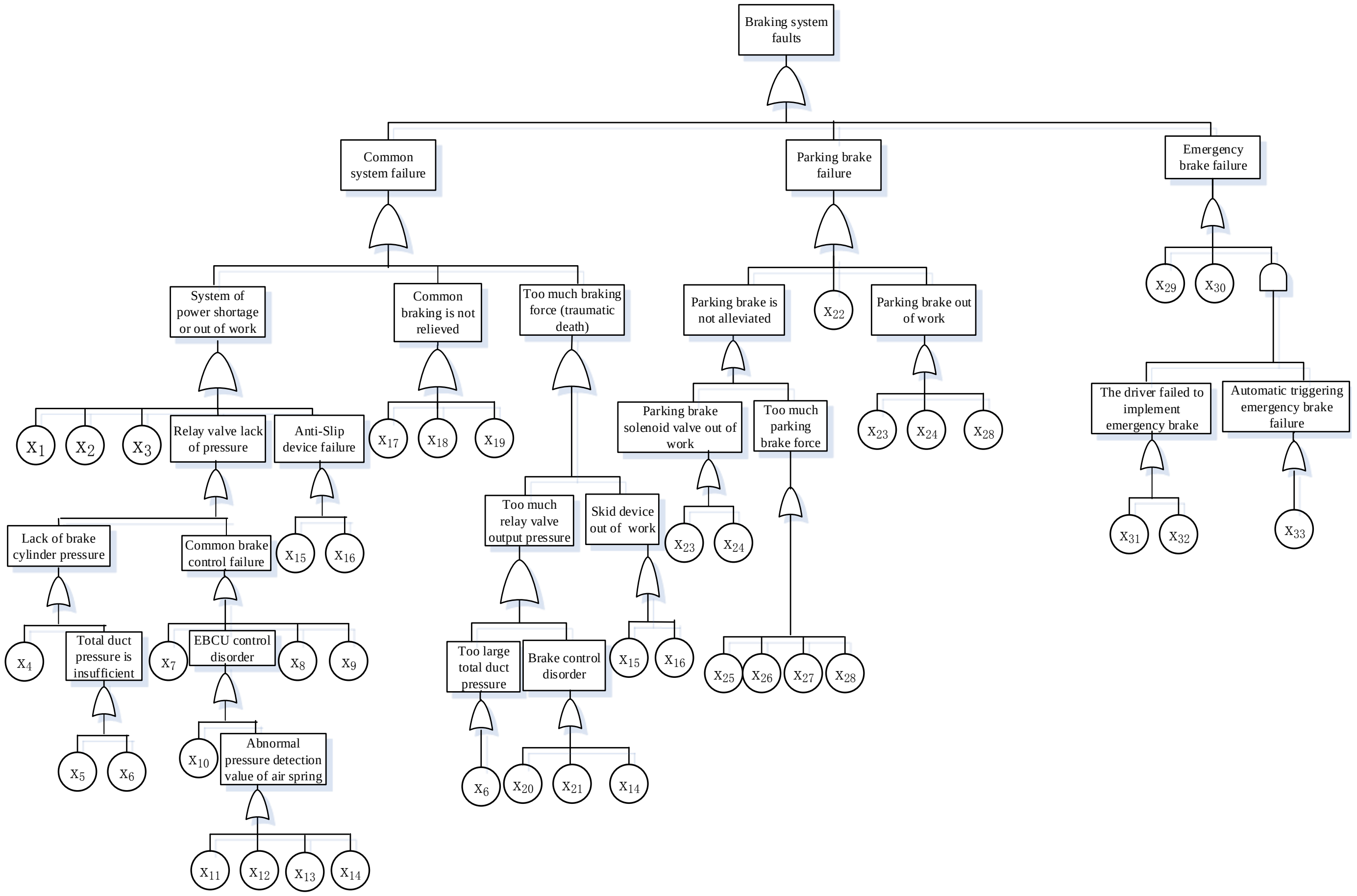

Figure 22 A metro train's braking system based on FTA

TABLE 9 GO-Bayes compared with FTA

Model Feature	GO- Bayes	FTA
Modeling oriented	success	Failure
Modeling method	bi-direction induction	deductive
Modeling consistency	basically identical	differences according to everyone's understanding
Structure	similar principle diagram	hierarchical logic diagram
Volume	compact, small size	multi-layer, huge volume
Elements	component, logic diagram	fault event, logic gate
Description	reflect original system structure	reflect the failure cause and effect
Notation	more operators with rich expression	less operators with poor expression

V. CONCLUSION

This paper presents a new structural GO-Bayes method. It is a comprehensive system safety analysis and evaluation modeling methodology. Using a system diagram model, we can obtain the system's normal work probability output, which is essential for fault backward reasoning. The paper discusses basic components or units and their related analysis results. The application of the proposed method to a metro vehicle braking system shows its contribution to safety analysis and assessment. The results can be used to trace, maintain and improve system components and eventually ensure the entire system's safe operation.

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