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A new algorithm of GO methodology based on minimal path set

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Abstract

The existing GO methodology algorithm is theoretical, and hard to solve with computer. In this paper, we research a new method to get the reliability of system based on GO methodology. According to some properties of the operators in GO chart, GO chart can be transformed into series structure, then the minimal path sets are induced based on Enumeration method from first operator to last one. It is very convenient for computer to calculate the system reliability with the new method based on minimal path sets. The case study indicates the method is suitable for practical engineering, which can be used to possess the quantitative analysis of complex GO methodology models.

Keywords: GO methodology; Reliability; Minimal Path Sets;

1. Introduction

The GO methodology is an available method of system reliability analysis. Different with some other modeling method, such as static FTA, it is a success-oriented one and mainly be used to solve the problem of systems with multiple states and time-sequential signals. This method was first introduced from Kaman Science Company of USA in the middle of 1960s, and had been used to analyze the safety and reliability of weapon system. In the early 1980s, Go methodology had got the further improvement and development.

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Meanwhile, on the basis of GO methodology two scholars developed the GO-FLOW methodology, which is more suitable for reliability analysis of phased-mission systems and dynamic systems [3-5].

In the early 1980s, Institute for Standardization of Nuclear Industry first introduced GO methodology in China. In recent years, GO methodology has developed rapidly in theory and practical method, such as the probability accumulation algorithm and probability quantitative analysis method with common cause failures. By far, GO methodology has been used to analyze or assess the reliability of many practical engineering systems, such as nuclear power plant power system, natural gas pipes system and aviation electronic equipment. Although GO methodology has many advantages, the existing algorithm is theoretical, and hard to solve with computer, which makes it difficult to apply and popularize in complex engineering systems. Therefore, the GO methodology for computer solving becomes the bottle neck to generalize the method [2].

In this paper, a new algorithm is provided. First, the GO chart is transformed into series structure. Based on each GO operator's attribute and characteristic, let the GO chart become a series structure, use new chart get the minimal path sets. Last, it can directly deduce the minimal path sets and calculate the value of system reliability. It will simplify the programming and decrease the computational consumption.

2. Algorithm of GO Methodology

Zhupei Shen had presented two algorithms of GO methodology [2].

One is State Composite algorithm, according to which, we can obtain operators' state composite sets and compute the signal state probability, then using combination and simplification to obtain minimum path sets and cut sets. However, if the number of operators rises, the number of state combination will explode.

The other is Probability Accumulation algorithm, which can be used to compute the state probability of the signal according to the operators' state probability formula and the state probability. Moreover, the algorithm can get the minimal cuts of the two-state system with quantificational computing [5].

2.1. Path Sets and Minimal Path Sets.

The system reliability may also be determined using minimal path sets. A path is a set of components whose functioning ensures that the system functions. A minimal path is one in which all the components within the set must function for the system to function [6].

2.2. GO Chart Processing

GO methodology has defined seventeen kinds of operators, denoted with the type of 1-17. In the GO methodology, every operator represent a specific component, the signal-flows represent connections between the operators. The operators represent specific function and the input and output signals have to obey the operation rules.

Although GO methodology owns seventeen kinds of operators, only ten of them are usually used. We denote them by set A, A={1,2,3,5,6,7,8,9,10,11}$A = \{1, 2, 3, 5, 6, 7, 8, 9, 10, 11\}$, the type 2, 10 and 11 operators are logical operators and they represent logical relation of multiple input signals, others are functional operators. The logical operator only represent the relationship, and don't have state probability, so the logical operators are not included in the minimal path set.

From the set of function operator, type 6, 7 and 8 operators have two input signals, when we deduce the minimal path sets by Enumeration method, first, put the second input signal in series with the main input signal. Then, delete the same operators between second input signal and main input signal. Then, getting a new chart where type 6, 7 and 8 operators have only one input signal. From Figure 1, we know type 1, 3, and 5 operators have only one input signal. These operators needn't to be possessed.

In the set of logical operator, these three kinds of operator only represent the logical relationship among the signals. Generally, each logical operator has at least two or more than two input signals. When deduce the minimal path sets, we need processing the logical operators. If GO chart include the type 2 operator, according to the property of OR gate, add the operator OR gate and the operators after OR gate to N signals before OR gate. If GO chart include the type 10 operator, let N signals before AND gate become one signal, after it delete the same operators in these N signals. If GO chart include the type 11 operator, let the operators which connect with the *K*-out-of-*M* gate become in series with each other by K operator, So we have C_M^K kinds of combination, and support the operators forward of these C_M^K kinds combination.

If a signal is connected to two or more operators as the input signal (or one operator have two or more than two output signals), then this signal is defined as a shared signal. When GO chart has a shared signal, copy all the operators behind this operator onto the shared signals.

2.3. Solve the Reliability Model with Minimal Path Sets

Use all the minimal path sets: $A_1, A_2, A_3, \cdots, A_n$ which are deduced by new series model of GO chart of the system. In case the system is on the successful state, only if exist at least one minimal path set. Supposed that S denotes the event of the system normal working, then:

$$S = \bigcup_{i=1}^{n} A_i$$

The i th minimal path set exists, meaning that every operator in this minimal path set is successful, x_{ij} $\boldsymbol{x}_{ij}$ represents the j th factor in the set i . Then:

$$A_i = \bigcap_{x_y \in A_i} x_{ij}$$

Construct the reliability mathematical model of the system with the probability equation of mutually inclusive events. The model is:

$$R_s = P(S) = P(\bigcup_{i=1}^{n} A_i) = \sum_{i=1}^{n} P(A_i) - \sum_{i<j=2}^{n} P(A_i \bigcap A_j) + \sum_{i<j<k-2}^{n} P(A_i \bigcap A_j \bigcap A_k) + \cdots + (-1)^{n-1} P(\bigcap_{i=1}^{n} A_i)$$

3. Case Study

3.1. System Definition

Water supply system as example has two states: the success and the failure. This system has one water source and two waterways, each way includes an electric pump, a check valve and two control valves which are in parallel and always closed. So every waterway has two water supply export, and the system have four water supply export. Electric pump on each waterway has its own power. Only the power state is success, the pump can work, two control valves in each waterway are controlled by own control signal. Only the control signal is success, the control valve can open. The successful state is that at least two water supply export successful. Figure 1 shows the water supply system principle diagram.

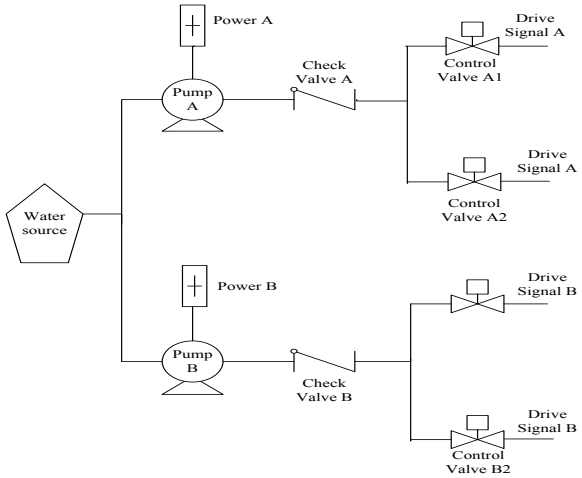

Figure 1 water supply system principle diagram

3.2. Establishing Reliability Model with GO Methodology

The GO methodology Model is easy established based on water supply system functional diagram. First, according to the function of water supply system components, corresponding type of operators represent specific components. For example, water source is the input of the system, which is represented by type 5 operator. Similarly, powers and drive signals are also represented by type 5 operator. The electric pump needs the control signal to operator normally, which is represented by type 6 operator. Here, the primary input signal is from water source, and the secondary control signal is the output of the power. Similarly, control valves must operate upon receiving the control signals, which are also represented by type 6 operator. The check valves are two states components, which we use operator 1.

For water supply system, at least two water supply export are successful, then the water supply is successful, this logical relationship is represented by type 11 operator. Figure 2 shows the GO chart of this water supply system.

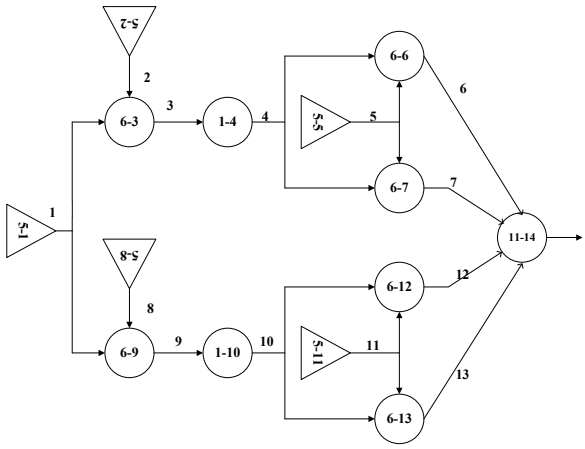

Figure 2 GO chart of water supply system

The first number in the operators of the GO chart represents the type of operators, the second number represents the numbering of operators, and the numbers on the signal line mean the numbering of signals.

The input of the system consists of the water power, the power and the drive signal sources, which are represented by Type 5 operator, the check valves are represented by Type 1 operator. The electric pumps and control valves are represented by Type 6 operator.

3.3. Deducing the Minimal Path Sets on Go Chart

From Figure 2, the system starts from operator 5-1, ends with operator 11-14. This Go chart is too complex to deduce the minimal path sets directly, it should be dealt with, form the last operator to the first one. First, operator 11-14 is a 2-out-of-4 gate, let the four operators which connect with operator 11-14 in series by two, so there are C_4^2 kinds of combination, and the 6 kinds of combination are 6-6 and 6-7,6-6 and 6-12,6-6 and 6-13,6-12 and 6-13,6-7 and 6-12,6-7 and 6-13.

Next, from Figure 2, the operator 6-7 connect with operator 11-14, then find the operator which is the input of operator 6-7 based on GO chart. According to the figure 2, find that operator 5-5 and 1-4 are all connected with operator 6-7. Similarly, operator 5-5 and 1-4 are the input of operator 6-6, and in Figure 2, operator 6-6 is connected with operator 6-7. Operator 5-5 is the input of system, it has no input signal, needn't to deal it. Operator 6-3 is connected with operator 6-6 and behind operator 6-6, we find operator 6-3 has two input signal 5-1 and 5-2. Figure 3 is the one of the minimal path of the water supply system.

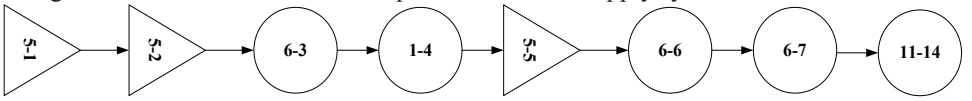

Figure 3 the first minimal path

Similarly, we deduce the rest of 5 kinds of combination. At last, according to the operator type, we remove all logical operators and get the final minimal path sets in Table 1, and Figure 4 shows the final Go chart.

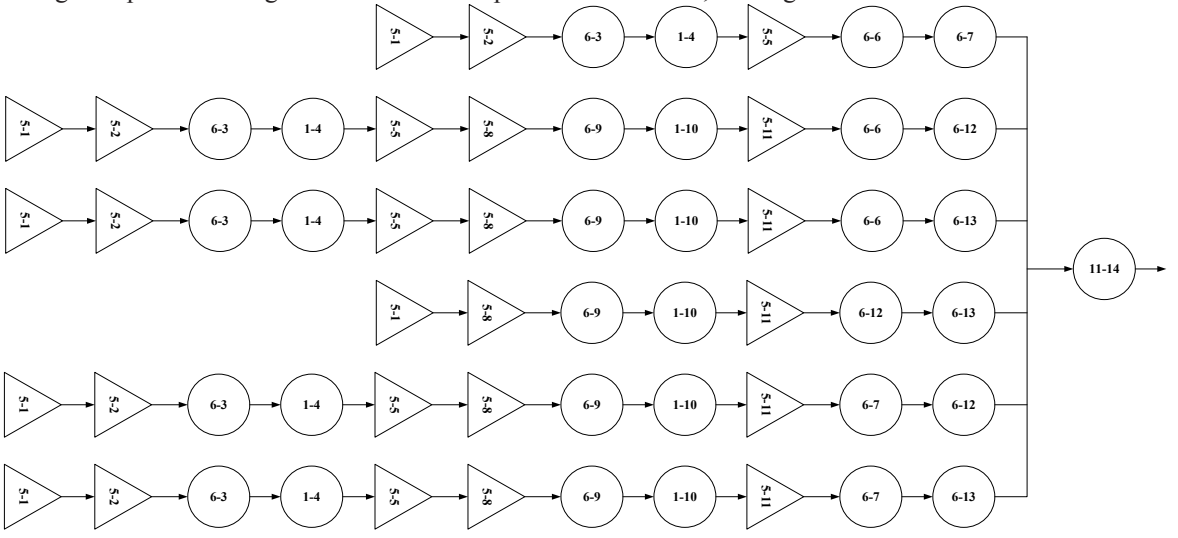

Figure 4 the final chart

Table 1. Final Minimal Path Sets

NO.	Minimal Path Sets
1	5-1,5-2,6-3,1-4,5-5,6-6,6-7
2	5-1,5-2,6-3,1-4,5-5,6-6,5-8,6-9,1-10,5-11,6-12
3	5-1,5-2,6-3,1-4,5-5,6-6,5-8,6-9,1-10,5-11,6-13
4	5-1,5-8,6-9,1-10,5-11,6-12,6-13
5	5-1,5-2,6-3,1-4,5-5,6-7,5-8,6-9,1-10,5-11,6-12
6	5-1,5-2,6-3,1-4,5-5,6-7,5-8,6-9,1-10,5-11,6-13

3.4. Calculation

The water supply system is a two-state system, including thirteen function operators; Table 2 shows the probability of failure of each component.

Table 2. the Failure Probability of the Components

NO.	type	component	Probability of failure
1	5	Water source	0.999
2	5	Power A	0.99
3	6	Electric Pump A	0.99
4	1	Check Valve A	0.995
5	5	Drive Signal A	0.95
6	6	Control Valve A1	0.99
7	6	Control Valve A2	0.99
8	5	POWER B	0.99
9	6	Electric Pump B	0.99
10	1	Check Valve B	0.995
11	5	Drive Signal B	0.95
12	6	Control Valve B1	0.99
13	6	Control Valve B2	0.99
14	11	4/2	

Hence, the result of the mission reliability based on the minimal path sets is as followed.

$$R_s = P(S) = P(A_1 \bigcup A_2 \bigcup A_3 \bigcup A_4 \bigcup A_5 \bigcup A_6) = 0.990881232$$

4.Conclusions

In this paper, we propose a new method to calculate the reliability of GO methodology. According to logical relationship of the operators in GO chart, we transform GO chart into series model, then get the minimal path sets based on enumeration method from first operator to last one. This new algorithm is suitable for computer aided solving. The application of the case indicates the method can be used in practical engineering, which can efficiently deal with the quantitative analysis of complex GO methodology models.

References

[1] Zeng Shengkui, Zhao Tingdi, Zhang Jianguo, Kang Rui and Shi Junyou, a course in System reliabiltiy design and analysis, Press of Beihang University,Beijing; 2001.
[2] Shen Zupei and Huang Xiangrui, GO methodology and application, Tsinghua University Press, Beijing; 2004.
[3] Shen Zupei and Tang Hui, System reliability analysis with shared caused failures using the GO methodology. Tsinghua Uinv(Sci&Tech), 2006; Vol 46, No.6, p. 829-832.

[4] Heqing Li and Qing Tan, Reliability Analysis of Hydraulic System for Type Crane Based on Go Methodology, 2009 Second International Conference on Intelligent Computation Technology and Automation; 2009
[5] Yi Ren, Leixing Kong, Zhi Fu, An Algorithm of GO Methodology based on Connection Matrix of Minimal Path Sets, 2010 IRAST International Congress on Computer Applications and Computational Science 2010; p.923-927
[6] Charles E.Ebeling, An Introduction to Reliability and Maintainability Engineering. Beijing: Tsinghua University Press; 2008.