Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2014, 6(3):482-488

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Maloperation consequence identification in process transition

Zhang Yuliang, Zhang Beike, MA Xin, Gao Dong* and CAO Liulin

College of Information Science and Technology, Beijing University of Chemical Technology, Beijing, China

---

ABSTRACT

Based on hazard and operability study (HAZOP) and concept of qualitative simulation, an automatic method for adverse consequence identification of potential maloperation is proposed. The method was shown by a heating furnace process. The results show that automatic control process can be simulated qualitatively; hazard and state evolution of qualitative model can be identified for given maloperation.

Keywords: maloperation, consequence identification, process transition, hazard and operability study, qualitative simulation

---

INTRODUCTION

Chemical processes can operate in different steady states, and the change from one steady state to another is called process transition. Some common transitions that chemical processes undergo are startups, shutdowns, and grade changes. Abnormal situations can occur more frequently during process transitions due to sudden changes involved in process states in this period and probabilities of operator errors [1].

To guarantee safe operation, process hazard analysis (PHA) is very important to proactively identify the potential safety problems and recommend possible solutions [2]. In the chemical process industry, HAZOP is the most widely used and recognized as the preferred PHA approach. HAZOP is widely used to identify potential hazards and operability issues [3-5].

During a transition, there is a great amount of operator involvement in the operation of the plant, which increases the probability of abnormal situations. If operations of operators deviate from normal operating procedure, accidents and other abnormalities might happen [6].

Through literature search, we find that few works specially study PHA for process transition. In literature [7], a procedure to aid hazards identification for process chemicals during shutdown is listed. In literature [8], a proton-exchange-membrane fuel-cell (PEMFC) system is the subject of an operational and process-safety analysis.

In this paper, based on HAZOP and concept of qualitative simulation, an automatic method for maloperation consequence identification is proposed. Qualitative model of production process is expressed by a novel directed graph. Operating procedure is expressed by using defined syntax. The proposed algorithm conducts qualitative simulation of process transition and adverse consequence identification.

EXPERIMENTAL SECTION

2 PROPOSED METHOD

2.1 Qualitative model of production process

Fig. 1 shows graphic elements that are used to construct qualitative model of production process.

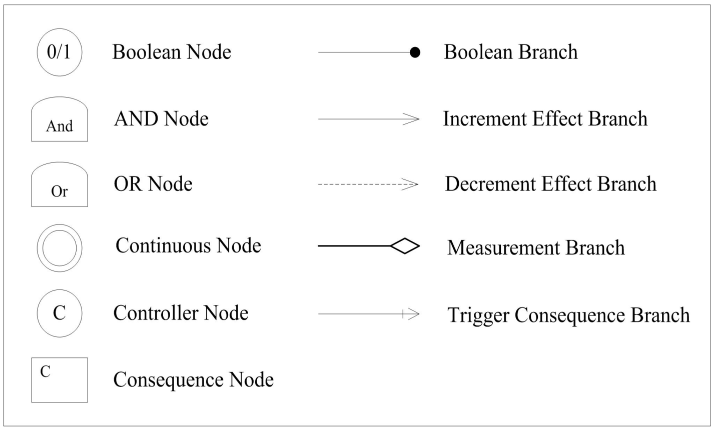

Figure 1 Graphic elements used to construct qualitative model of production process

Every branch can have a condition. -||- is used to mark the starting point of the branch when condition exists. If condition doesn't exist or condition exists and is satisfied, then branch is enabled.

Boolean Node is used to express open or closed state of switch valve, whether flow or level exists or not, and whether a description is true or not. Boolean Node has parameter y_0, and y. The value of parameter y_0 is previous value of parameter y. The value of parameter y is determined by following way: If input branch, namely branch of pointing Boolean Node, is enabled, y = 1 when parameter y of start node of input branch is not 0; y = 0 when parameter y of start node of input branch is 0.

Boolean logic provides an easy and intuitive way to express causality in production process. AND Node and OR Node have parameter y, and the value is calculated according to conventional computation method of Boolean logic. Boolean Branch is designed to point Boolean Node, AND Node, and OR Node.

Continuous Node is used to represent process variable whose value can change continuously, like level and temperature. Continuous Node is expressed by parameters y_0, y, $\triangle y$. The value of parameter y_0 is previous value of parameter y. The value of parameter y is the value of process variable. The parameter $\triangle y$ is variation of y. The general form for using Continuous Node is shown in Fig. 2. Increment Effect Branch and Decrement Effect Branch are designed to point Continuous Node. w_j ($j \in \{1,2,\cdots,r\}$) is increment or decrement effect weight and is determined by following four types of expression. Type 1: $w_j = a$, Type 2: $w_j = n_j.\Delta y * k$, Type 3: $w_j = \frac{n_j.\Delta y}{n_j.\Delta y_{\max}} * f_1 * f_2 \cdots f_n * \Delta y_{\max}$, and Type 4: $w_j = \frac{n_j.y}{n_j.y_{\max}} * f_1 * f_2 \cdots f_n * \Delta y_{\max}$. a is a fixed value, $n_j.\Delta y$ represents variation of y of start node of the j th input branch, k is a coefficient, $\Delta y_{\max}$ represents maximum variation of y of current node, which is caused by start node of input branch, and $f_1, f_2, \cdots f_n$ represent n constraint functions. Every constraint function is expressed according to form $\frac{n.y}{n.y_{\max}}$.

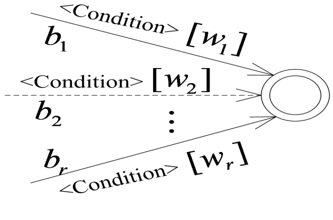

Figure 2 General form for using Continuous Node

The values of parameters "$\triangle$y" and "y" are determined by following way:
When input branch b_j ($j \in \{1,2,\cdots,r\}$) is enabled,

$$\Delta y = \sum_{j=1}^{r} \varphi_j w_j \tag{1}$$

$$\varphi_j = \begin{cases} +, & b_j \text{ is Increment Effect Branch} \\ -, & b_j \text{ is Decrement Effect Branch} \end{cases} \tag{2}$$

r is the number of input branches. If every input branch is not enabled, Δy will be 0.

$$y = \begin{cases} UL, & y_0 + \Delta y > UL \\ y_0 + \Delta y, & LL \le y_0 + \Delta y \le UL \\ LL, & y_0 + \Delta y < LL \end{cases} \tag{3}$$

Controller Node is used to qualitatively simulate function of PID controller. In this paper, pure proportion controller is used to control qualitative model. Controller Node is expressed by parameters *Mode*, K_P, *SP*, *PV*, *K*, $\triangle y$. The parameter *Mode* represents work mode of controller. The parameter K_P is proportion coefficient. The parameter *SP* is set value of controller, and *PV* is measured value of controlled variable. The parameter *K* represents positive or negative effect of controller. That *K* is 1/-1 indicates positive effect/negative effect. The parameter $\triangle y$ represents variation of controller output. Value of *PV* is value of parameter *y* of start node of input branch. When *Mode* = MANU, *SP* = PV. Value of parameter $\triangle y$ are determined by following way.

$$\Delta y = \begin{cases} \text{value set manually}, & Mode = MANU \\ K * \dfrac{K_P * (PV - SP)}{PV_{max} - PV_{min}} * 100, & Mode = AUTO \end{cases} \tag{4}$$

Consequence Node is used to contain possible adverse consequence led by maloperation. Trigger Consequence Branch is designed to point Consequence Node.

2.2 Operating procedure

In this paper, an operating procedure consists of one or more operating stages, and an operating stage consists of one or more basic actions. Every operating stage achieves an operating goal through finite basic actions. A template representation for operating procedure provides an intuitive way to express basic action [9]. In this paper, name of operating stage is expressed in natural language. A basic action of operator is expressed qualitatively according to a template representation as shown below.

Action Item_Number [Para = Value] / [ActEndCon]

The following actions exist: open, close, run, stop, set, and wait. "Item_Number" represents the item number of equipment or process variable. "ActEndCon" is end condition of the basic action. The basic action will be performed repeatedly if this condition is not satisfied. The content in square brackets is optional.

Before adverse consequences of designated maloperations are identified, these maloperations should be expressed in operating procedure according to guidewords, such as No, Before, After, Early, and Late. For examples, for guideword "No", delete one or more operating stages or basic actions in operating procedure; for guideword "After", move one or more operating stages or basic actions backward.

2.3 Algorithm

After applying one guideword to normal operating procedure, an operating procedures including maloperation will be got. Then use proposed algorithm shown in Fig. 3 to qualitatively simulate process transition, for example startup process. When "Use depth-first strategy to update state of qualitative model of production process from current node" is performed, values of parameters of nodes in production process model are updated according to method given in section 2.1. Once one branch pointing Consequence Node is enabled, adverse consequence contained in Consequence Node will be output, and execution of algorithm will stop.

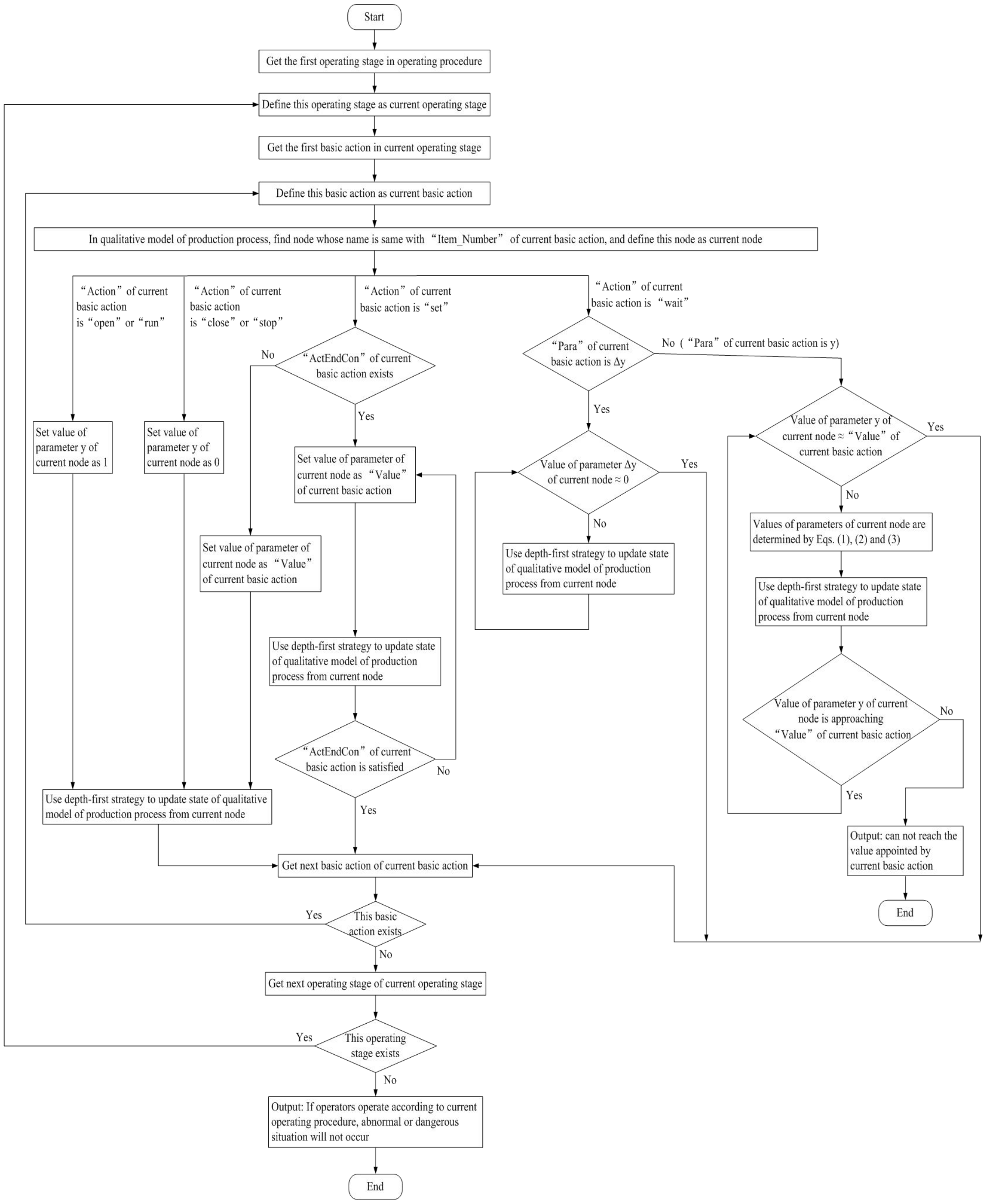

Figure 3 Algorithm used to identify adverse consequence of maloperation

3 CASE STUDY

Heating furnace is important equipment in petrochemical industry. Therefore, one heating furnace process is used to show proposed method, as shown in Fig. 4. "DO-01" is damper, and AI-01 represents oxygen content in flue gas.

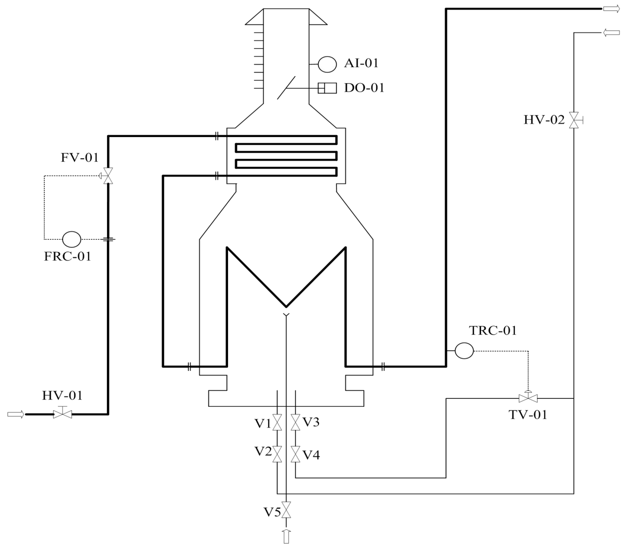

Figure 4 Production process of one heating furnace

For production process shown in Fig. 4, the qualitative model has been constructed, as shown in Fig. 5.

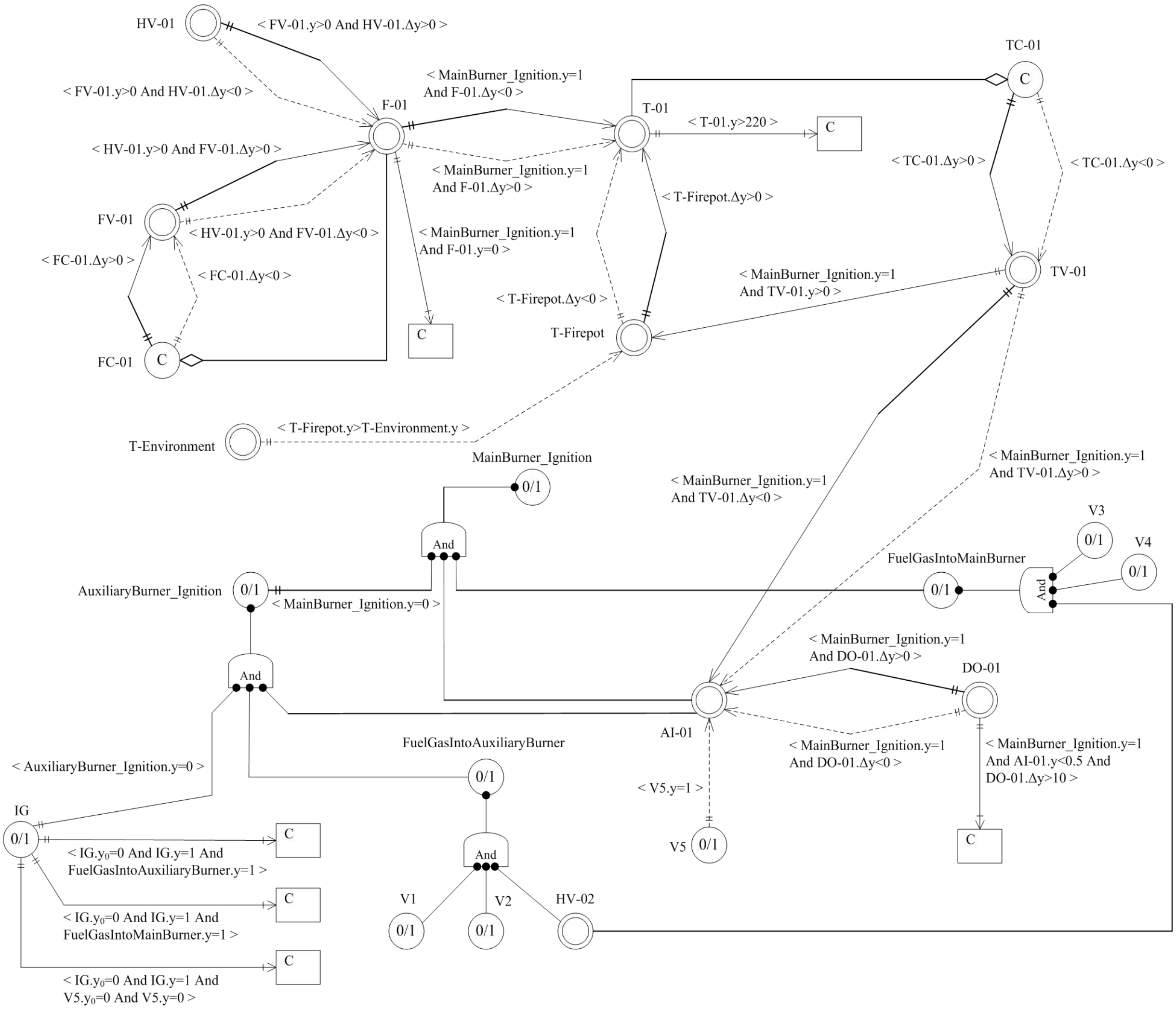

Figure 5 Qualitative model of production process for heating furnace

Table 1 shows the startup operating procedure for heating furnace.

Table 1 Startup operating procedure for the heating furnace process

Operating Stage		Basic Action	
No.	Name	No.	Expression
1	Lead kerosene to heating furnace	1	set HV-01 Δy = 10 / HV-01 y = 100
		2	set FC-01 Δy = 2 / F-01 y ≥ 5
2	Flush firepot with steam	1	set DO-01 Δy = 10 / DO-01 y = 100
		2	open V5
		3	wait AI-01 y = 10
		4	close V5
3	Ignite auxiliary burner	1	set HV-02 Δy = 10 / HV-02 y = 100
		2	set DO-01 Δy = -10 / DO-01 y = 50
		3	open IG
		4	open V1
		5	open V2
4	Ignite main burner	1	open V3
		2	open V4
5	Increase temperature	1	set TC-01 Δy = 2 / TV-01 y = 40
		2	wait T-01 y = 200
		3	set TC-01 Mode = AUTO
		4	wait T-01 Δy = 0
6	Increase kerosene flow	1	set FC-01 Δy = 2 / F-01 y ≥ 15
		2	set FC-01 Mode = AUTO
7	Wait steady production state	1	wait F-01 Δy = 0
		2	wait T-01 Δy = 0

In order to save space, only two examples are shown below.

Example 1
When normal operating procedure shown in Table 1 is performed, dynamic change of process variable T-01 from operating stage "Increase temperature" is shown in Fig. 6. What should notice is that abscissa axis represents number of times of qualitative model update rather than time. After T-01 reaches 200 ℃, it decreases with increment of F-01. Then T-01 reaches steady state slowly under the control of TC-01.

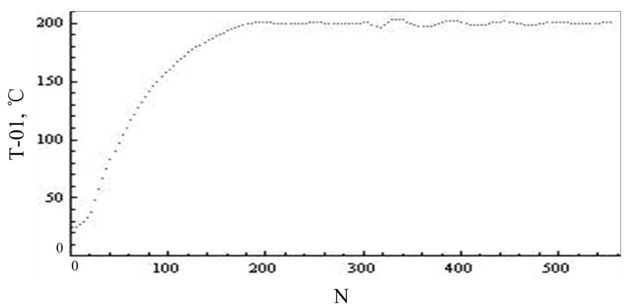

Figure 6 Dynamic change of process variable T-01

Example 2
Apply guideword "After" to basic action "open IG" in operating stage "Ignite auxiliary burner": move basic action "open IG" backward until the end of this operating stage. For operating procedure including this maloperation, when basic action "open V1" is performed, the state update process of qualitative model from node V1 is "V1 (1) → And (0) → FuelGasIntoAuxiliaryBurner (0) → And (0) → AuxiliaryBurner_Ignition (0) → And (0) → MainBurner_Ignition (0)". The value in round brackets is node's final value after state update process of qualitative model from node V1. When basic action "open V2" is performed, the state update process of qualitative model from node V2 is "V2 (1) → And (1) → FuelGasIntoAuxiliaryBurner (1) → And (0) → AuxiliaryBurner_Ignition (0) → And (0) → MainBurner_Ignition (0)". When basic action "open IG" is performed, condition "IG.y_0=0 And IG.y=1 And FuelGasIntoAuxiliaryBurner.y=1" within branch going from node IG is satisfied. Namely, this branch is enabled. Therefore, adverse consequence "Fuel gas has been in firepot before auxiliary burner is ignited. Firepot has a risk of explosion." in Consequence Node pointed by this branch is output. Then adverse consequence identification process for maloperation stops.

CONCLUSION

Based on hazard and operability study technique and concept of qualitative simulation, an automatic method for adverse consequence identification of maloperation in process transition was proposed. The method is applied to a heating furnace process. The results show that (1) automatic control process can be simulated qualitatively; (2) hazard and state evolution of qualitative model can be identified for given maloperation. Dynamic change of process variable may not match real situation exactly, but it can qualitatively express effect of operation on production process. After analysis for possible plant maloperations, some measures can be taken to effectively avoid maloperations or reduce losses led by maloperations.

REFERENCES

[1] Bhagwat, A., Srinivasan, R., Krishnaswamy, P. R., *Chem. Eng. Sc.*, **2003**,58, 309–325.
[2] Zhao, C., Bhushan, M., Venkatasubramanian, V., *Process Saf. Environ.*, **2005**, 83, 509–532.
[3] Vaidhyanathan, R., Venkatasubramanian, V., *Computers chem. Engng*, **1996**, 20, 1589-1594.
[4] Palmer, C., Chung, P.W.H., *J. Loss Prev.*, **2008**, 21, 537-542.
[5] Mushtaq, F., Chung, P.W.H., *J. Loss Prev.*, **2000**,13, 41-48.
[6] Sundarraman, A., Srinivasan, R., *Comput. Ch. E.*, **2003**, 27, 1455-1472.
[7] Malmén, Y., Nissilä, M., Virolainen, K., Repola, P., *J. Loss Prev.*, **2010**, 23, 249-252.
[8] Gerbec, M., Jovan, V., Petrovčič, J., *Int. J. Hyd. E.*, **2008**, 33, 4147-4160.
[9] Palmer, C., Chung, P.W.H., *Reliab. Eng.*, **2009**, 94, 1095-1106 .