21st European Symposium on Computer Aided Process Engineering – ESCAPE 21
E.N. Pistikopoulos, M.C. Georgiadis and A. Kokossis (Editors)

An Evaluation Method for Plant Alarm System Based on a Two-Layer Cause-Effect Model

Naoki Kimura,[a] Kazuhiro Takeda,[b] Masaru Noda,[c] Takashi Hamaguchi[d]

[a]*Faculty of Engineering, Kyushu University, 744 Motooka, Fukuoka 819-0395, Japan*
[b]*Faculty of Engineering, Shizuoka University 3-5-1 Johoku Hamamatsu466-8555,Japan*
[c]*Graduate School of Information Science, Nara Institute of Science and Technology, 8916-5 Takayama, Ikoma 630-0192, Japan*
[d]*Graduate School of Engineering, Nagoya Institute of Technology, Gokiso, Showa-ku, Nagoya 466-8555, Japan*

Abstract

Industrial plant alarm system forms the core element of almost all modern operator interfaces used to automatically monitor plant conditions and alert plant operators to any significant changes that require diagnosis and/or countermeasures. In this paper, we propose a method for quantitatively evaluating the diagnostic and timely characteristics of alarm system that uses a two-layer cause-effect model to measure three rates used as indices: effective, recall, and timeliness rates. The effective and recall rates are used to evaluate the diagnostic abilities of the alarm system in identifying root causes of assumed malfunctions. The timeliness rate is used to evaluate the plant alarm system's ability to generate diagnostic alarms quickly enough for operators to respond in a timely manner and correct the problem. The case study demonstrated the feasibility of the proposed method.

Keywords: Plant alarm system, Effective rate, Recall rate, Timeliness rate, Two-layer cause-effect model.

1. Introduction

Plant alarm system is important for the safe and reliable operation. When process variables become abnormal, alarms notify operators by sound, visual indication, message, etc. A poorly designed alarm system causes nuisance alarms, standing alarms, and alarm flooding and can even result in incidents or accidents (ISA, 2010). The Engineering Equipment and Materials Users' Association (EEMUA, 2007) issued a comprehensive guideline for designing, implementing, evaluating, improving, and buying an alarm system. This guideline summarizes some of the characteristics that each alarm should have; namely that it be relevant, unique, timely, prioritized, understandable, diagnostic, advisory, and focused. The diagnostic and timely elements are the most important characteristics of alarms. Izadi *et al.* (2009) proposed using the receiver operating characteristic (ROC) curve to illustrate the false alarm rate and the missed alarm rate trade-offs in alarm design, but did not mention a quantitative evaluation method from the viewpoints of diagnostic and timeliness characteristics.

In this paper, we propose a method for quantitatively evaluating the diagnostic and timely characteristics of alarm system that uses a two-layer cause-effect model to measure three rates used as indices: effective, recall, and timeliness rates. In this study, a case study demonstrated the feasibility of the proposed method.

2. Evaluation Method for Plant Alarm System

2.1. Diagnostic Alarm Variables Derived by Two-Layer Cause-Effect Model

Takeda *et al.* (2010) proposed an alarm variable selection method based on a two-layer cause-effect model. The model represents the cause and effect relationships between the deviations of state variables, such as process variables and manipulated variables, from normal fluctuation ranges. It is represented by a directed graph, where two types of nodes are defined.

i+: Upward deviation of state variable *i* from normal fluctuation range
i−: Downward deviation of state variable *i* from normal fluctuation range

In the two-layer cause-effect model shown in Figure 1, a single direction arrow links the deviation of a state variable and its affected state variable. The letters F and L indicate flow rate sensor and valve positions, respectively.

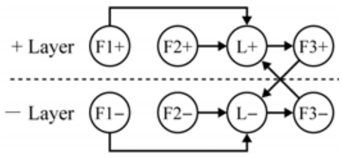

Fig. 1 Example of two-layer cause-effect model

An evaluation method for plant alarm system derives the sets of the state variables with the direction of their deviation from the normal fluctuation range. The derived sets are theoretically guaranteed to be able to qualitatively distinguish all assumed malfunctions in a plant when alarm limits are adequately set to those state variables. In this study, the derived sets are referred to as the sets of the diagnostic alarm variables.

2.2. New Indices for Evaluating Alarm System

In a previous study, we introduced two indices, the effective and recall rates, used to evaluate the diagnostic characteristic of a plant alarm system (Kimura *et al.*, 2010). Alarms are classified by diagnostic characteristic and generation. As shown in Table 1, w is the number of diagnostic alarms generated, x is the number of not generated diagnostic alarms, and y is the number of non diagnostic alarms generated. The effective rate, that is, the percentage of diagnostic alarms generated by the alarm system to all generated alarms, is calculated using Eq. (1). The recall rate, that is, the percentage of diagnostic alarms generated to all diagnostic alarms, is calculated using Eq. (2). High effective and recall rates indicate that the alarm system possesses strong enough characteristic to identify the root causes of assumed malfunctions.

In this study, we propose also using a timeliness rate, calculated using Eq. (3), for evaluating the timeliness characteristic of a plant alarm system. In Eq. (3), t_e is the elapsed time from the beginning of the malfunction to when all diagnostic alarm is generated, and t_a is the longest available time considering the time it takes for operators to respond and correct the problem generating the alarms after the malfunction occurs, which is determined in accordance with plant dynamics. A low timeliness rate indicates that the plant alarm system generates diagnostic alarms too late for operators to respond and correct the problem in a timely manner. Alarm system must be modified by alarm limits setting and so on. The effective, recall, and timeliness rates for each malfunction are calculated in accordance with simulation results.

$$\text{Effective rate [\%]} = w \,/\, (w + y) * 100 \quad (1)$$

$$\text{Recall rate [\%]} = w \,/\, (w + x) * 100 \quad (2)$$

$$\text{Timeliness rate [\%]} = \begin{cases} 100 & \text{if } 0 \le t_e \le t_a \\ 100\left(1 - \dfrac{t_e - t_a}{0.5 t_a}\right) & \text{if } t_a < t_e \le 1.5 t_a \\ 0 & \text{if } 1.5 t_a < t_e \end{cases} \quad (3)$$

Table 1 Criteria of diagnostic alarm system

	Generated	Not generated
Diagnostic alarms	*w*	*x*
Non diagnostic alarms	*y*	–

2.3. Procedure for Conducting Evaluation

First, the sets of diagnostic alarm variables that can be used to identify all assumed malfunctions in a plant are derived using the two-layer cause-effect model. The assumed malfunctions are then simulated using a model of the plant, and all alarms generated after each assumed malfunction occurs are recorded.

3. Case Study

3.1. Example Plant and Plant Alarm System

The proposed indices are demonstrated through a case study that uses the two-tank system in Fig. 2 as an example plant. Product is fed to Tank 1 and transferred to Tank 2. A certain amount of the product is recycled to Tank 1 from Tank 2. The letters P, F, L, and V in Fig. 2 indicate pressure, flow rate and liquid level sensors, and valve positions, respectively.

In this example plant, five types of malfunctions are assumed to be distinguishable from the operation of the plant alarm system.

Mal-1: High feed pressure (t_a = 120 min.)
Mal-2: Low feed pressure (t_a = 120 min.)
Mal-3: Blockage in recycle pipe (t_a = 30 min.)
Mal-4: Wrong valve operation of V4 open (t_a = 80 min.)
Mal-5: Wrong valve operation of V4 close (t_a = 80 min.)

Figure 3 shows the two-layer cause-effect model of the example plant. To distinguish the above 5 malfunctions, 2 types of alarm limits, high limit (PH) and low limit (PL), for 12 measured process variables were set as shown in Table 2. If the value of a state variable exceeds the corresponding alarm limit, the corresponding alarm is generated. The alarm settings in Table 2 were determined by taking account of plant dynamics.

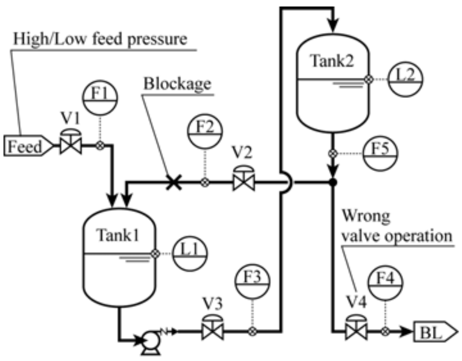

Fig. 2 Example plant of two-tank system

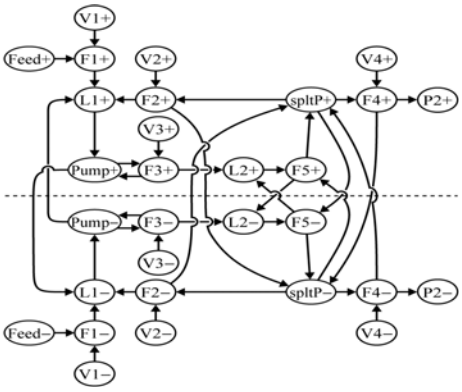

Fig. 3 Two-layer cause-effect model

Table 2 Alarm system and their PH and PL limits

Type	Alarm variables	Normal values	PH/PL settings	Units
Flow rate	F1	5603	5883/5323	kg/hr
	F2	16806	17647/15966	kg/hr
	F3	22409	22656/22083	kg/hr
	F4	5603	7128/4505	kg/hr
	F5	22409	1328/1183	kg/hr
Liquid level	L1	2.20	2.31/2.09	m
	L2	50.0	52.5/47.5	%
Valve position	V1	0.714	0.750/0.678	-
	V2	0.876	0.919/0.832	-
	V3	0.815	0.856/0.774	-
	V4	0.777	0.816/0.738	-

3.2. Results of Diagnostic Alarm Selection

All the sets of diagnostic alarms for the example plant, which can be theoretically used to distinguish all assumed malfunctions, were derived from the two-layer cause-effect model by using our previously reported diagnostic alarm selection method (Takeda *et al*., 2010). The minimum number of diagnostic alarms was three. Table 3 shows an example of the sets of the minimum number of diagnostic alarms and the alarm generation patterns used to distinguish each assumed malfunction.

Table 3 Example of sets of diagnostic alarm and alarm generation patterns

Alarm	F1		L1		V4	
variables	PH	PL	PH	PL	PH	PL
Mal-1	○		○			
Mal-2		○		○		
Mal-3				○		
Mal-4				○	○	
Mal-5			○			○

3.3. Evaluation Results for Each Assumed Malfunction

Table 4 shows the generated alarms and their generation time after each assumed malfunction, which were obtained using a dynamic simulator (Visual Modeler, Omega Simulation Co., Ltd.)

Table 4 Simulation results for each assumed malfunction

Malfunction	Generated alarms	Alarm generation times [min.]
Mal-1	L1.PH	32
Mal-2	F1.PL	10
	L1.PL	27
	L2.PL	118
Mal-3	L2.PH	19
	L1.PL	36
Mal-4	V4.PH	10
	F4.PH	10
	L2.PL	16
	L1.PL	120
Mal-5	F4.PH	10
	L2.PH	23
	L1.PH	175

Table 5 summarizes the evaluation results for each assumed malfunction. The effective rates were 100% for all assumed malfunctions, meaning that all generated alarms were diagnostic alarms. The recall rates for Mal-1 and Mal-5 were less than 100%, meaning that some diagnostic alarms were not generated and that distinction of the two failed. The operators could not distinguish Mal-3 and Mal-4 in the available time using the alarm system because their timeliness rates were less than 100%.

Table 5 Evaluation results for each malfunction

Index	Mal-1	Mal-2	Mal-3	Mal-4	Mal-5
Effective rate	100%	100%	100%	100%	100%
Recall rate	50%	100%	100%	100%	75%
Timeliness rate	Not distinguished	100%	60%	0%	Not distinguished

4. Conclusion

We proposed a method based on a two-layer cause-effect model for evaluating the characteristics of an alarm system. Simulation results using an example plant demonstrated its feasibility. We plan to develop a method for rationalizing plant alarm system in accordance with proposed indices, which are effective, recall and timeliness rates.

References

EEMUA, 2007, Alarm Systems - A Guide to Design, Management and Procurement, London
ISA, 2009, Management of Alarm Systems for the Process Industries, North Carolina
Izadi et al., 2009, Proc. SAFEPROCESS 2009, 651–656, Barcelona
Kimura et al., 2010, Human Factors (in Japanese), 15(1), 28–35
Takeda et al., 2010, Use of Two-Layer Cause-Effect Model to Select Source of Signal in Plant Alarm System, KES 2010, Part II, LNAI 6277, 381–388