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IPL2 and 3 performance improvement method for process safety using event correlation analysis

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ABSTRACT

Alarm management efforts have recently intensified, and many tools based on the guidelines in EEMUA 191 have been used to analyze alarm system performance at chemical sites. However, attempts to improve alarm systems using conventional methods have not made satisfactory progress, because they focused on evaluating current performance without providing information that would be useful for improving and rationalizing the alarm system. In this paper a novel method using event correlation analysis is proposed as a means of improving IPL2 and 3 performance, including alarm systems and operator actions. This method's effectiveness was evaluated with data from an alarm system improvement project at a chemical site.

1. Introduction

Safe operation is a top priority for chemical plants. To provide protection from hazardous incidents, a safety concept that has been extensively applied at various plants (AIChE/CCPS, 1993) is that of eight independent protection layers (IPLs), as shown in Table 1.

The second and third layers (IPL2 and 3) are related to the alarm system. The primary purpose of IPL2 is the supervision of a normally operating plant with a basic process control system. When the process variables deviate from the set points, the system activates alarms and notifies the operator to take corrective action. IPL3 represents critical alarms and corresponding operator interventions. Failure in the functions of IPL2 and 3 results in production loss. Therefore, it is important from both a safety and a production standpoint for IPL2 and 3 to function effectively.

For rationalization of alarm systems, EEMUA 191 (Engineering Equipment & Materials Users' Association, 1999) is widely accepted as a de facto standard. EEMUA 191 defines an alarm system as "a very important way of automatically monitoring the plant condition and attracting the attention of the process plant operator to significant changes that require assessment or action." It specifies several performance metrics that can be used to assess alarm system performance:

- Operator questionnaires;
- Alarm usefulness surveys;
- Assessment of number of alarms in a system;
- Measurement of average alarm rate;
- Measurement of number of alarms following a major plant upset;
- Measurement of operator response time;
- Measurement of number of standing alarms;
- Analysis of the priority distribution of alarms configured and occurring;
- Correlation techniques.

Among these performance metrics, operator questionnaires are especially important for improvement of IPL2 and 3 performance because they evaluate the alarms' appropriateness for the operators (Bransby & Jenkinson, 1998). However, questionnaire-based evaluation is often subjective, and may contain bias arising from the format of the questionnaires or from individual respondents. Therefore, in order to evaluate IPL2 and 3 performance more objectively, it is necessary to analyze how the actual alarms propagate after a fault, and how the operators intervene in response to the alarms.

As a conventional method for fault propagation analysis, signed directed graphs (Shiozaki, Shibata, Matsuyama, & O'Shima, 1989) and multilevel flow models (Bergquist, Ahnlund, & Larsson, 2003; Dahlstrand, 2002) have been actively researched. Also, there have been a few systematic methods for rationalizing operator actions, the most notable being virtual operator models (Liu, Kosaka, Noda, & Nishitani, 2007a; Liu, Kosaka, Noda, & Nishitani, 2007b; Noda &

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Table 1
Independent protection layers for process safety.

<table>
<tr><th>Layers</th><th>Definitions</th><th colspan="2">Functions</th></tr>
<tr><td>IPL8</td><td>Community Emergency Response</td><td colspan="2" rowspan="4">Minimize damage from an incident</td></tr>
<tr><td>IPL7</td><td>Plant Emergency Response</td></tr>
<tr><td>IPL6</td><td>Physical Protection (Dikes)</td></tr>
<tr><td>IPL5</td><td>Physical Protection (Relief Devices)</td></tr>
<tr><td>IPL4</td><td>Automatic Action SIS or ESD</td><td></td><td rowspan="4">Prevent an incident from happening</td></tr>
<tr><td>IPL3</td><td>Critical Alarms, Operator Supervision, and Manual Intervention</td><td rowspan="3">Ensure safe and productive operations</td></tr>
<tr><td>IPL2</td><td>Basic Controls, Process Alarms, and Operator Supervision</td></tr>
<tr><td>IPL1</td><td>Process Design</td></tr>
</table>

Nishitani, 2009). However, such model-based methods are complicated and difficult for site engineers or operators to put into practical use because much effort is required to adjust the models whenever the process devices are replaced or operating policy is changed.

In this paper, we provide a new method of improving IPL2 and 3 performance that deals with operator actions as well as alarms, and is easy for site engineers and operators to use. We focus on the relationship between alarms and operator actions, which are extracted from historical event log data with event correlation analysis.

In Section 2 of this paper we describe a new method for IPL2 and 3 performance improvement. In Section 3, we provide chemical plant data showing the effectiveness of the method. Section 4 provides conclusions. Section 5 discusses future work.

2. New method for IPL2 and 3 performance improvement

2.1. Concept

This paper proposes a novel method by which even those without particular expertise in data analysis, such as site engineers and operators, can improve the IPL2 and 3 performance of their plant quickly, easily, and effectively. In the method, IPL2 and 3 performance is evaluated by extracting the relationships between alarms and operator actions in their temporal context, as mentioned in EEMUA 191. In other words, the method focuses on whether the alarms and corresponding operator actions are appropriate for each other. Since this method provides clues for analyzing fault propagation paths, the origin of chain alarms, and operator knowledge extracted from event log data for alarms and operators actions, it reduces the need for on-site investigations with the use of piping and instrumentation diagrams.

As a way to extract clues from event data to improve IPL2 and 3, event correlation analysis (Nishiguchi & Tsutsui, 2005), which will be described in detail in the next section, is used. Event correlation analysis defines the correlation of discrete event data, and quantifies the degree of relationships and the order of occurrence of alarms and operator actions. (Note that the target process is assumed to be equipped with a non-faulty alarm system, in the sense that each alarm is able to occur correctly to signal the defined fault.)

Examples of extracted relationships that may signify a problem are listed below, together with the corresponding solution.

i. Consequential alarms

When several alarms are strongly related, they are likely to be consequential alarms. The number of such alarms can be reduced by alarm filtering techniques.

ii. Complex operator actions

When several operator actions are strongly related, they are likely to be complex sequential operations, which can be reduced by automation.

iii. Unnecessary alarms

When there is a high-frequency alarm without related operator actions, it may be unnecessary. The occurrence of such alarms can be reduced by changing the alarm settings or putting the contents of the alarm into an operator message.

iv. Causes of upset

When alarms and operator actions occur in a consistent order, the first event to occur is likely to be the source of plant upset.

2.2. Event correlation analysis

This section provides more detail concerning event correlation analysis, which quantifies the interrelationship and sequence of events (alarms and operator actions). Although the correlation coefficient is usually used to measure the relationship between two continuous values, it is a well-known fact that it cannot be applied to event data (Li, 1990), such as alarm and operator action log data. In event correlation analysis, event pairs separated by consistent time intervals are considered to be related, since the length of the time lags is determined by factors such as process dynamics and operator response time. A similarity measure, which is explained below, between all event pairs is calculated from the log data along with the probability distribution of correlation regarding independent event pairs. Calculating similarities and intervals between occurrence times results in the definition of groups with consequential events as well as their order of occurrence. Specifically, we use the following four steps.

- *Step 1*. Convert to binary sequences

In the first step, alarm and operator action log data containing occurrence time and event type are obtained from the distributed control system (DCS). The log data is converted into multiple event time series $s_i(t)$, specifically a binary sequences (or point process [Daley & Vere-Jones, 1998]) for each type of event i, the value of which is 1 if it occurs one or more times within the time window Δt and 0 if it does not (Fig. 1; for simplicity, in the following we refer to event type i, etc. as event i).

$$s_i(n) = \begin{cases} 1, & \text{if some points in } (n\Delta t, (n+1)\Delta t] \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

where n is a unit of time, and Δt is the window size, which should be adjusted according to variations in the process dynamics and operator response time.