# Performance Monitoring of Industrial Plant Alarm Systems by Statistical Analysis of Plant Operation Data

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**Abstract.** Industrial plan alarm systems form an essential part of the operator interfaces for automatically monitoring plant state deviations and for attracting plant operators' attention to changes that require their intervention. To design effective plant alarm systems, it is essential to evaluate their performances. In this paper, some performance monitoring methods of plant alarms systems for alarm system rationalization are reviewed.

**Keywords:** Plant Alarm System, Nuisance Alarms, Plant Operation Data, Event Correlation Analysis.

## 1 Introduction

The advance of distributed control systems (DCSs) in the chemical industry has made it possible to install many alarms cheaply and easily. While most alarms help operators detect an abnormality and identify its cause, some are unnecessary. A poor alarm system might cause alarm floods and nuisance alarms, which reduces the ability of operators to cope with plant abnormalities because critical alarms are buried under a lot of unnecessary ones (EEMUA, 2007). Therefore, it is important to monitor and assess the overall performance of the alarm system continuously (ISA, 2009).

## 2 Key Performance Indicators of Plant Alarm System

Various types of key performance indicators (KPIs) are used for evaluating performance levels of an alarm system. EEMUA(2007) suggested some KPIs for alarm performance monitoring, such as average alarm rate, maximum alarm rate, and percentage of time alarm rates are outside of acceptability target.

The average alarm rate is calculated by total number of alarms annunciated to the operator / total number of time period. Recommended target for average alarm rate in steady operation is less than one per 10 minutes. The maximum alarm rate is the maximum number of alarms annunciated to the operator during any of the 10 minutes time slice. Rates approaching 10 alarms in 10 minutes is not reliably sustainable by an

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operator for long periods. Percentages of time alarm rates are outside is useful for showing improvement made to an alarm system during alarm rationalization.

The “top-ten worst alarm method” has been widely used in the Japanese chemical industry to reduce the number of unnecessary alarms. It is used to collect data from the event logs of alarms during operation, and it creates a list of frequently generated alarms.

Although this method can effectively reduce the number of alarms triggered at an early stage, it is less effective at reducing them as the proportion of the worst ten alarms decreases. Because the ratio of each alarm in the top-ten worst alarm list is very small in the latter case, effectively further reducing the number of unnecessary alarms becomes difficult.

## 3 Event Correlation Analysis of Plant Operation Log Data

Nishiguchi and Takai (2010) proposed a method for data-based evaluation that referred to not only alarm event data but also operation event data in the operation data of plants. The operation data recorded in DCS consist of the times of occurrences and the tag names of alarms or operations as listed in Table 1, which we call “events” hereinafter.

**Table 1.** Example of operation data

| Date/Time | Event | Type |
|---|---|---|
| 2011/01/01 00:08:53 | Event 1 | Alarm |
| 2011/01/01 00:09:36 | Event 2 | Operation |
| 2011/01/01 00:11:42 | Event 3 | Alarm |
| 2011/01/01 00:25:52 | Event 1 | Alarm |
| 2011/01/01 00:30:34 | Event 2 | Operation |

The operation data are converted into sequential event data $s_i(k)$. When event $i$ occurs between $(k\text{-}1)\Delta t$ and $k\Delta t$, $s_i(k) = 1$, otherwise $s_i(k) = 0$. Here, $\Delta t$ is the time-window size and $k$ denotes the discrete time. The cross correlation function, $c_{ij}(m)$, between $s_i(k)$ and $s_j(k)$ for time lag $m$ is calculated with Eq. (1). Here, $K$ is the maximum time period for lag and $T$ is the time period for complete operation data.

$$c_{ij}(m) = \begin{cases} \sum_{k=1}^{T/\Delta t - m} s_i(k) s_j(k+m) & (0 \le m \le K/\Delta t) \\ c_{ji}(-m) & (-K/\Delta t \le m < 0) \end{cases} \tag{1}$$

When two events, $i$ and $j$, are independent of each other, the total probability that two events will occur simultaneously more than $c_{ij}^*$ times, which is the maximum value of the cross correlation function with time lag m is given by Eq. (2), where $\lambda$ is the expected value of $c_{ij}$.

$$P(c_{ij}(m) \ge c_{ij}^* | -K/\Delta t \le m \le K/\Delta t) \cong 1 - \left( \sum_{l=0}^{c_{ij}^*-1} \frac{e^{-\lambda} \lambda^l}{l!} \right)^{2K+1} \tag{2}$$

Finally, the similarity, $S_{ij}$, between two events, $i$ and $j$, is calculated with Eq. (3) (Nishiguchi and Takai, 2010).

$$S_{ij} = 1 - P(c_{ij}(m) \ge c_{ij}^* | -K/\Delta t \le m \le K/\Delta t) \tag{3}$$

A larger similarity means a stronger dependence or closer relationship between the two events. After similarities are calculated between all combinations of any two events in the plant log data, all events are classified into groups with a hierarchical method for clustering.

The following four types of nuisance alarms and operations can be found by analyzing the results obtained from clustering.

1. Sequential alarms: These are when a group contains multiple alarm events that occur sequentially. Changing the alarm settings of sequential alarms may effectively reduce the number of times they occur.
2. Routine operations: These can be when a group includes many operation events and operation events in the same group appear frequently in the event log data. These operation events can be reduced by automating routine operations using a programmable logic controller.
3. Alarms without corresponding operations: These can be when a group contains only alarm events and operation events are not included in the same group. As every alarm should have a defined response, these may be unnecessary and should be eliminated.
4. Alarms caused by operation: Operations can cause alarm events to occur after all operation events in a group. These are unnecessary because they are not meaningful or actionable.

## 4 Alarm System Evaluation of Ethylene Plant

Idemitsu Kosan Co. Ltd. started operations at the ethylene plant of their Chiba complex in 1985. The plant log data gathered in one month included 914 types of alarm events and 857 types of operation events, and a total of 51640 events was generated. Figure 1 shows the points at which 1771 types of alarm and operation events occurred.

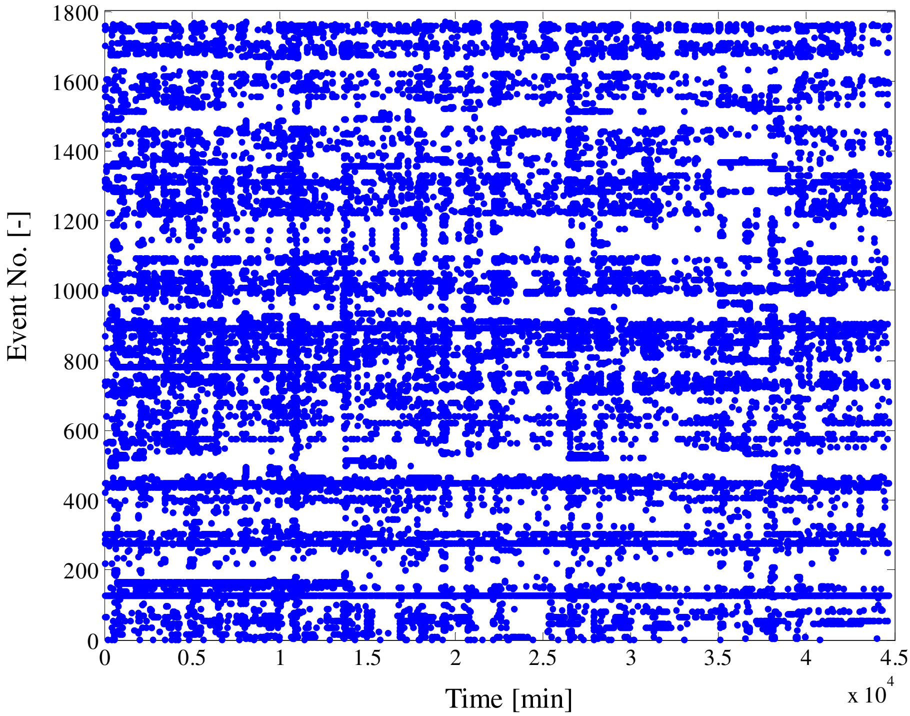


**Fig. 1.** Operation data of ethylene plant (Noda *et al.*, 2012)

Event correlation analysis was applied to the operation data obtained from the ethylene plant (Noda *et al.*, 2012). By using the hierarchical method of clustering, 1771 types of alarms and operation events were classified into 588 groups. Figure 2 is a similarity color map of events in the top 10 worst groups, where the alarm and operation events are ordered in accordance with the group Nos. The red indicates that two events have a high degree of similarity.

The top group contains five types of alarm events and ten types of operation events, and the total number of events in the group accounted for 5.8% of all generated events at the ethylene plant. Although the total number of events in the worst 10 groups accounted for 32.4% of all generated events at the plant, this included only 4.2% of alarm and operation event types.

Evaluation results showed that the method could effectively identify unnecessary alarms and operations within a large amount of event data, which should be helpful for reducing the number of unnecessary alarms and operations in other industrial chemical plants.

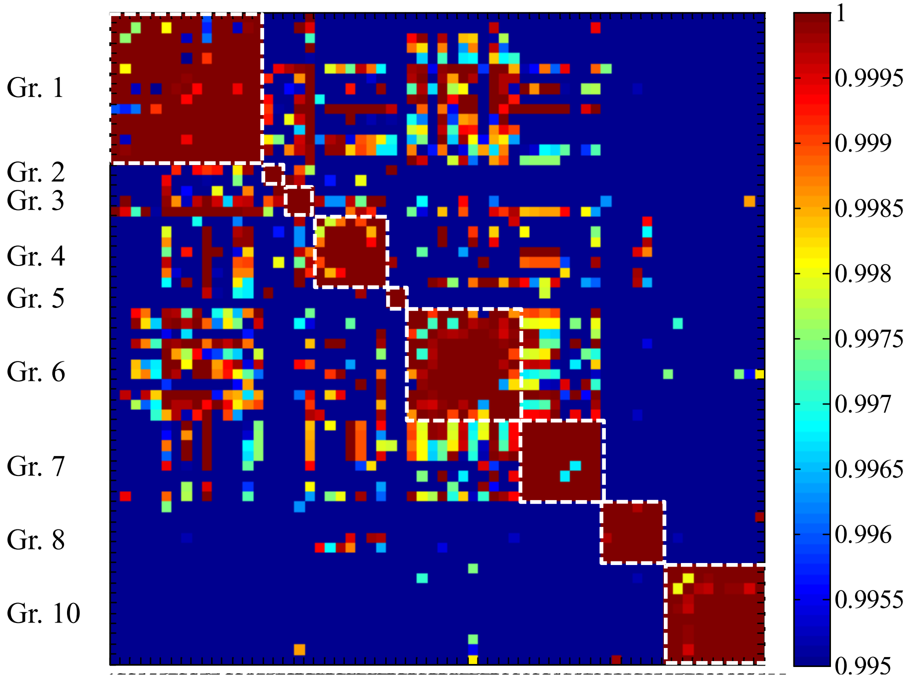


**Fig. 2.** Similarity color map (Noda *et al.*, 2012)

## 5 Conclusions

This paper reviewed quantitative evaluation methods for plant alarm systems based on plant operation data to rationalize plant alarm systems. Monitoring and assessment of performance of the plant alarm system may trigger maintenance work or identify the need for changes to the alarm system.

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