An Application of Advanced Alarm Management Tools to an Oil Sand Extraction Plant ⋆

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Abstract: For better performance analysis and design improvement of industrial alarm systems, a variety of advanced alarm management tools have been developed recently. These tools are quite comprehensive and handy in various applications, such as the assessment of alarm systems, detection of nuisance alarms, alarm flood analysis, and recommendation of better configurations. To demonstrate the effectiveness of these tools, this paper presents some industrial case studies based on the alarm data collected from an oil sand extraction plant operated by Suncor Energy in northern Alberta, Canada. Application results show the practicality and utility of the advanced alarm management tools for alarm rationalization and routine alarm management.

Keywords: Alarm systems, oil and gas industry, alarm performance analysis, software tools.

1. INTRODUCTION

Alarm systems are critical assets of modern industrial plants to assist operators in managing plant upsets and hazardous situations. However, in actual industrial processes, alarm systems often function poorly and become less effective in notifying abnormalities. Rather than assisting, poorly configured alarms, lead to operators being confounded by many nuisance alarms that can distract attention from real alarms, which increases the risk of hazardous conditions in industrial operations. With increasing emphasis on the process safety, alarm management in modern industrial plants has received increasing attention from both academic researchers and industrial organizations.

To design, implement, and maintain modern alarm systems, a revised and updated set of standards and guidelines such as the EEMUA-191 (2007) and ANSI/ISA-18.2 (2009) have been published and widely accepted by industrial practitioners with the focus on safe process operation. According to EEMUA-191 (2007) and ANSI/ISA-18.2 (2009) standards, the alarm rate should be limited to no more than 6 per hour for each operator. However, most alarm systems are unable to meet this benchmark due to poor design of alarm systems. Nuisance alarms, such as chattering alarms, fleeting alarms, standing alarms, and redundant alarms, have been identified as the main problems contributing to the inefficiency of alarm systems. If these alarms are minimized in the alarm rationalization process, then the efficiency, reliability, and quality of alarm systems can be improved markedly.

Systematic methods on the alarm configuration and alarm system assessment have been developed based on three indices, namely, the false alarm rate, missed alarm rate and averaged alarm delay (Adnan et al., 2011; Xu et al., 2012; Cheng et al., 2013). Good alarm configuration and efficient alarm system design are critical in preventing nuisance alarms. But to evaluate and manage nuisance alarms, some more advanced solutions are needed. A quantitative measure based on run length distributions was introduced to study chattering alarms (Kondaveeti et al., 2013; Naghoosi et al., 2011). Furthermore, a variety of techniques have been developed to remove chattering alarms based on alarm data (Wang & Chen, 2013, 2014; Kondaveeti et al., 2013). To deal with chattering alarms caused by oscillating processes, an online detection and removal approach was presented by Wang & Chen (2013).

The management of correlated alarms is another important issue in alarm systems. Yang et al. (2013) detected correlated alarms based on the distribution of correlation delays. Furthermore, binary similarity coefficients were employed to quantify alarm correlations (Kondaveeti et al., 2012; Yang et al., 2013). Yang et al. (2012) quantified the correlation level using cross correlation to yield a measure of similarity based on the binary transformed data. The detection of industrial incidents based on alarm

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data is another topic of great interest. To find root causes or assist the prediction of alarm floods, approaches have been developed to discover useful information from alarm data. The dynamic time warping (DTW) algorithm and the modified Smith-Waterman algorithm were utilized to compare alarm floods and find sequence patterns (Ahmed et al., 2013; Cheng et al., 2013). In addition to this, some visualization tools, e.g. the high density alarm plot (HDAP) and the alarm similarity color map (ASCM), also play a vital role in the detection of plant incidents and nuisance alarms (Kondaveeti et al., 2012).

Advanced alarm management tools introduced above provide handy solutions in detecting nuisance alarms, recommending better settings, and assessing performance of alarm systems. To demonstrate the effectiveness of these tools, this paper shows some industrial case studies based on alarm data collected from an oil sand extraction plant operated by Suncor Energy in northern Alberta, Canada. Application results show the practicality and utility of the advanced alarm management tools for alarm rationalization and routine alarm management.

The rest of the paper is organized as follows. The industrial process, routine alarm management, and performance of alarm systems at a Suncor oil sand extraction plant are described in the 2nd section. Section 3 presents a series of application results of advanced alarm management tools developed by the authors and co-workers and applied to the real world data. Section 4 concludes the paper; and the final section proposes areas of future work.

2. INDUSTRIAL ALARM MANAGEMENT

This section provides backgrounds of the oil sand extraction plant and introduces the routine alarm management. The performance assessment of the alarm system is presented based on the collected alarm data.

2.1 Description of the Oil Sand Extraction Plant

The oil sand extraction plant is a critical part of the oil sand upgrading process operated by Suncor Energy in northern Alberta, Canada. It refines bitumen from oil sands and upgrades it into crude oil products. The mined oil sand is a mixture of bitumen, mineral and water, among which the bitumen, consisting of viscous hydrocarbons, is the component to be extracted. The Suncor oil sand extraction plant separates bitumen from raw oil sands through the hot water processing technology, the principe of which can be concisely described by Fig. 1.

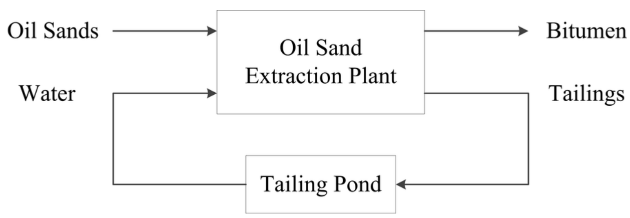

Fig. 1. Oil sand extraction process.

Water is heated to a certain temperature and mixed with the oil sand in an agitation vessel, where the oil sand is disintegrated and the slurry is separated. Then, the bitumen floats to the top of the slurry as a froth. After the bitumen froth is extracted, the middlings are left and treated for further refinement. Through the froth flotation technique, the bitumen contained in the middlings is recovered in the separation and upgrading step.

2.2 Routine Alarm Management

The oil sand extraction plant is comprised of a variety of interconnected units, including water supply cells, froth flotation cells, and tailing cells. To ensure safe operation of the whole plant, thousands of alarms are configured to monitor velocities, temperatures, pressures, and electrical points in pumps, pipelines, vessels, etc. Once an alarm is activated, operators are supposed to take the necessary corrective action to mitigate the source of the fault or the alarm. The routine alarm management of the oil sand extraction plant covers various functions, including design, configuration, rationalization, and documentation of alarms, which can be summarized as the alarm management lifecycle process in ANSI/ISA-18.2 (2009). The assessment and maintenance of alarm systems as an on-going and regular maintenance activity are critical in ensuring good alarm performance, ensuring safe process operation, and preventing equipment failures. In this way, changes are continuously made to alarm systems by process engineers based on routine reports generated by the proposed tools.

2.3 Performance of the Alarm System

The assessment of alarm systems is an important activity during the implementation stage of the alarm management lifecycle (ANSI/ISA-18.2, 2009). The overall performance of the alarm system during a specified time period should be assessed and reported. Accordingly, the need for changes to alarm systems can be identified by comparing the performance metrics with the alarm management goals. Industrial data was collected from the oil sand extraction plant over 16 days. 96 alarm tags were found to have been in the alarm "ON" state more than 2000 times during the specified time period.

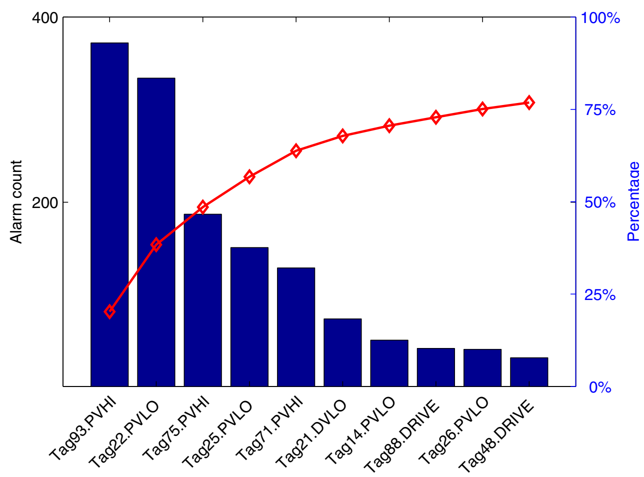

Fig. 2. Top 10 bad actors.

The bar chart in Fig. 2 presents the alarm counts for the top 10 bad actors while the red line shows the accumulated percentage of alarms by these 10 tags. Based on the fact that the top 10 bad actors contributed more than 75% of the total annunciated alarms, the performance of alarm systems could be improved significantly if actions were taken to reconfigure and rationalize these alarms.

From the view of operators, the alarm priority is an important piece of information in indicating the seriousness of possible abnormalities. Therefore, the distribution of alarm priorities deserves attention. Table 1 depicts the priority distribution based on the alarm occurrence and compares it with the best practice recommended by ANSI/ISA-18.2 (2009). According to Table 1, the emergency alarms were not annunciated, which indicates that there were no serious abnormalities during the specified time period.

Table 1. Distribution of alarm priorities.

Alarm Priority	Best Practice	Detected Distribution
Low	$\sim 80\%$	61%
High	$\sim 15\%$	39%
Emergency	$\sim 5\%$	0

To observe the historical alarm data and give preliminary performance assessment of alarm systems in a convenient way, the high density alarm plot (HDAP) was developed by Kondaveeti et al. (2012) and used in practice for automated reporting (Kondaveeti et al., 2013). Based on the collected alarm data, a high density alarm plot for top 40 bad actors are generated as shown in Fig. 3. Using this plot, we notice several instances of chattering alarms and correlated alarms as highlighted by dashed rectangles. But to achieve reliable detection and reduction of nuisance alarms, more advanced alarm management tools are needed.

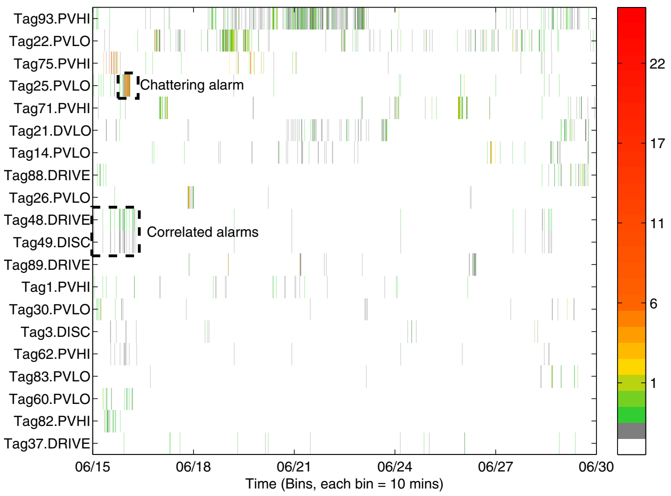

Fig. 3. High density alarm plot.

3. APPLICATION RESULTS

This section presents some results for the application of advanced alarm management tools to the alarm data from the oil sand extraction plant. The principle of each function and interpretations to the application results are presented.

3.1 Detection of Correlated Alarms

Correlated alarms are referred to as alarms occurring within a short time period of each other, including related alarms and consequential alarms (Rothenberg, 2009). Correlated alarms could be either redundant or overlapped alarms to indicate the presence of the same abnormality, which may increase the monitoring burden of operators. Therefore, detection and quantification of correlated alarms is important in improving alarm monitoring. The detection and quantification methods by Kondaveeti et al. (2012) are used to analyze the collected alarm data. An alarm similarity color map for the top 40 bad actors is generated as shown in Fig. 4.

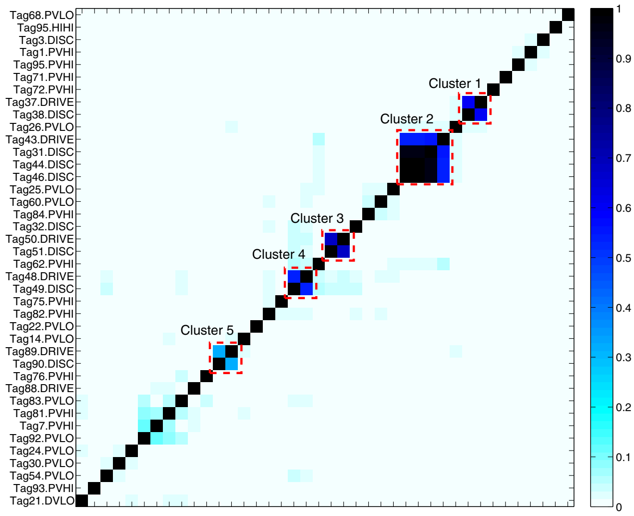

Fig. 4. Alarm similarity color map.

The vertical axis of the plot indicates the alarm tags while the horizontal axis has the same labels from left to right. The diagonal denotes the similarity between each alarm signal with itself. According to Fig. 4, some clusters consisting of highly correlated alarm tags are found and highlighted by dashed squares. The tag names of the correlated alarms in the corresponding clusters are shown in Table 2.

Table 2. Clusters of correlated alarms.

Cluster No.	Alarm Tags
1	Tag37.DRIVE, Tag38.DISC
2	Tag43.DRIVE, Tag31.DISC Tag44.DISC, Tag46.DISC
3	Tag50.DRIVE, Tag51.DISC
4	Tag48.DRIVE, Tag49.DISC
5	Tag89.DRIVE, Tag90.DISC

It is obvious that alarms in each cluster have very similar tag names. That is because different alarms are configured to monitor different measures in the same equipment. Thereby, the detection result in Table 2 is reasonable due to the physical connection of these alarms. Meanwhile, in the 2nd cluster, “Tag31.DISC”, “Tag44.DISC”, “Tag46.DISC” are highly correlated, which means the configuration of the three alarms could be redundant. Based on the above analysis, the alarm similarity color map is a good source of information to identify correlated alarms.

Furthermore, the analysis result can help to suppress redundant information, or correlated alarms can be grouped to operators as symptoms to detect the same abnormalities. Furthermore, the overlapped and redundant alarms need to be discussed to see if they can be reconfigured or one or more alarms can even be removed.

3.2 Detection of Chattering Alarms

Chattering alarms are one of the major contributors in raising alarm count per hour and thus responsible for violating the alarm management standards. Recently ANSI/ISA-18.2 (2009) came up with a recommendation for chattering alarms. According to the standard, any alarm occurring more than 3 times over a 60 seconds period can be considered as a case of alarm chattering. In Kondaveeti et al. (2013), a chattering index (ψ) was developed based on the run length distribution (RLD). It takes values between 0 and 1, with a higher value corresponding to a more serious chattering problem. Based on ANSI/ISA-18.2 (2009), a threshold for the case of alarm chatter is $\psi = 0.05$ alarms/second. For complete coverage of RLD based chattering index, the theoretical description can be found in Kondaveeti et al. (2013).

Fig. 5 shows the chattering indices of the top 25 bad actors for the collected alarm data. Alarm tags "Tag75.PVHI", "Tag14.PVLO", "Tag83.PVLO", and "Tag81.PVLO" are identified as apparent chattering alarms. Should these alarms be reduced efficiently, the performance of alarm systems can be improved considerably.

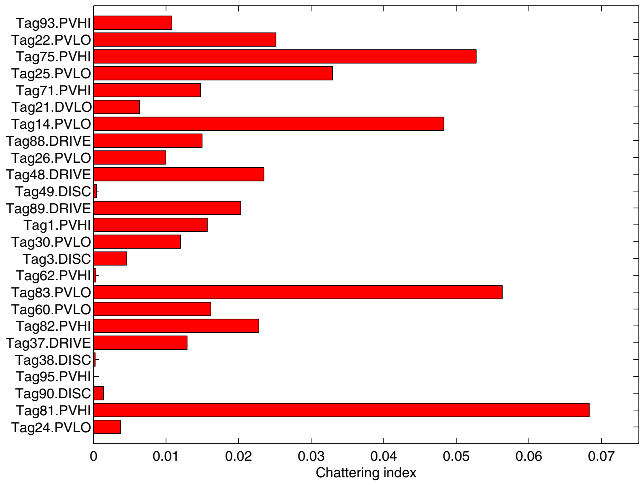

Fig. 5. Chattering Index for top 25 bad actors.

3.3 Setting of Delay-Timers

Once chattering alarms are identified and quantified, the next step is to reduce the alarm count. One of the most widely used practice in industries is the delay-timer, which can be directly applied to alarm signals. In Kondaveeti et al. (2013), a very effective way of designing delay-timers is proposed, which can be very handy for alarm rationalization work. This method is based on run-length distributions. The off-to-on (RTN-to-ALM) run-length distribution is used to design off-delay-timers, whereas the on-to-off (ALM-to-RTN) run-length distributions are used for the design of on-delay-timers. It is worth mentioning that in practice industry operators generally prefer off-delay-timers over on-delay-timers, specially for safety related alarms. The off-delay timer ensures that an alarmed variable remains in the alarm state unless it clears the alarm threshold and is in the normal operating region for a specified number of consecutive sample periods. In other words a chattering alarm is turned into a standing alarm.

To illustrate the methodology, the chattering alarm tag "Tag75.PVHI" is considered for the design of an off-delay-timer. Fig. 6 shows the off-to-on run-length distribution for the tag along with a curve showing the percentage alarm reduction after applying an off-delay-timer of a particular length. For example, if a 30 seconds off-delay-timer is applied to "Tag75.PVHI", the alarm count would be reduced by 61.83%.

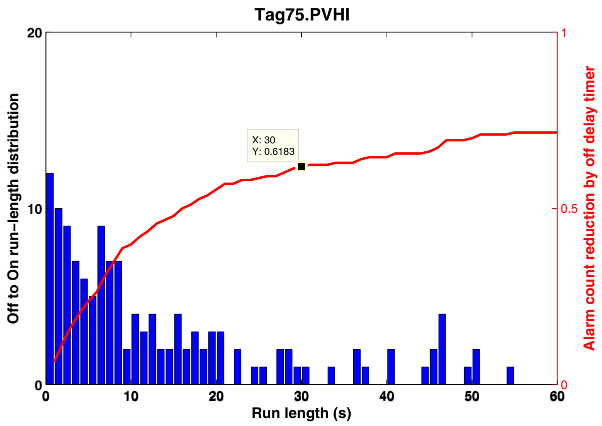

Fig. 6. Off-to-on run-length distribution of "Tag75.PVHI".

In a similar manner, one can design delay-timers for different chattering tags. Table 3 summarizes the results of application of delay-timers on chattering tags. It is obvious that considerable number of chattering alarms can be removed based on these recommendations. The analysis results can help efficient implementation of delay-timers in practice.

Table 3. Recommendations for the setting of delay-timers.

Alarm Tag	Type of Delay-Timer	Length	Alarm Reduction
Tag75.PVHI	Off-delay-timer	30 s	62%
Tag25.PVLO	Off-delay-timer	40 s	69%
Tag14.PVLO	Off-delay-timer	40 s	37%
Tag83.PVLO	On-delay-timer	35 s	65%
Tag81.PVLO	On-delay-timer	18 s	98%

3.4 Detection of Oscillation

An oscillating alarm is another type of alarm chattering. An oscillating alarm is an indication of some underlying process variable oscillations. Cheng (2013) has developed the work related to identification of oscillating alarms. For the considered industrial case study, oscillations in two tags were identified. The percentage of oscillations for the first one was significant as shown in Table 4.

Six oscillating periods could be found for "Tag25.PVLO". The first one was highlighted as the red block shown in

Table 4. Alarm tags caused by oscillation.

Oscillating Tags	Percentage of Oscillating Periods
Tag25.PVLO	39%
Tag71.PVHI	4%

Fig. 7. It is obvious that the alarm was activated almost periodically with an oscillation period of 42 seconds time period. Such results can help operators quickly identify an oscillating process. Ideally the corresponding PV tag should also be examined in the spectral domain to confirm the oscillations.

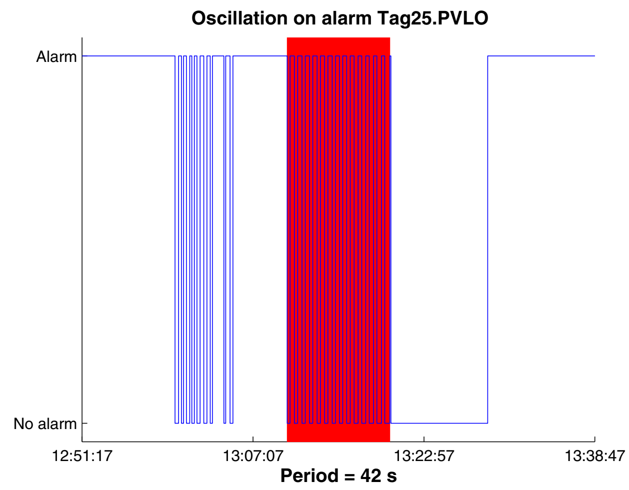

Fig. 7. Oscillation instants for "Tag25.PVLO"

3.5 Alarm Flood Analysis

Alarm floods are said to occur when the number of annunciated alarms arise massively and exceed the operators speed of response capability. As a result, ISA-18.2 (2009) and EEMUA-191 (2007) recommends 10 alarms over a 10 minutes period as a rule of thumb to identify alarm floods. To refine alarm floods from alarm data, a burst alarm rate plot is produced as shown in Fig. 8 based on the collected data.

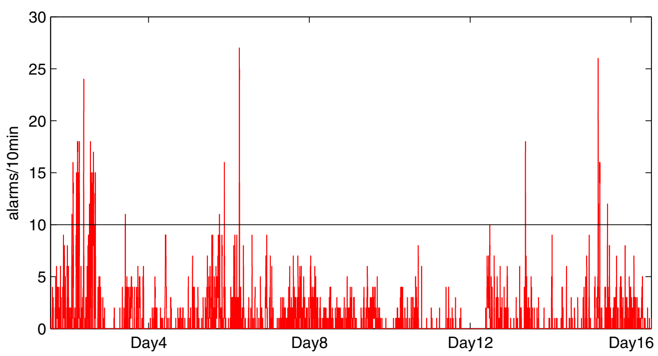

Fig. 8. Burst alarm rate plot.

Over the 16 days periods, 14 alarm floods were extracted. The longest alarm flood occurred on the 2nd day with 52 alarms while the shortest one only contained 10 alarms. To find the root causes of alarm floods, the pattern matching approach proposed by Cheng et al. (2013) was utilized to compare alarm floods. A similarity plot was generated for the 14 alarm floods as shown in Fig. 9. Axis labels indicate the indices of the 14 alarm floods sorted by the occurrence time. The diagonal cells show the results for comparing each alarm flood with itself (and hence the similarities are equal to 1, the highest).

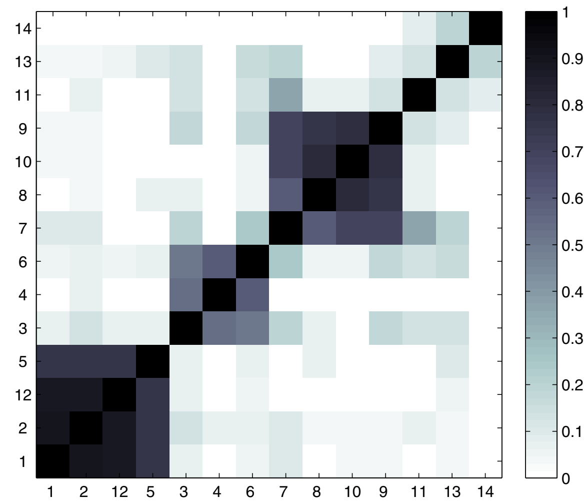

Fig. 9. Clustering plot of alarm floods.

According to Fig. 9, the 7th, 8th, 9th, and 10th alarm floods were very similar. The result was reasonable since all four alarm floods occurred close to each other within 2 hours on the 2nd day. The incidents might be not completely solved, leading to reoccurrence of the same sequence pattern. We could also find some alarm floods occurring at different time periods, but were very similar in the chronological sense, e.g. the 2nd and 12th alarm floods. These alarm floods may have been caused by the same fault. The facts found in the clustering plot could be helpful in identifying root causes or detecting such plant abnormalities that lead to floods.

4. CONCLUSION

The recently developed suite of advanced alarm management tools are quite comprehensive and handy for monitoring and analyzing alarm system performance on a regular and on-going basis. This paper has illustrated the effectiveness of these tools by applying them to an oil sand extraction plant operated by Suncor in northern Alberta. According to the application results, these tools have demonstrated their practicality and utility in monitoring and analyzing the performance of an industrial alarm system. The tools have also led to suggestions and guidelines on how to improve the system performance so that it is compliant with the most recently suggested safety standards. Specifically the suite of tools has helped to detect nuisance alarms, and recommend better configurations. The application of these tools will help in conducting the routine alarm system performance reporting and with compliant performance the tools can also reduce alarm loading to operators.

5. FUTURE WORK

As an offline analysis technique, the advanced alarm management suite of tools applied in the specific application is quite comprehensive and useful. For future research, the following areas could be of great significance in improving alarm management:

(1) State based alarming: In the oil extraction plant, most alarms in a process unit pertain to the normal operating state of a piece of equipment. However, many units often have several normal, but different, operating states. DCS alarm capabilities are normally only for single-state, single-value set points and priorities. State-based alarming methods aim at producing dynamic alarm configurations based upon the specific process and equipment conditions.
(2) Knowledge based alarm flood analysis: Through the sequence alignment approaches, sequence patterns can be extracted from historical alarm floods. To interpret these patterns, process knowledge such as the operator actions and engineering experience should be incorporated. Using labeled data, the online prediction of faults is supposed to be achieved in early stages of incoming alarm floods.
(3) Online application of alarm management tools: Techniques such as the grouping of correlated alarms and setting of delay-timers could be efficient in reducing nuisance alarms if they can be implemented online. The automated analysis functions will significantly alleviate operators' burden. Some online methods have been developed as given in (Wang & Chen, 2013, 2014; Yang et al., 2013).

REFERENCES

Adnan, N.A., Izadi, I., & Chen, T. (2011). On expected detection delays for alarm systems with deadbands and delay-timers. *Journal of Process Control*, 21, 1318-1331.

Ahmed, K., Izadi, I., Chen, T., Joe, D., & Burton, T. (2013). Similarity analysis of industrial alarm flood data. *IEEE Transactions on Automation Science and Engineering*, 10, 452-457.

Cheng, Y. (2013). *Data-driven Techniques on Alarm System Analysis and Improvement.* Ph.D. Thesis, Fall 2013, University of Alberta, AB, Canada.

Cheng, Y., Izadi, I., & Chen, T. (2013). Pattern matching of alarm flood sequences by a modified Smith-Waterman algorithm. *Chemical Engineering Research and Design*, 91, 1085-1094.

Cheng, Y., Izadi, I., & Chen, T. (2013). Optimal alarm signal processing: filter design and performance analysis. *IEEE Transactions on Automation Science and Engineering*, 10, 446-451.

EEMUA (Engineering Equipment and Materials Users' Association) (2007). *Alarm Systems: A Guide to Design, Management and Procurement, Second Edition.* London: EEMUA Publication 191.

Hollifield, B., & Habibi, E. (2007). *Alarm Management: Seven Effective Methods for Optimum Performance.* Research Triangle Park, NC: ISA.

ISA (2009). *Management of Alarm Systems for the Process Industries. ANSI/ISA-18.2-2009, 2nd ed.* The International Society of Automation, Research Triangle Park.

Kondaveeti, S. R., Izadi, I., Shah, S. L., Black, T., & Chen, T. (2012). Graphical tools for routine assessment of industrial alarm systems. *Computers and Chemical Engineering*, 46, 39-47.

Kondaveeti, S. R., Izadi, I., Shah, S. L., Shook, D. S., Kadali, R., & Chen, T. (2013). Quantification of alarm chatter based on run length distributions. *Chemical Engineering Research and Design*, 91, 2550-2558.

Kondaveeti, S. R., Grover, P., Khan M., Shah, S. L. (2014). An application for automated reporting of industrial alarm system performance. *Proceeding of the 11th World Congress on Intelligent Control and Automation*, Shenyang, China, 2014.

Naghoosi, E., Izadi, I., & Chen, T. (2011). Estimation of alarm chattering. *Journal of Process Control*, 21, 1243-1249.

Rothenberg, D.H. (2009). *Alarm Management for Process Control: A Best-Practice Guide for Design, Implementation, and Use of Industrial Alarm Systems.* New York: Momentum Press.

Wang, J., & Chen, T. (2013). An online method for detection and reduction of chattering alarms due to oscillation. *Computers and Chemical Engineering*, 54, 140-150.

Wang, J., & Chen, T. (2014). An online method to remove chattering and repeating alarms based on alarm durations and intervals. *Computers and Chemical Engineering*, 67, 43-52.

Xu, J., Wang, J., Izadi, I., & Chen, T. (2012). Performance assessment and design for univariate alarm systems based on FAR, MAR, and AAD. *IEEE Transactions on Automation Science and Engineering*, 9, 296-307.

Yang, F., Shah, S.L., Xiao, D., & Chen, T. (2012). Improved correlation analysis and visualization of industrial alarm data. *ISA Transactions*, 51, 499-506.

Yang, Z., Wang, J., & Chen, T. (2013). Detection of correlated alarms based on similarity coefficients of binary data. *IEEE Transactions on Automation Science and Engineering*, 10, 1014-1025.

