After the Alarm Rationalization –
Managing the DCS Alarm System

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Abstract

EEMUA\(^1\) has issued recommendations for alarm system performance targets that might appear overly aggressive to some in the petrochemical industry. Results from an Abnormal Situation Management\(^2\) Consortium study that benchmarked alarm system performance across over 30 member sites suggests that alarm rationalization and achieving EEMUA recommendations for the number of configured alarms is not the sole driver - or "silver bullet" - of solid alarm system performance. NOVA Chemicals, one of the participants in the study, has been able to achieve those performance targets in several plants. This paper discusses what efforts have gone into achieving those alarm system performance targets in NOVA Chemicals’ Ethylene 3 plant. While NOVA Chemicals has performed alarm rationalization on these exemplary performing consoles in Ethylene 3, perhaps as important have been the continuous improvement / lifecycle maintenance activities that NOVA Chemicals has performed since the rationalization and which will be described in the paper.

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I. Introduction

Alarm Management has been a problem for control room operations for many years, gaining in notoriety since the introduction of the distributed control system in the early 1980’s. It is only now becoming a system that is receiving the attention it deserves due to an increased understanding of the impact of alarm management on plant performance, reliability and safety.

The Abnormal Situation Management® (ASM®) Joint Research and Development Consortium is a group of 11 companies and universities that are finding approaches and solutions to mitigate – or where possible avoid – abnormal situations from occurring in production facilities. Abnormal Situation Management is often described as an integrated approach to improve reliability and operational integrity. Major aspects of the ASM Consortium’s work has included (a) prevention, (b) early detection, and (c) mitigation of abnormal situations in industrial facilities (including petrochemical, refining, oil and gas processing, power generation, pulp and paper plants).

Alarm management is one area of particular interest and significant research for the ASM Consortium because it was the initial driving force for the Consortium’s formation in 1993 as well as NOVA Chemicals Corporations’ (“NOVA Chemicals”) participation. Recently the Consortium has added to its detailed knowledge from prior research about alarm management with the completion of three major activities:

1) A two-phase alarm performance benchmarking study across 30 of its members’ plants,
2) A human performance modelling project using high fidelity plant simulators,
3) An Alarm Management Effective Practices guideline from the collective experiences of the Consortium members.

This paper will show some of the alarm performance benchmarking results and some of the initial conclusions that the research team has been able to derive from them. The ASM Consortium will be continuing its research in this important area.

One of the participants in the benchmarking study was NOVA Chemicals’ Ethylene 3 plant in Alberta, Canada. This world scale plant has been able to demonstrate that the EEMUA performance goals can be met for months at a time, though alarm performance issues still present challenges for unplanned major plant disturbances.

Ethylene 3 started production in Aug. 2000 and is capable of producing 2.8 billion pounds of ethylene each year. It is a facility jointly owned by Dow Chemicals Canada Inc. and NOVA Chemicals and operated by NOVA Chemicals along with other ethylene, polyethylene and utilities plants at its major Joffre, Alberta facility.

NOVA Chemicals has presented 2 papers at previous AIChE conferences which described how it used a “Designing for Abnormal Situation Management” approach to several elements of its control systems including control room design, operator console, operator user interfaces. Alarm Management was a part of that project and has been essential to the success of the operator user interface.

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II. Role of Alarms in Situation Awareness and Response

Of the many roles and responsibilities of console operators, perhaps the most challenging and time consuming is that of situational awareness and response. In this role the console operator is proactively monitoring the plant “to establish and maintain their awareness of the current state of the process relative to plant production goals, process operational limits and operating constraints.”

The states or modes of the plant can vary from normal, planned off-normal, abnormal or emergency shutdown. In normal mode the objective of the operator is to monitor the process and be aware of potential problems that can rapidly move them to a different state. In normal modes the operator is also looking for suboptimal conditions that require attention and adjustment to optimize the process. In a planned off-normal period, the operator will be executing the planned procedural operation and their duties are to monitor the process to ensure that the correct trajectory or plan is followed. “Once an abnormal or emergency situation is detected, the console operator is typically the focal point in the efforts to mitigate, compensate or recover from the undesirable situation.”

Alarms should play a key role in the situation awareness and response activities of console operators though the role of alarms needs to vary to match the different plant states to meet the changing needs of the operator. Designing the alarm system for the different plant modes and operator needs allows it “to assist the operator in detecting process problems and prioritizing their response.”

Table 1 outlines the varying roles of the operator and the alarm system to the different plant states.

<table>
<thead>
<tr>
<th>Plant State</th>
<th>Operator’s primary role</th>
<th>Alarm system’s primary role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Plant monitoring, optimization of production, and coordination of maintenance.</td>
<td>Inform operator of minor operating adjustments needed</td>
</tr>
<tr>
<td>Planned off-normal</td>
<td>Manage and coordinate the execution of the changes as the plant may be transitioning to a new production grade, starting up or shutting down pieces of equipment</td>
<td>Identify to the operator that execution is NOT occurring as planned or required</td>
</tr>
<tr>
<td>Abnormal situation</td>
<td>Situation management by intervening and augmenting the regulatory control system actions when the control system can no longer cope with the situation</td>
<td>Identify what is wrong and when operator intervention is required</td>
</tr>
<tr>
<td>Emergency shut-down</td>
<td>Ensure a safe shutdown</td>
<td>Identify when safety actions are required</td>
</tr>
</tbody>
</table>

Table 1: Roles of Operators and Alarms for Differing Plant States

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III. ASM Alarm System Benchmarking

The ASM Consortium supported the work of the Engineering Equipment and Materials User Association (EEMUA) in the development of its EEMUA Publication 191, which had defined some aggressive alarm system metrics that needed to be confirmed as being attainable. These levels included recommendations such as:

- Less than 1 alarm/10 minutes average alarm rate during normal operations; and
- Less than 10 alarms in first 10 minutes of a major plant upset

In 2001, the ASM Consortium initiated a series of research projects to benchmark the performance of alarm systems in member’s facilities throughout North America. The motivation for this work was to assess whether members were achieving the EEMUA recommendations for alarm system performance as well as to contextualize that performance relative to plant complexity, degree of alarm rationalization, nature of plant operation (batch, semi-batch, continuous), and so on.

The study was conducted in two phases. In the initial stage, the participating companies agreed upon the set of metrics, duration of the data collection periods and committed to providing at least 3 months of data to Honeywell for each console in the study. Honeywell collated and analyzed the information and presented the results anonymously back to the project team. Participants in the 2nd phase were asked to provide additional console data and also anecdotal information about their alarm management practices which was used to examine the possible critical elements to explain the varying alarm performance results.

The project collected a total of 90 sets of monthly data from 37 unique consoles (three consoles appeared in both studies, which accounts for the 40 entries in Figures 1 and 2). Each console represented a portion or area of a plant that was typically operated by a single console operator under normal plant conditions. Some of these consoles will add additional console operators for planned major events such as a plant start-up. Static alarm configuration information was collected for all consoles and included number of analog points, number of control valves, digital points, and so on plus all their related alarm configuration information.

Dynamic alarm information was also provided from each console for the monthly periods. The dynamic information represented elements such as average and peak alarm rates over 10 minute windows. Figure 1 shows one example of that information in a plot of the overall average alarm rate from the 40 consoles.

Each bar represents the lowest, average and highest monthly average alarm rate for a single console that submitted 3 months of data. Single points represent consoles in the second phase that were only required to submit one month of data. The consoles have been grouped according to the proportion of configured alarms in each console’s control system versus the EEMUA configured alarm recommendations (see Figure 41 on page 104 of EEMUA Publication No. 191). For example, the first 2 consoles at the left side of the chart had configured alarm totals of over five times that recommended by the EEMUA guideline. On the right hand side of the chart is a scale representing the 5 alarm performance categories described in Table 2 below.

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The median overall avg. alarm rate for the ASM Phase 1 and 2 studies is 1.77 alarms/10 min.

**Figure 1:** Overall Average Alarm Rate

### Table 2: – EEMUA Benchmarks for Assessing Average Alarm Rates

<table>
<thead>
<tr>
<th>Long Term Average Alarm Rate in Steady Operation (per 10 minute window)</th>
<th>Acceptability</th>
</tr>
</thead>
<tbody>
<tr>
<td>More than 10 alarms</td>
<td>Very likely to be unacceptable</td>
</tr>
<tr>
<td>More than 5 but less than 10</td>
<td>Likely to be over demanding</td>
</tr>
<tr>
<td>More than 2 but less than 5</td>
<td>Possibly over demanding (Note: category not defined in EEMUA guide)</td>
</tr>
<tr>
<td>1 or more but less than 2</td>
<td>Manageable</td>
</tr>
<tr>
<td>Less than 1 alarm</td>
<td>Very likely acceptable</td>
</tr>
</tbody>
</table>

Overall average alarm rates were calculated for the entire month of each data set and included all modes of plant operation (normal, planned off normal, abnormal and emergency). The EEMUA acceptability categories are designed for only normal plant operation, which biases against those consoles in the ASM studies that had non-normal operation during the month. The average alarm rate across the ASM studies was 2.3 alarms per 10-minute period compared to the British Health and Safety Executive (HSE) study of 5 alarms per 10-minute window that led to the EEMUA guidelines document.

What the chart in Figure 1 demonstrates is that the “very likely acceptable” level of performance is being achieved by one quarter of the consoles. The plot also shows that there appears to be very little correlation between the alarm rate and the number of configured alarms in the various consoles (r = 0.103, p > 0.50).

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12 EEMUA (1999), Figure 42, p. 105.
The chart in Figure 2 displays the average peak alarm rate distribution to examine how much of the time each console was experiencing a specific alarm rate.

Figure 2: Average Peak Alarm Rate Distribution

The contribution chart was generated by averaging values across each console’s set of three month data, if applicable, for the Peak Alarm Rate Distribution intervals (e.g., “% with < 1”, “% with 1-10”, and so on). The % of 10 minute periods for the various alarm count intervals are plotted on a Log scale to highlight those periods in which there were peak alarm rates and increased operator workload (e.g., Consoles 1530, 2296, 2766, and 2783 clearly had at least one bad day, on average, per month).

However, care is needed in interpreting the Log-plotted results. As a general rule, bar lengths cannot be compared between consoles (e.g., Console 2878 has 9.5% for 1-10 alarms and this colored bar looks as long as Console 1730’s 1-10 alarms bar, which is actually representing 34.0%).

Figure 2 shows that 24 of the 40 consoles (60%) had at least one significant alarm flooding incident (over 100 alarms in a 10 minute window). In the case of 4 consoles, they averaged over 1% of their time per month (over 7 hours per month on average) when their alarm rates were exceeding 100 alarm messages in each 10 minute window.

From a more positive aspect, 2 consoles had 3 months in which they never exceeded a peak alarm rate of 20 alarms per 10 minute window, which indicates that the EEMUA standards for peak alarm rates, though very aggressive, are within reach.

One other aspect that is highlighted in this plot is that the degree of rationalization, which has been used to group the consoles on the X axis, appears to have only minor relevance to the actual peak alarm rates. (Each of the plants were requested to indicate the percentage of alarms rationalized on that console (e.g., 0 – 20%, 21-40 %, and so on).)

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“Some of the key findings from the Benchmarking Study include:

- Sites can meet and sustain the “Manageable” and “Very Likely Acceptable” EEMUA levels of overall average alarm rate performance in normal operation
- 70% of the consoles, on average, had overall average alarms rates of more than 1 alarm every 10 minute window (i.e. had more alarms than the “Very Likely Acceptable” level)
- Top ten Worst Actor tags often account for over 50% of the alarm rate
- Alarm bursts (greater than 30 alarms per 10 minute window) occurred at least once, on average, each month for 38 of the 40 consoles during the evaluation period
- Significant periods of peak alarm rates exceeding 100 alarms per 10 minute window were experienced at least once by 60% of the consoles during the evaluation period
- The degree of alarm rationalization or configured alarm levels does not appear to be the single significant factor in determining alarm rate performance.”

What the benchmarking information reveals is that the initial alarm specification and rationalization activities in the design of the alarm system which limit the number of alarms configured in the system do not guarantee good alarm system performance and conversely, good alarm system performance can be achieved without having a fully rationalized console. To better understand how a plant can achieve the recommended alarm performance levels, the following sections of this paper will examine the work that is underway at NOVA Chemicals’ E3 facility where they have been able to consistently meet the recommended alarm levels.

IV. Alarm Management Lifecycle

Alarm management is not a one time project that can be executed and closed up in a tidy manner with a close-out report. Instead alarm management requires a continuous lifecycle approach regardless of whether it is a new or an existing plant. Figure 3 shows a simplified diagram illustrating the major elements of the E3 Alarm Management Life Cycle Model.

In the case of NOVA Chemicals’ E3 plant, there have been several key elements which have led it to be successful. Some of these aspects were executed as part of the design project while others have been through the continuous improvement efforts, and a third group (Management Principles) has been necessary for all aspects.

Management Principles

From the outset of the E3 project in 1997, there has been tremendous support for an evergreen alarm management approach and the entire “design for ASM” philosophy. This philosophy meant that there was a clear understanding of the roles of the operator, the operator user interface and the alarm management system and how they interacted, as well as a willingness to commit the necessary resources to realize the philosophy. It was certainly not an afterthought by a project team getting ready for start-up to check to see if any alarms or the user interface had been created. It was a core element of the project from the outset.

Design and Implementation

The initial project design and implementation aspects of the E3 project included the early development of an alarm and operator interface philosophy. In 1997, NOVA Chemicals was in a unique position to apply the direct concepts about operator user interface designs that had been developed in ASM Consortium research projects and which had tightly integrated alarms into the graphics as navigation drivers. NOVA Chemicals’ approaches to alarm management were drawn from the broad experiences of the other user member companies such as ChevronTexaco and BP Amoco. With elements such as these, coupled with management support, NOVA E3 could begin to develop a life cycle approach to alarm management, knowing what the alarm system had to deliver.

The E3 alarm philosophy defined for all plant personnel the expectations of the alarm system, the operators and the supporting tools and applications. Alongside the Alarm Philosophy, a matching Operator User Interface Philosophy was developed that described the principles of the operator interface and the way that alarm information, trends, online information and advanced applications would be integrated. Together these two documents describe the core of the console operator’s situation awareness, and response support tool set.

Following the Alarm and Operator Interface Philosophy developments the project focused on capturing the alarm specification information from the series of plant reviews (PHA, SIL Analysis, etc.) and plant design information, as shown in Figure 4. This information was used in the alarm rationalization reviews (also known as Alarm Objectives Analysis) where multi-discipline teams performed the tag-by-tag review to determine the appropriate alarm settings. At the conclusion of this rigorous review process, E3 significantly fewer configured alarms than the older NOVA Chemicals’ E1 and E2 ethylene plants. E1 and E2 then used some of the design approaches implemented in E3 to improve their configurations though due to resource limitations they did not perform the rigorous tag by tag rationalization review. Today E3 still has from 16 to 43 % fewer absolute alarms and over 50 % fewer alarms configured per total points than the E1 and E2 ethylene plants which illustrates some of the difference that the rigorous approach can achieve. All three plants each employ two console operators to manage their alarms.
With the rationalization information captured in an electronic database where it could be retrieved by the operator interface, the alarm implementation process occurred. The implementation included the initial alarm settings along with alarm support applications to address known modal changes in plant operation.

### Alarm Performance Monitoring

After the alarm system had been implemented and the plant started up, the performance monitoring of the alarm system began in E3, where any existing plant would enter the Alarm Lifecycle process (see Figure 3). Effective performance monitoring required the selection of key performance indicators for the alarm system. Monthly alarm metrics for E3 were set as follows:

- Average # of Alarms/10 Minute window
- Time in burst conditions (>10 alarms/10minute interval)
- Time weighted Average of Number of Standing Alarms

The average number of alarms for normal operation had been well defined in the EEMUA guide shown earlier in Table 2.

From the ASM Alarm performance research and from the data collected at NOVA, we have seen that alarm rates of less than 1 alarm per 10 minute window are achievable for normal operation. Upsets including major equipment trips or entire plant trips still often create an alarm burst of more than 10 alarms per 10 minute window for one or two periods. NOVA Chemicals is addressing this area and some of these activities will be described later in the paper.

Performance monitoring should also include a worst actors list of tags on a daily, weekly and monthly basis. This is a list of alarms that have occurred and are ranked by their frequency of occurrence. On existing plants, this is often the very first performance area to examine as often the worst 10 or 20 tags can account for a large (>50%) portion of the total alarm rate. A corrective action program that initially focuses on these tags can often make a significant improvement to the overall alarm rates at a console.

With the performance monitoring systems in place, the information can be collected and used to develop a continuous improvement plan that is described in more detail in following section. The plan uses the performance information to assess what types of alarm problems exist in the system and potential attack strategies to address them.

Figure 3 also illustrates how a comprehensive and effective Management of Change (MOC) program is required to manage the entire Lifecycle process. Without change control of the alarm settings, the system will be adjusted to the point where its performance and usefulness to the operators is very low. The MOC process is used whenever plant modifications impact the control system or the operator user interface.

### Table 3: Joffre E1, E2 and E3 Configured Alarms

<table>
<thead>
<tr>
<th></th>
<th>Total Points</th>
<th>Total Alarms</th>
<th>Reduction in # Alarms (%)</th>
<th>Total Alarms / Total Points</th>
<th>Relative Improvement (%)</th>
<th># Controllers</th>
<th>Total Alarms / Controllers</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>8330</td>
<td>5847</td>
<td>16.6</td>
<td>0.70</td>
<td>51.3</td>
<td>532</td>
<td>11.0</td>
</tr>
<tr>
<td>E2</td>
<td>9779</td>
<td>8641</td>
<td>43.6</td>
<td>0.88</td>
<td>61.3</td>
<td>613</td>
<td>14.1</td>
</tr>
<tr>
<td>E3</td>
<td>14262</td>
<td>4874</td>
<td>0.34</td>
<td>0.34</td>
<td></td>
<td>740</td>
<td>6.6</td>
</tr>
</tbody>
</table>

With the rationalization information captured in an electronic database where it could be retrieved by the operator interface, the alarm implementation process occurred. The implementation included the initial alarm settings along with alarm support applications to address known modal changes in plant operation.
V. Continuous Improvement Plans

The Alarm Life Cycle model represents a continuous improvement program. In the previous section we defined the process that NOVA used for its E3 plant, a new grassroots plant to design and implement its alarm system and reach the performance measurement step in the Lifecycle. Today E3 is an existing or brownfield plant and it continues to use the Life Cycle model. Presently E3 has very good alarm performance under normal and planned off-normal modes of operation. However by monitoring its alarms during major plant upsets, E3 still has opportunities to significantly improve its alarm performance even after its extensive alarm rationalization efforts during the design stages.

Figure 4 shows the average monthly alarm rates for the past 2.5 years in E3 on the 2 control consoles. The months where there have been significant plant upsets or outages stand out clearly in the plot as large spikes in the data against the typical lower base levels of alarms. There is also a significant difference between the more batch-oriented operations of the cracking console as compared to that of the finishing console. The cracking console manages the hot end of the plant (furnaces) and also includes the utilities (i.e., steam, fuel gas, quench water, etc.) units of the plants which present more difficulty in terms of alarm management particularly during plant upsets as utility loads vary.

Caution must be used in comparing one major plant upset against another, as they are never matching events in nature or duration. Both of these factors can significantly effect the alarm distribution and monthly average information.

The major improvement factors that have been implemented after the E3 plant start-up include:
- Improved setting of alarm dead-bands and delay-timers
- Use of difference alarms on redundant measurements
- Use of common maximum or minimum alarms
- Design for purpose alarms (i.e., mass balance, heat balance)
- Increased use of dynamic modal alarming applications and logic programming
Figures 5 and 6 show the alarm rate distributions for the 2 consoles in E3. For both consoles, a significant portion of their time (approximately 58% for cracking and 69% for finishing) there are no new alarm messages for the console operator. The peaks shown in Figure 4 from the plant upsets correspond to the extended red bars in Figures 5 and 6 where more than 10 alarms were received for a portion of the 10 minute periods.

However these are still exceptional results especially compared to the ASM benchmarking survey results presented earlier where many consoles were experiencing peak alarm rates 10 times higher than those in E3.

**Figure 4: E3 Monthly Average Alarm Rates**
Figure 5: E3 Cracking Console Alarm Rate Distribution

Figure 6: E3 Finishing Console Alarm Rate Distribution
The alarm performance assessment step shown in the Life Cycle model would be the starting point for any brownfield plant that was looking to begin an alarm improvement program. Measure where you are presently at, examine the gaps between your current performance and where you need to be, and then assess what actions will move you to the new state in the easiest and shortest manner.

To achieve the changes to the alarm system may require updates to the alarm and operator interface philosophies. This would be followed by a re-specification of alarms, then by new alarm implementations, which would lead the plant back to the assessment stage of the Life Cycle.

With alarm management – you will never, ever be finished.

Improvement plans can take several forms. For plants that have continuously poor alarm performance results during all operating modes, the worst actors list is often a good trigger for which type of improvement plan is required. If the 10 worst actors continuously represent a significant portion of the alarms (>50 %), then the focus should be on understanding and correcting these specific problems. If the problem is not centered on a small group of tags but is still characterized by high average alarm rates at all times, then the improvement plan may need to consider a broader and much more time-consuming alarm rationalization review.

For other plants that generally have good alarm performance in normal operation like E3, a more detailed improvement plans are required to address the specific events that cause the alarm problems.

Another valuable activity that E3 has employed in its continuous improvement program is the re-validation of its alarm rationalization information. E3 performs an alarm rationalization update on a three-year rotation (33 %/year) using their alarm review team as part of an evergreen safety program. This substantial commitment of resources and effort demonstrates management’s support for the Alarm Management at this plant. This revalidation work is in addition to the alarm reviews are undertaken as required by the MOC process for all process changes. The revalidation exercise updates any information that might have been overlooked and acts as a training exercise for individuals who were not involved in the initial plant reviews.

**VI Alarm Management Success Factors**

Some of the factors that have contributed to the success of Alarm Management in E3 include:

**Management Understanding and Support**

The efforts to continuously refine and improve the alarm management system require a great deal of time and effort from the Operations and Technical personnel. This would not be possible without very strong management understanding and support.

**Operator User Interface and Alarm Management Integration**

Performing the best alarm design and rationalization that is possible in a plant will not guarantee good alarm performance. The operator user interface and its components (i.e. graphics, trends, online information, display hierarchy, etc.) must be designed to support and augment alarms by providing the console operators with good situation awareness and response capabilities.

E3 designed the operator interface and alarm management program with just that in mind. Figure 7 shows how the alarm specification and alarm performance information is brought to the operator from a context sensitive menu via a right mouse click on any tag in the operator interface. The operator’s confidence and support of the alarm management system are significantly increased when they can have ready access to this information,
The alarm performance monitoring developments that have been made with the alarm and event historian have been essential to the continuous improvement efforts at NOVA. Key elements of this have been:

- Worst actors monitoring,
- Average and peak alarm rate monitoring,
- Standing and stale alarm analysis,
- Disabled/Inhibited or Shelved alarm monitoring,
- Excellent Systems Engineering support

**Operator Training Program**

Operator training is an important element to the continuous improvement plan for alarm management in E3. Operators must be given the knowledge and skills to effectively use the alarm management systems and its support applications. In E3, the dynamic training simulator and the overall training program play a large role in ensuring that all staff understand and respect the alarm management system as a tool to support situation awareness and response. The E3 training program includes:

- Scenario reviews and “what-if” training exercises,
- Use of the situation support tools and applications,
- Development, testing and use of all dynamic modal alarm strategies,
- Use of the alarm summary features during periods of high alarm rates.
- Routine alarm management duties for the console operator (i.e. shift turnover, etc.).
VII. Conclusions and Summary

The ASM Alarm Performance research has shown that there are significant challenges for many plants to meet the EEMUA alarm performance recommendations for both normal and off-normal plant modes of operation. The research has also shown, that though this performance is not being met at most consoles, several consoles in the industry are coming close to or are achieving these levels for a significant portion of their operating periods.

The research and the E3 results also indicate that good alarm design and rationalization are important and will assist a plant in terms of its alarm management, however they are not sufficient or the sole drivers to lead to good sustained alarm performance. Probably more important for long-term excellence in alarm performance is a life-cycle approach that includes performance monitoring and continuous improvement.

VIII. References


