Development of an alarm analysis process for use within the process industries

Neil Hunter, Consultant, Human Reliability Associates Ltd.
Jamie Henderson, Consultant, Human Reliability Associates Ltd.
David Embrey, Managing Director, Human Reliability Associates Ltd.

Alarm management forms an essential component of process control in the major hazards industries. Effective alarm systems should facilitate prompt and reliable operator responses. The UK regulator, the Health and Safety Executive (HSE), requires Control of Major Accident Hazard (COMAH) sites to provide evidence that alarm systems have been both properly conceived during plant design, and are subject to ongoing management and review to ensure that alarms remain effective. This includes providing evidence within Safety Reports that best practice standards are applied on site.

Traditional alarm management software is widely available to help benchmark system performance and identify areas for improvement. Whilst such software provides important data regarding alarm metrics (average alarm rate, number of alarms during upsets, etc.), it does not typically provide a detailed insight into how the system supports the operator when the need to respond to a critical alarm arises.

The Alarm Review Tool (ART) is proposed as a means to bridge this gap by providing a facility for the rapid and detailed analysis of high-criticality alarms. The tool is based on the principles set out in EEMUA 191: *Alarm systems, a guide to design, management and procurement* (EEMUA, 2013), and facilitates the assessment of high-criticality alarms by organising the guidance in this document according to a simple information processing model of alarm response.

1. Introduction

The purpose of an alarm within a control loop is to prompt operator intervention to regain control of a process parameter which the automated system cannot itself contain. A well designed alarm system should prevent (or at the very least reduce) demand on the automated control loop or safety instrumented system (SIS). Good alarms alert, inform and guide an operator to make a reliable and timely response to regain control of a process before it deteriorates into a potentially unsafe state (EEMUA, 2013). Verifying that timely operator response is possible, and that alarms are effective in supporting this response, requires careful analysis of how the alarm information is presented within the system.

EEMUA 191 (EEMUA, 2013) provides extensive guidance on the design and management of effective alarm systems. However, the very comprehensiveness that makes it such a valuable resource can make it difficult for the casual user to ensure that the alarms at their facility meet the requirements of the guidance. This paper describes a process, the Alarm Review Tool (ART), which has been designed to provide a straightforward means for assessing the adequacy of critical alarms against EEMUA 191 guidance, using a simple Human Factors (HF) framework. The process helps to ensure that critical alarms can be assessed quickly against key EEMUA 191 principles, organised according to the stages of alarm response (e.g. perception of the alarm signal, diagnosis of the alarm state then planning and execution of the response). There is also the facility for analysis of the management arrangements which support alarm systems.

This review process aims to provide operators of Major Accident Hazard (MAH) facilities with the knowledge that their alarm systems have been benchmarked against industry best practice by providing the opportunity for deficiencies to be identified in a coherent and structured manner.

2. Lessons from history

Poor alarm management has been implicated in many high profile disasters, for example the explosions at the Texaco Milford Haven oil refinery (HSE, 1997) and the Longford gas plant (Hopkins, 2000). Whilst excessive alarm load was recognised as an important factor in each of these incidents, other inadequacies relating to alarm design, presentation and management were also identified. For example, the investigation into the Longford Gas plant explosion found that the plant was habitually run beyond alarm set points, whilst the Texaco Milford Haven investigation identified poor prioritisation and delayed alarm response as contributory to the subsequent loss of containment and explosion.

3. Literature and UK regulatory context

EEMUA 191 (EEMUA, 2013) comprehensively outlines the principles of effective alarm system design, including the management of HF issues. For example, how an alarm should be presented within the DCS, and what information and functionality should be available to support operators in navigating to the required controls to execute a response. EEMUA 191 also provides a wealth of information regarding the wider organisational arrangements which should be in place to support the design, maintenance and improvement of alarm systems.

Effective alarm management is particularly important in the process industries given the potential Major Accident Hazard (MAH) implications of their operations. In the UK, onshore high hazard sites are regulated by the Health and Safety

Executive (HSE) under the COMAH (Control of Major Accident Hazard) Regulations (HSE, 2006). A core requirement of these regulations is for operators to submit a Safety Report which demonstrates to the regulator that their activities are, as far as is reasonably practicable, safe and that MAH events are suitably controlled. One aspect of this is the need to demonstrate that alarm systems have been both properly conceived during plant design, and are subject to ongoing management and review to ensure that alarms continue to support safe and reliable operations.

There are two aspects to this: firstly, dutyholders must ensure that their alarm system is safe, and that it offers reliable protection against MAH events. Secondly, they must provide evidence to the UK regulator that the system is designed in accordance with best practice and that there is a *verification* process in place which ensures that the system fully supports effective operator response. This includes providing a demonstration that best practice standards for alarm design are being applied on site.

4. Improving alarm systems – the challenge

It is essential that high hazard sites operate with confidence that, when a high-criticality alarm arises, those charged with the task of responding to the alarm can indeed do so. This confidence is particularly important at times of high workload or elevated alarm levels, for example during a serious plant upset. Failure to ascertain whether a reliable operator response is probable undermines the foundations upon which the entire alarm system is based.

However, providing this verification can be difficult. Firstly, modern process plants are complex, with distributed systems to maintain process control across extensive networks. Secondly, the number of variables associated with the effective design and presentation of an alarm can be significant. In short, there are many alarms to assess and many factors to consider for each alarm.

Many MAH sites with complex alarm systems utilise alarm management software as part of their assurance strategy. Such software provides data for alarm system performance which can be used to judge the overall adequacy of the system (for example average alarm rate, number of alarms following an upset, number and distribution of alarms by priority). This information is important from the perspective of performance monitoring and for developing alarm rationalisation strategies to reduce alarm load and improve system performance. Alarm metrics can also be interrogated at a deeper level to examine, for example, response times to particular alarms. Alarm management software is therefore often viewed as an important tool in the quest to improve alarm systems.

However, such software often provides little insight into how the operator interacts with the DCS to respond to an alarm and whether, and where, the operator encounters any difficulty in doing so. With the exception of drawing conclusions about the overall alarm load, such software rarely provides much analysis regarding which specific features of the alarm system present problems to the operator and the aspects of system design that need to be addressed to improve alarm reliability. Therefore, in the context of achieving reliable verification that operators will respond to an alarm, the limitations of tools that measure overall alarm load as the sole means to achieve this should be recognised. Where sites utilise this method as the only means of alarm system analysis it could be argued that the reliability of response, at times of highest need during a serious plant upset, may often be based upon little more than assumption.

Given the complexity of the task facing many MAH operators, a pragmatic solution is therefore required to provide the verification which they, and the Regulator, require: that their alarm system is safe and that a reliable response to the most critical process alarms is possible.

5. Possible approaches to analysis of HF issues related to alarms

One obvious approach is for the MAH operator to carry out their own full review of the content of EEMUA 191 and assess their most critical alarms against this guidance. This is clearly achievable. However, the time and resource required for such an unstructured analysis may present difficulties, particularly for smaller sites. Whilst EEMUA 191 is an excellent source of information, the presentation of that information within the document does not necessarily support a simple, systematic and consistent analysis process.

For example, in the guide, specific information relating to individual alarm design is often incorporated within wider guidance relating to organisational arrangements to support alarm systems. Moreover, information relating to how alarms should be presented to facilitate prompt and effective identification by operators is distributed throughout the document, rather than being collated in one discrete, easy-to-interpret section.

Unless significant time is spent reviewing the guidance, it may be difficult to identify the key information against which alarms should be assessed to determine that a specific alarm adheres to the various requirements of the guidance. The extensive nature of EEMUA 191 means that this approach, when coupled with the number of potential alarms to be reviewed at any given site, may appear an overwhelming challenge.

An alternative approach is to carry out full task and failure analyses of the highest criticality alarms in the context of response tasks (see, for example, Energy Institute, 2011). While this would represent a thorough approach it may present its own challenges. For example, whilst such analyses should give a fully-rounded analysis of the task in the operating context, these analyses can be complex and potentially time consuming, and will often require external HF support. In addition, whilst such approaches provide an excellent framework for identifying potential failures for the full range of different task types, they do not necessarily provide specific support for assessing the cognitive aspects of alarm response (e.g. diagnosing the causes of alarms and deciding upon appropriate responses). Finally, EEMUA 191 outlines a substantial number of specific design expectations and it is uncertain whether a traditional failure analysis approach would reliably identify all of these factors.

6. Overview of the alarm review process

The potential complexity associated with assessing alarms, coupled with the inconsistent approach which many MAH operators take to verify that alarm systems optimise operator response, encouraged the authors of this report to develop an analysis process that could potentially support MAH sites in the analysis of critical alarms.

The Alarm Review Tool, or ART, provides a means for MAH operators to reliably and rapidly analyse critical alarms and their associated management systems against the alarm system design principles described in EEMUA 191. It distils the key guidance from EEMUA 191 into related sections, meaning that the user can be confident that they have considered all of the relevant information for a specific alarm from the guidance without having to hunt through the document.

The process has been designed to provide a comprehensive analysis of the alarm system, and currently comprises four core elements:

1) Critical alarm screening: This is a facility for alarm filtering to determine whether alarms which are currently assigned highest criticality within the system justify that categorisation. This screening helps, in the first instance, identify alarms which have been wrongly prioritised. This ensures that time spent analysing alarms is initially focused on those alarms which are most important. Such high level screening can also assist with rationalisation by identifying alarms which are not truly critical.

2) Individual alarm review: This element facilitates a quick but thorough review of individual safety-critical alarms against the usability principles outlined in EEMUA 191. This examines all HF aspects of alarm response from signal presentation, availability of DCS information for diagnosis, to execution of response. This depth of analysis provides the necessary verification that alarm design is optimised. This constitutes the main section of the tool and is described in further detail in section 7.

3) Alarm management system review: This is an in-depth assessment of the management system which supports the alarm system. It examines the adequacy of organisational arrangements for the ongoing maintenance, development and review of the alarm system. It is envisaged that this review would take place periodically – for example by undertaking an initial management system review then possibly only re-reviewing at a later date if significant organisational changes have occurred which affect the management of the alarm system.

4) Alarm performance metrics: This provides a facility for recording and trending alarm metrics in relation to ongoing rationalisation provided via the alarm review tool. This charts alarm system improvements in relation to any changes made to problem alarms.

The analysis can be completed as a paper analysis. However, a software tool has also been developed to speed to assessment process and facilitate the aggregation of multiple analyses. This is still in the process of being developed, however screenshots from a prototype of this software are included in this paper to illustrate the process.

7 Detailed alarm review process

7.1 Organisation of alarm review process

As indicated earlier, the key focus of the process is the individual alarm review. Whilst guidance regarding the adequacy of supporting management arrangements is also important, this is not the kind of analysis which MAH operators will have to carry out frequently. Rather, they require assurance that their most critical process alarms are as well designed as possible.

To achieve this objective, the process organises the guidance presented in EEMAU 191 according to a simple information processing framework (see, for example, Rasmussen, 1986). Such a model describes how operators within a human-machine interface make sense of unfolding events around them. It proposes that a stimulus is identified (perceived), decoded (diagnosed), computations are made (plans developed) which then prompt an output (purposeful action). When an alarm signal arises, the operator must identify that signal, diagnose the alarm cause and location, determine the appropriate response (amongst potentially many alternatives) then execute the response. A well designed alarm system should support the operator during each discrete stage of alarm response. In this case, the stages are:

- Perceive alarm
- Maintain salience of alarm
- Diagnose cause of alarm
- Plan alarm response
- Respond to alarm

The second category, maintaining salience, is really an extension of the first, alarm perception, but has been included separately as an important potential failure, particularly in situations of alarm overload where it is important that high priority alarms are not lost amongst subsequent alarms.

There are two main reasons for choosing to organise the process in this manner. Firstly, this type of framework is a well-established, and hence understood and easily communicated, method for considering how people react to stimuli as they are presented. Secondly, the sequential nature of such a model is helpful in organising the content of EEMUA 191 into the different phases of alarm response.

In practice, this means that, for each alarm identified as critical, the analyst must answer a number of questions based on the guidance provided in EEMUA 191. These questions, are, as previously described, organised according to the simple information processing model. Figure 1, below, shows a screenshot from the software that illustrates three of the questions in the *'Maintain salience'* section of the process. The analyst must agree or disagree with each statement; a negative response is indicated by a red colouring, and accompanied by a suggested action. At the time of writing, there are 35 statements in total to assess for each critical alarm. Preliminary testing indicates that each alarm might take around fifteen minutes to assess, depending on the number of negative assessments made. If the analyst is unsure of the meaning of a statement, there is a further information button.

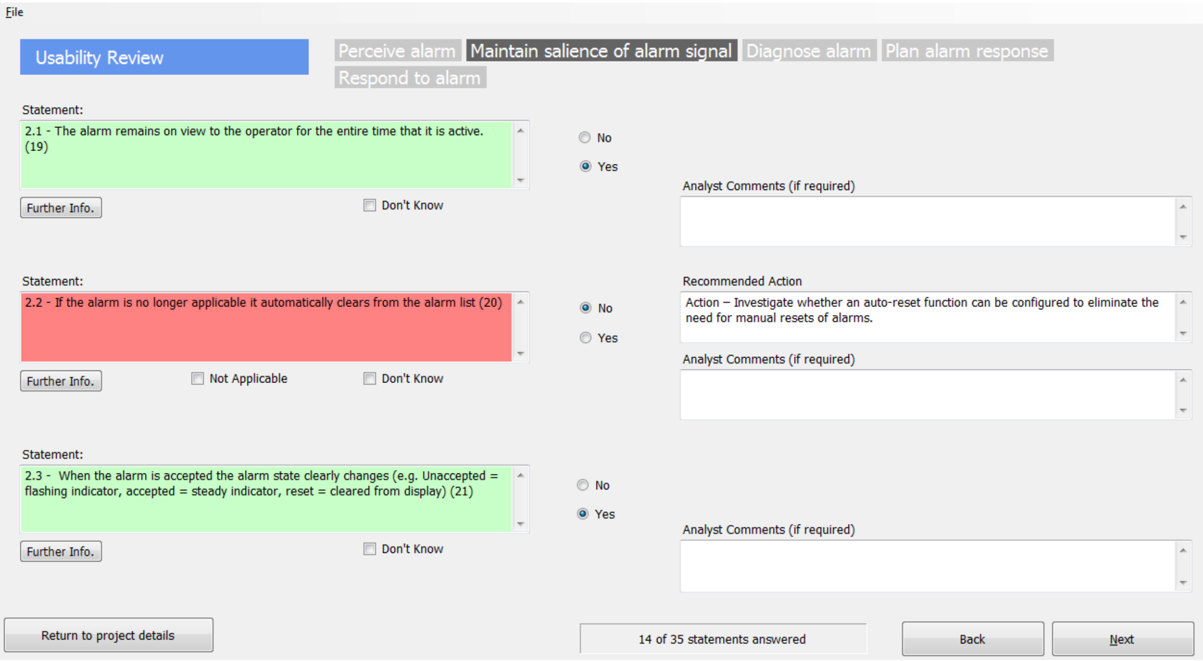

Figure 1 Example statements in the 'Maintain Salience' phase of the critical alarm review process

7.2 Reports and recommendations

For each alarm that is analysed, where the review identifies aspects of alarm design which are sub-standard, the software automatically develops a report which clarifies the nature of the deficiency and provides associated recommendations for improvement (see Figure 2, below).

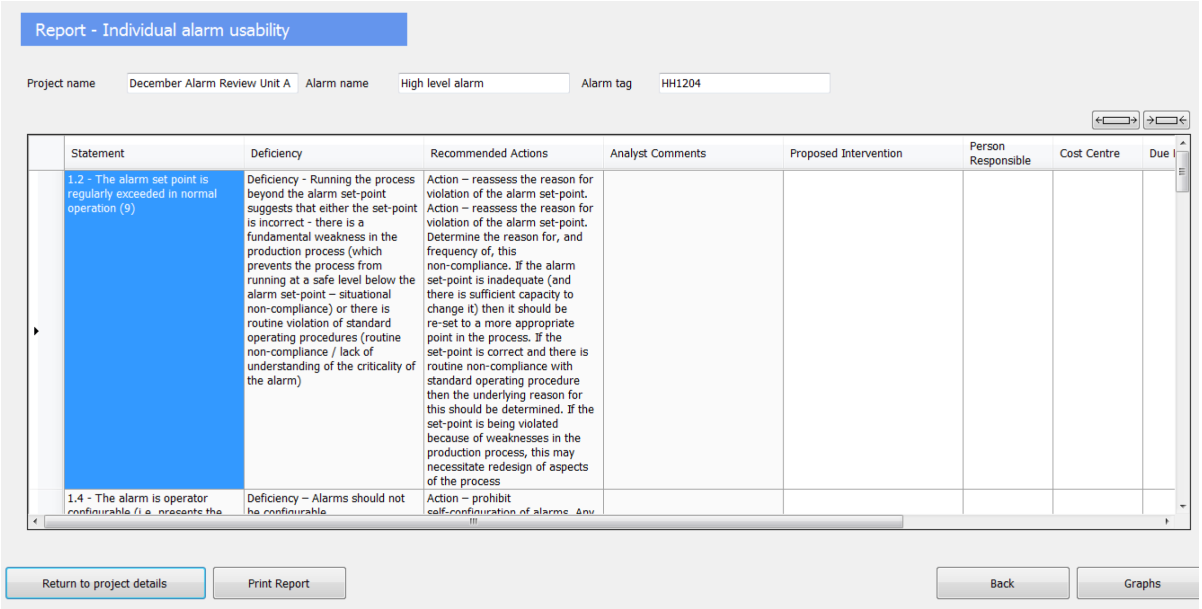

Figure 2 Example summary report for one critical alarm

The deficiencies and recommendations are derived from EEMUA guidance, essentially clarifying where a key design principle is absent and providing advice for improvement. A report outlining identified deficiencies is provided for each reviewed alarm. The software allows an otherwise time consuming process to be completed quickly, whilst ensuring that the analysis itself remains thorough and consistent across all reviewed alarms.

7.3 Representing data and cross-comparison

Data analysis and performance monitoring are clearly important from a management review perspective. The prototype software has the facility to present alarm review findings graphically. The tool has been designed to group alarm reviews into *Projects*. This enables the user to analyse the outcomes of individual alarm analyses, or groups of analyses, using a graphs function (see Figure 3, below).

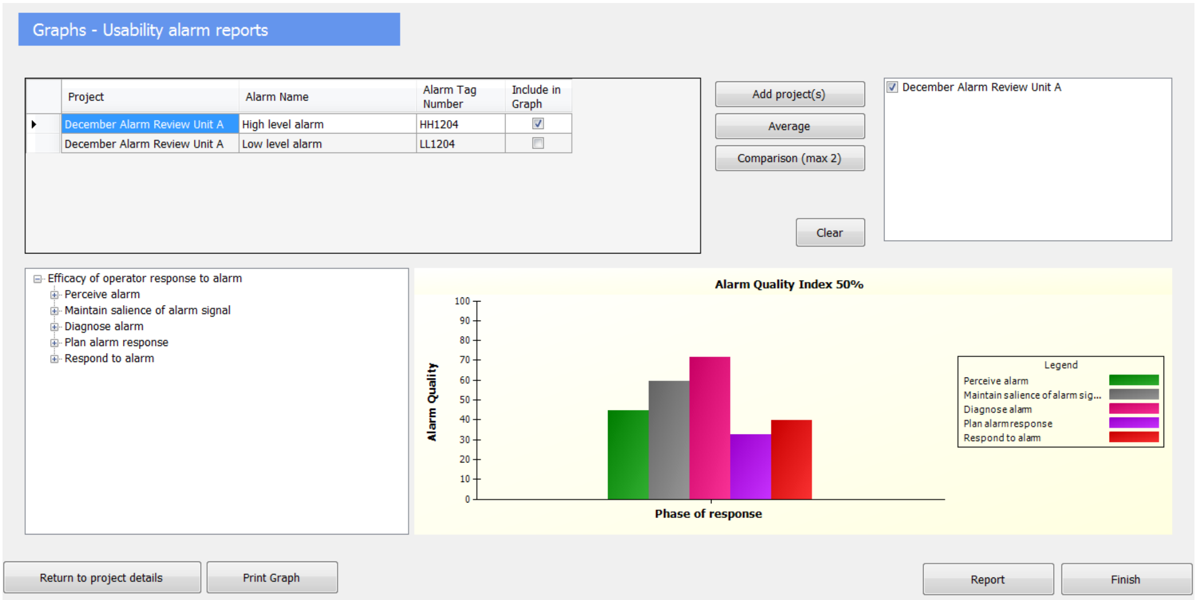

Figure 3 Example of data output for critical alarm usability analysis

The main graph (bottom right of Figure 3), presents an Alarm Quality Index (AQI) for the selected alarm (if all the statements have been assessed as good, than the AQI will be 100%). This is broken down by phase of the information processing model, so that the analyst can determine where the strengths and weaknesses of a specific alarm lie. For example, the support for diagnosing an alarm cause might be good, whereas the support for planning and executing responses may be weaker (as is the case in the example shown).

By selecting more than one alarm in the Project box (top left of Figure 3), the user can create a graph that produces an average AQI for all selected alarms. The primary purpose of this is to enable comparisons between different alarm projects (e.g. the average AQI for one unit versus another, or for comparing results in a single unit over time).

8. Further work

As previously mentioned, a prototype software tool has been developed to support the ART process. At the time of writing (December 2014) the process has been preliminary tested with the input of three MAH sites in the UK. This testing has considered both the content and presentation of the alarm review statements and their associated outputs. Our intention is to undertake further testing to develop the prototype and improve both its usability and content. The testing completed thus far has indicated a number of areas for further development.

The first of these is a requirement to develop the ability of the process to assist users in determining whether or not an alarm is critical. This is a difficult area, as the definition of a critical alarm may vary from site to site and needs to take account of the different purposes of alarms (e.g. safety, production, environmental issues). One approach may be to allow users to provide their own definition of alarm criticality, which the process could then provide support for testing.

Another area that will be explored is the degree to which some of the issues raised are more likely to be properties of the alarm system in general rather than individual alarms. For example, when evaluating a statement such as ‘The alarm is visually distinct from other classes of process alarms and alerts’, it may be that the answer will be true for all alarms in the system being examined. If this is the case then it may be possible to speed up the analysis process by repeating answers for all alarms being assessed in a given system.

Finally, care will have to be taken to ensure that the contents of the tool both accurately and comprehensively represent the contents of the EEMUA 191 guidance. Failure to achieve this means there is a danger of overconfidence in a given alarm system arising from the results of this analysis. To this end, consideration will be giving to providing more explicit cross-references to the original guidance in the software.

9. Conclusions

Assuring the reliability of alarms by using a detailed alarm analysis is considered central to reliable process control. High-criticality alarms often represent an important layer of protection to reduce demand on engineered process safeguards. Failure to verify the reliability of operator response to critical alarms risks missing serious alarm system deficiencies which may inhibit successful operator response. Traditional alarm analysis software used to measure system performance is widely used across industry. However, such software often provides little insight into the alarm design issues which present challenges to the operator during response to individual alarms. The alarm analysis tool aims to bridge this gap by providing a structured framework for the consistent analysis of alarms against best practice design principles. We would welcome approaches from any individuals or organisations with an interest in participating in the development of this process.

10. References

Energy Institute (2011) *Guidance on human factors safety critical task analysis*. Available at http://www.energypublishing.org/__data/assets/file/0014/64022/Guidance-on-HF-safety-critical-task-analysis.pdf

Engineering, Equipment and Materials Users Association (EEMUA) 191 (2013) *Alarm systems, a guide to design, management and procurement* (3rd Edition).

Health and Safety Executive (1997) ‘*The explosion and fires at the Texaco Refinery, Milford Haven, 24 July 1994: A report of the investigation by the Health and Safety Executive into the explosion and fires on the Pembroke Cracking Company Plant at the Texaco Refinery, Milford Haven on 24 July 1994*’.

Health and Safety Executive (2006) *A guide to the Control of Major Accident Hazard Regulations 2006 (as amended)* Available at http://www.hse.gov.uk/pubns/priced/l111.pdf

Hopkins, Andrew (2000). *Lessons From Longford: The Esso Gas Plant Explosion*, CCH Australia Limited.

Rasmussen, J. (1986). *Information processing and human-machine interaction: An approach to cognitive engineering*. Amsterdam, The Netherlands: North-Holland.