Situation Awareness for Refining and Petrochemical Process Operators – Not by Technology Alone

Charles Bloom, Peter Bullemer, Richard Barreth, & Dal Vernon Reising
Human Centered Solutions LLC

An important responsibility of console operators is to prevent and respond to abnormal situations. The nature of the abnormal situation may be of minimal or of catastrophic consequence; it is the job of the operations team to identify the cause of the situation and execute compensatory or corrective action in a timely and efficient manner. Abnormal situations extend, develop, and change over time in the dynamic process control environments increasing the complexity of the intervention requirements. Proactively maintaining their situation awareness of the process, where it is, where it is going, and how quickly it is going there, is what is required of both console and field operators to effectively prevent and respond to abnormal situations when they arise. Successfully responding to abnormal situations depends upon both console and field operators knowing not only what tasks to perform and how to perform them, but also when to perform them. To become proficient, an operator must know what to watch, how frequently to watch, what to do, how to do it, and when to do it – all components of knowledge that contribute to effective situation awareness. To attain situation awareness, operators must be able to assess what the current state of the system is, and using their mental model of process operations, assess what the future state of the process will be in response to specific operator actions.

Situation Awareness

Considerable study in the fields of military and civil aviation has identified that problems with situation awareness were found to be the leading factor contributing to both military aviation mishaps (Hartel, Smith & Prince, 1991), as well as accidents among major airlines (Endsley, 1995). This research has led to considerable study into pilot decision-making and the development of methods for training to improve situation awareness in aircraft pilots. However, up to this point, little of what has been learned with regard to situation awareness training for pilots has found its way into the refining and petrochemical industry.

Endsley (1995) proposed a three level model of model of situation awareness. Level 1 Situation Awareness involves the perception of important information – failure to perceive important information leads to the formation of an incorrect picture of what is going on (poor situation awareness). Level 2 Situation Awareness involves how people comprehend the perceived information with regard to their
specific job tasks and goals – failure to accurately comprehend what is happening can also lead to incorrect situation awareness, by virtue of an incomplete or inaccurate picture of what is actually happening. Level 3 Situation Awareness involves being able to forecast where the situation is going – failure to accurately predict what will happen can lead to initiating the wrong corrective actions. As the research has pointed out, failures at any level can ultimately lead to errors and accidents.

In Endsley’s study of aviation mishaps, it was found that of the accidents attributed to situation awareness issues, 76% were due to a loss of Level 1 situation awareness: information not observed, information not available, information difficult to detect, human memory error, or a misperception of information – emphasizing the critical importance of perception on accurate situation awareness.

**Situation Awareness for Process Operations**

Cochran & Bullemer (1996) in their paper on abnormal situation management, describe what has since become known as the Paradox of Automation. To paraphrase Cochran & Bullemer, the paradox of automation postulates that as the level of automation increases in the domain of supervisory control, operations professionals are faced with increasing complex decisions in managing abnormal situations. Further, better automation leads to more sophisticated processes, which in turn leads to a “weaker” understanding of the process by the very operations professions who must control it, ultimately leading to more opportunities for error. As a consequence of the paradox of automation, when things go wrong, these operations professionals have difficulty intervening to correct the problem.

Endley’s model of situation awareness can be easily extended to fit the job of a refinery console operator. When considered in the context of the console operator, perception of important information can be done by noticing patterns or changes in key operating parameters, hearing verbal radio transmissions, hearing audible alarms and reading the subsequent alarm descriptions, reading specific SP and PV values, and noticing deviations and process movements. Comprehension involves knowing where the process is running, having an accurate mental model of how the process operates and of how to respond correctly, how close to critical operating limits the process might be, how optimally it is running, and whether the process is stable or not. Projection involves anticipating how quickly the process or given variable might exceed a limit, whether a control action taken is having the desired result, if the process will remain / become steady, and how quickly the process will stabilize.

To illustrate the impact a lack of situation awareness can have on refining operations, I would like to describe a situation observed in industry, one that may not be restricted to this single example. In this example, the board operator received a low flow alarm on their Coke Heater not long after the team
had completed a Coker drum switch. The board operator immediately concluded that they were experiencing bottoms pump cavitation (a common occurrence during drum switches) and directed the field team to bottoms pumps. His specific message over the radio was not “I just received a low flow alarm on the Coke Heater,” but rather “we have bottoms pump cavitation.” The field team immediately began troubleshooting the bottoms pumps and after some time believed they had restored flow. In fact, the Coke heater PSV was relieving, which in turn reduced pump discharge pressure leading to erroneous believe that they had restored flow, confirming the board operator’s diagnosis of pump cavitation.

While this was going on, the board was experiencing an alarm flood, and the board operator, already focused on the bottoms pumps, did not pay close attention to the alarms coming in. Because of alarm floods, the board operator missed a high level alarm from the blow down tower and a high pressure alarm on the outlet of the Coke heater which would have told him that problem was not resolved by working on the bottoms pumps. Eventually, the unit went in to shut down. As it turns out, the actual problem was that during the Coker drum switch, the field operator closed the wrong inlet valve during the drum switch, a possibility no one even considered during the incident.

Looking at this incident in terms of situation awareness failures, there are several things that went wrong that could have been avoided had the operations team maintained better situation awareness at the time of the incident. In situation awareness terms:

- **Failure to know what’s going on in the plant can lead to erroneous conclusions, which in turn can lead to taking the wrong corrective actions.** First, all operators failed to consider what had just been going on in the plant – a Coker drum switch – and ignored the big picture. Second, the field team was so focused on the bottoms pumps, they all failed to perceive or attend to auditory evidence of a PSV release. Third, the field operator working the valves ignored that the valve was harder to turn then usual, something he recounted during the incident investigation. Finally, the alarm flood made finding alarms that might have disputed the erroneous conclusion difficult.

- **Human beings are prone to interpreting events in terms of their own, recent experiences.** The board operator jumped to an erroneous conclusion based on his recent experience without considering alternative causes or more importantly – what had just been going on in the plant. In addition, when communicating the problem to the operations team, the board operator
communicated the suspected cause (bottoms pump cavitation), not the actual problem or event (low flow alarm on Coker heater).

- **Operating teams that lack a common focus in dealing with upsets can wind up working at cross-purposes.** The incident investigation also revealed some field operators had a different perception of the problem, but were so busy following direction they had no time to suggest alternatives.

- **Workload and alertness levels can have significant impacts on operator situation awareness.** The incident occurred in the early morning hours when operators’ alertness levels were down, and just following an exhausting drum switch leaving them fatigued.

**Training for Improved Situation Awareness**

Human Centered Solutions (HCS) has developed a training program designed to improve operator situation awareness that is focused on four basic principles:

1. Understanding human information processing capabilities and limitations
2. Understanding the influence mental models have on operator performance
3. Understanding alertness and its effect on human performance
4. Understanding what comprises effective communication and collaboration

**Human Information Processing Capabilities and Limitations**

Operator situation awareness requires a thorough understanding of human information processing and how that can be used to influence information *perception*. Research has shown that certain stimuli automatically draw people’s attention, such as high intensity stimuli (e.g., things that are bright, loud, or smelly, etc.), moving stimuli (e.g., flashing lights or oscillating sounds), or even emotive stimuli (e.g., hearing your name). Understanding this leads to the development of operator tools and user interfaces that employ these techniques to focus attention on key elements (filtering out less important/distracting information). Certain techniques (e.g., overview displays, salience coding of DCS graphics, and communication practices, etc.) can be used to focus attention for most operators at an expert level, improving their situation awareness.

Improving the perception of important information in displays should enable proactive rather than reactive monitoring and control by process operators. Improvements in this area include both operator tools and training, including:
• How to develop and use effective of trends, summary displays, overview displays
• How to employ salience coding in displays to make important information stand out, and less important information move to the background
• How to present information (data in context) rather than just data alone.
• How to develop and employ an effective alarm management program to facilitate accurate assessment of the importance and severity of alarmed events
• How to apply a more effective alarm response strategy then the typical event interrupt strategy of dealing with each interruption as it occurs

Influence of Mental Models on Operator Performance

The concept of mental models and the impact an individual’s mental model of the process can have on their data interpretation (i.e., comprehension and projection) is also important to understand as regards to situation awareness. Each operator has their own mental model of the process, its equipment, and its dynamics, that evolves based on their training and operating experiences. Each operator relies on their mental model to interpret and understand the information he sees and hears, and to predict the potential implications. Because of differences in training and job experiences, every operator has a different mental model, introducing variability across the operations team. In some cases, mental models may be inaccurate or missing critical relations among process variables, which would in turn lead to operators drawing incorrect conclusions and incident responses. Development of a common mental model of plant operations can enable operations teams to maintain more accurate situation awareness, and execute a more effective upset response.

Specific operator tools and training to enable development of a more common mental model of plant operations across the operating team include:

• Developing and training to common functional models of process operations (a functional model describes process units in terms of systems, subsystems, and equipment).
• Develop and train to common, team-developed cause/effect analyses (e.g., fish bone root cause diagrams) to identify from among the potential problem causes.
• Emphasizing the importance of teamwork in an upset, particularly with regard to delegation of responsibilities and tracking progress to ensure all members of the operations team are working together to solve the problem. Of particular import to teamwork is the importance of ensuring that someone is assigned the responsibility of maintaining the big picture of what is going on,
what the risks are, and ensuring the team is all on the same page working towards the same goal.

Alertness and Human Performance

The concept of alertness, how alertness levels can be influenced and how alertness levels can also impact operator situation awareness is also important. Studies of vigilance research have shown that, for most or all operators engaged in attention-intensive and monotonous tasks, retaining a constant level of alertness is rare if not impossible. Figure 1 below is adapted from the research by Yerkes & Dodson (1908) and Naatanen (1973) to depict the typical pattern observed in error rates as a function of level of alertness. The Yerkes-Dodson law states that for complex tasks (such as process control) performance was weakest during both low and high states of arousal. Adapting this model for error rates, as can be seen by examination of Figure 1, when operators’ level of alertness is low (when they have been engaged in an intensive vigilance task where little has changed for a long period of time), the likelihood of an error is high. Conversely, when their level of alertness is high (such as in a plant upset when they are dealing with alarm floods and multiple operating parameters that are nearing or exceeding their critical limits), the likelihood of an error is also high.

![Figure 1: Error Rates as a Function of Level of Alertness](image)

Specific operator tools and training to enable a more alert and “situationally” aware workforce include:

- Training both operators and supervisors on how to recognize the signs of long-term fatigue or chronic stress.
• Implementing an effective alertness recovery program that includes using a buddy system for high risk periods when operators are most susceptible to the effects of fatigue brought on by virtue of the nature of shift-work, exercising, or even taking breaks to re-energize operators.
• Training in how to support optimal alertness, visual acuity and circadian rhythm adjustments in the control room environment.

**Effective Communication and Collaboration**

Understand the components of successful communication and collaboration required for situation awareness and abnormal situation management recovery. Laberge, Bullemer & Whitlow (2008) in a study of communication and collaboration failures in the process industries, found that communication failures can occur within or between teams, across functional groups or companies, or even with process equipment. Klein (2001) found that these failures could occur at any of the five phases of collaboration: preparation, planning, direction, execution and assessment. Laberge, Bullemer & Whitlow (2008) found that of the top five failure modes observed in their study of 14 incident reports, four were collaboration failures (planning, individual and team execution, work direction and supervision, and activity assessment) while the fifth was failed communication between functional groups.

Specific tools and training for improved communication and collaboration involves implementing a structured communications program that includes:

• A comprehensive start of shift briefing/team meeting to ensure all operators are on the same page with regard to plant status, maintenance activities, equipment out of service, disabled alarms, etc.
• Establishing a structured radio protocol to designed to take into consideration human limitations with regard to auditory short term memory by keeping transmissions to one message in one direction at a time to make sure not to overload listeners auditory short term memory and using a formal structure to ensure speaker and listener are clearly identified, and a repeat back strategy to ensure the message was heard correctly.

**Situation Awareness Training Effectiveness**

To assess the effectiveness of our situation awareness training program focused around the previously described four principles, HCS conducted three, two-day pilot training sessions at a US refining plant. The participants in the training were 20 operators from four different shift teams from a single operating area at the refinery. The training included instruction in each of the areas described...
previously, as well as a number of plant-specific upset scenarios developed specifically for use as exercises for operating teams to practice (themselves) and critique (other teams) the application of those skills and techniques from in the training.

At the completion of each training session, operators were asked to assess the value of the training received by rating their agreement with five statements on a scale of 1-Strongly Disagree to 6-Strongly Agree. The results of this assessment are presented in Figure 2 below.

![Figure 2: Training Course Value](image)

In general, all operators strongly agreed with each of the assessment statements, indicating that in the perception of the operator trainees the workshop helped them:

- Understand the importance of establishing and maintaining good situation awareness.
- Understand what factors can influence situation awareness on the job.
- Understand the importance of teamwork.
- Learn specific techniques to improve their situation awareness on the job.
- Improve the way they will approach their work in the future.
References


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