Improving the Operations Team Situation Awareness: Lessons Learned from Major Process Industry Incidents

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Situation awareness (SA) refers to the perception of what is happening around you, understanding it's meaning now and in the future in terms of the need for action. In the context of operations, it is the perception and comprehension of the plant condition in the collective minds of an operations team that allows them to make effective decisions and take appropriate actions. Team situation is defined as the degree to which every team member possesses situation awareness required for his or her responsibilities. For an organization to accomplish high team situation awareness, the individuals' situation must be high and the shared situation awareness between members must also be high.

In study of accidents involving major airlines, 88% of those involving human error were problems with situation awareness rather than decision making or flight skills (Endsley, 1995). Recently, the Abnormal Situation Management® Consortium[1] funded a study to investigate the contribution of ineffective operations team situation awareness to major process industry incidents. The study team analyzed 20 public and 12 private incident reports to identify root causes associated with team situation awareness failures. The main finding from this investigation was that the majority of the operations practice failures (50%) across these 32 incident reports involved failures associated with team situation awareness.

The objective of the paper is to raise awareness of the prevalence of operations practice challenges associated with ineffective operations team situation awareness. The presentation explores implications of these failure modes for effective operations practices including adopting ASM Consortium solution innovations in communications and collaboration, first-line leadership, operator interface design and operator development and training.

Team 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.

[1] This research study was sponsored by the Abnormal Situation Management® (ASM®) Consortium. ASM and Abnormal Situation Management are registered trademarks of Honeywell International, Inc.

Endsley (1995) proposed a three level model of model of situation awareness for an individual person. 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.

Team situation awareness is defined in the context of a team itself, where a team has

- A common goal for the team members
- Specific roles defined for each team member
- The roles of different team members are interdependent

(Endsley, Bolte, & Jones, 2003). However, a team does not have a 'suprabrain' (Endsley et al, 2003). Rather, only each individual team member can have their own situation awareness. Team situation awareness then is defined as the degree to which every team member possesses situation awareness required for his or her responsibilities (Endsley et al, 2003). For an organization to accomplish high team situation awareness, the individuals' situation must be high and the shared situation awareness between members must also be high (Endsley et al, 2003). Shared situation awareness then is defined as the degree to which team members have the same situation awareness on shared situation awareness requirements. The contributing elements of team situation awareness then can be seen in Figure 1.

Figure 1 Contributing elements to team situation awareness (Endsley et al, 2003)

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. Based on the significance of situation awareness in aviation, the ASM Consortium conducted an investigation of the impact of ineffective situation awareness on human reliability and process safety performance.

Effective Operations Practices

The ASM Consortium's mission is to empower and enable operating team to proactively manage their plants to maximize safety and minimize environmental impact while allowing them to optimally operate their plants (www.asmconsortium.org). Prevention, early detection and mitigation are key elements to managing abnormal situations, in order to reduce unplanned outages and process variability that increase production, safety and environmental risk to plant employees and local communities. While the ASM Consortium recognizes that mechanical integrity is important to process safety, our focus on the operations team has led to an emphasis on operational integrity to reduce the likelihood of abnormal situations and ultimately improve process safety as well as plant performance. Hence, the perspective of the ASM Consortium is that effective abnormal situation management practices are directly related to addressing plant process safety.

The relation between abnormal situation management a process safety can be illustrated using the safety pyramid (see Figure 2). At the bottom of the pyramid, unsafe behaviors can lead to near miss event that have the potential to be process safety incident events.

Effective operations practices are seen as an opportunity to reduce the probability of unsafe behaviors through improved operational discipline, human reliability and performance. Moreover, effective abnormal situation management is the key step in preventing the occurrence of near-miss events that have the potential for process safety incident consequences further up the safety pyramid.

The ASM Consortium has defined an abnormal situation as an event where an industrial process is disturbed and the base control system cannot cope, requiring the operations team to intervene to supplement the control system. The objective of abnormal situation management is to bring the process back to normal before safety shutdown control systems or other safety protection systems are engaged. This definition may be narrower than other existing definitions of an abnormal situation. This definition is specifically used to distinguish between normal, abnormal and emergency situations from the perspective of console operations.

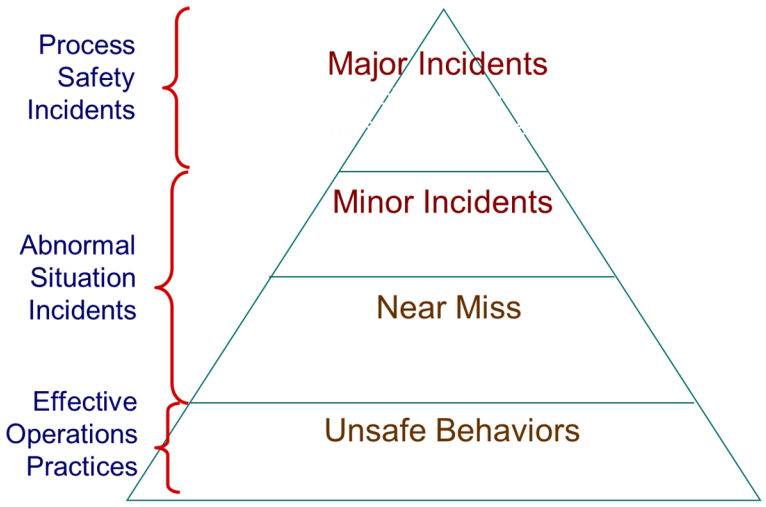


Figure 2 Illustration of the relation ASM to Process Safety Management in the Safety Pyramid (CCPS, 2011)

The ASM Consortium developed a framework for characterizing operational problems relevant to abnormal situation management and operator performance (Bullemer, Reinhart, Soken, Ramanathan, & Corwin, 1994). This framework is also based on various models of human supervisory control putting the terminology in the vernacular of process automation and control.

The framework as depicted in Figure 3 defines distinct activity types of an operator or an operations team that occur in the prevention or response to an abnormal situation. The framework has been explicitly constructed to support the concept of an operator that proactively monitors a stable process for potential deviations and proactively responds to disturbances before they escalate into unplanned loss conditions.

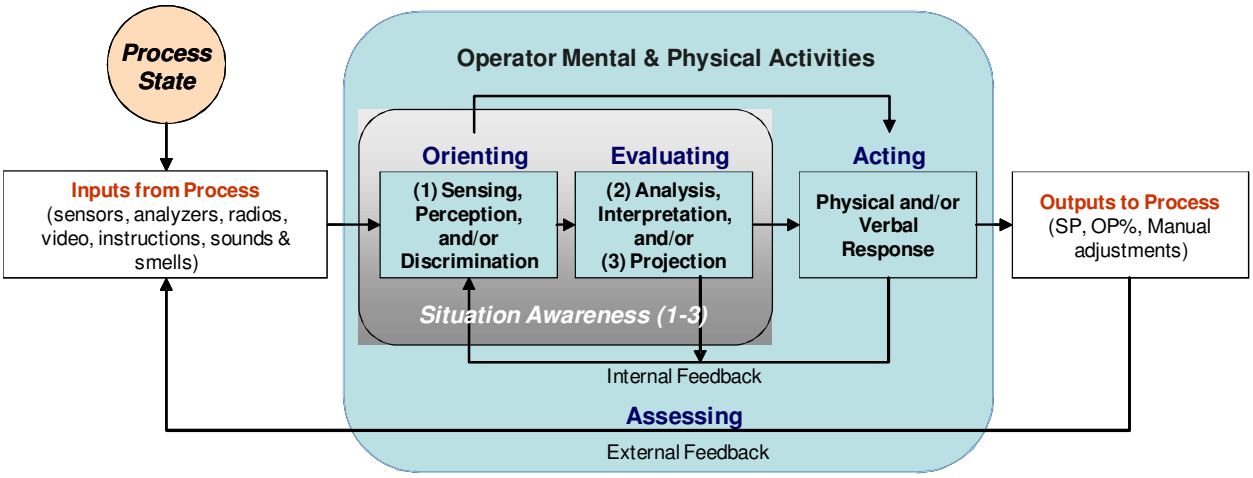


Figure 3 The ASM framework for operator or operations team interventions for abnormal situations.

As depicted in Figure 3, the ASM framework for abnormal situation management shows four basic stages or activity types for operators to prevent and respond to abnormal situations:

- ***Orienting*** – Sensing, Perception, and/or Discrimination (i.e., detect)
- ***Evaluating*** – Information Processing (i.e., understand)
- ***Acting*** – Physical and/or Verbal Response (i.e., respond)
- ***Assessing*** – Information Processing (i.e., verify)

This ASM framework provides the characterization of the basic types of activities that an operator and an operations team engage in to manage situations. The activities of orienting and evaluating comprise activities supporting operator and team situation awareness. From an effective operations perspective, organizations should be concerned with how well operators perform these activities because it can directly impact plant performance. Hence, operational problems can be characterized as problems with operator (human) error, reliability or performance.

Analysis of Process Industry Major Incidents

Process industry plants involve operations of complex human-machine systems. The processes are large, complex, distributed, and dynamic. The sub-systems and equipment are often coupled, much is automated, data has varying levels of reliability, and a significant portion of the human-

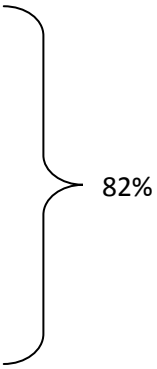
machine interaction is mediated by computers (Soken, Bullemer, Ramanathan, & Reinhart, 1995; Vicente, 1999). These systems are also social in that many plant operations function with a teamwork culture such that activities are managed by crews, shifts, and heterogeneous functional groups. Team members have to cope with multiple information sources, conflicting information, rapidly changing scenarios, performance pressure and high workload (Laberge & Goknur, 2005). Historically, the reporting of failures has tended to emphasize root causes associated with equipment reliability and less so on human reliability root causes (Bullemer, 2009). Consequently, there is limited information available on the frequency and nature of operations failures pertaining to human reliability. This tendency has limited the ability of process industry operations organizations to identify improvement opportunities associated with their management systems and operations practices.

To better understand the impact of ineffective operations practices, the ASM Consortium conducted a study to investigate operations failure modes in 32 major process industry incidents (Bullemer & Laberge, 2010). The study team defined an operations failure as a practice flaw that, if corrected, could have prevented the incident or mitigated its impact.

These failures were captured in the words of the incident investigators such as "Supervisor was not accessible". The next step was to identify common failure modes using the ASM Consortium's Guideline document, *Effective Operations Practices* (Bullemer, Barreth, Laberge, & Nimmo, 2008). Each operations failure was categorized in terms of failure of one of the effective operations practices such as *Ineffective First-line Leadership*. Further investigation of these common failure modes in terms of human reliability found 82% of the root causes were directly related to human performance (See **Error! Not a valid bookmark self-reference.**).

Table 1 Basic causes associated with the operations practice failures.

Basic Causes	#	%
Management System	279	29%
Work Direction	159	16%
Communications	131	14%
Procedures	82	9%
Training	64	7%
Human Engineering	56	6%
Quality Control	27	3%
Equipment-related Sources	166	18%
Total	964	100%

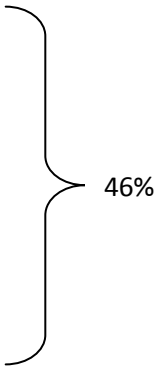


Given the significant impact of situation awareness in other industries, the ASM Consortium conducted a second analysis of the operation practice failures in the 32 major process industry incidents. The study team found 50% of the practice failures were related to situation awareness.

Table 2 shows the breakdown of basic causes associated with the operation practice failures. A total of 46% of the root causes were related to ineffective situation awareness.

Table 2 Basic causes related to ineffective situation awareness associated with operations practice failures

Basic Causes	%
Work Direction	13%
Communications	11%
Management Systems	8%
Human Machine Interface	5%
Procedures	4%
Training	4%
Quality Control	1%
Non-SA Related	54%



Further analysis of the root causes helps to understand potential areas improvement for situation awareness impact on operations practices. **Error! Not a valid bookmark self-reference.** shows that top ten root causes associated with situation awareness failures account for 65% of the SA related root causes.

Table 3 Top ten root causes associated with situation awareness failures.

Root Causes	%
No Communication	12%
Crew Team NI	11%
Displays NI	9%
No Supervision	9%
Communications NI	5%
SPAC Not Followed	5%
Situation Not Covered	4%
Pre-job Brief NI	4%
Learning Objectives NI	3%
No SPAC	3%
Total	65%

[NI = Needs Improvement; SPAC = Standards, Policies & Administrative Controls]

ASM Solutions for Team Situation Awareness

The effort to improve team situation awareness and the effectiveness of abnormal situation management to mitigate the occurrence of process safety incidents can start with addressing these top 10 root causes. The results of the analysis indicate value in focusing on the following operations practice areas, relating to the contributing elements of team situation awareness shown in Figure 1:

- Communications and Collaboration
- First-line Leadership
- Operator Interface Design
- Operator Development and Training

Communication and Collaboration

Examination of the top 10 root causes associated with situation awareness failures found three root causes related to communication and collaboration (21% of SA-related root causes):

- No communication (12%)—lack of communications within and between shift teams contributed to the failure to establish effective situation awareness
- Communication needs improvement (5%)—ineffective communications methods and tools contributed to poor situation awareness
- Pre-job briefing needs improvement (4%)—lack of or incomplete pre-job briefing among individuals working on a job contributed to incomplete situation awareness

Successful communication enables situation awareness under normal, abnormal and emergency situations. Communications practices allow operational and functional team members to efficiently perceive, orient, evaluate and act on information in the context of the current team goals and constraints. Team members coordinate with respect to goals and activities through the use of effective information media to ensure continuity in work conditions.

Key ASM solution elements for effective situation awareness include:

- Structured daily communications
- Operations & maintenance coordinated interactions
- Task-based communication protocols

In 2010, the ASM Consortium completed a research project that evaluated experimentally, the benefits of a structured shift handover and identified minimum requirements for an effective handover (Plocher, Yin, Thompson, Telner, & Laberge, 2010). Specifically the study examined the relative effectiveness of operator communications at shift handover using an integrated checklist and structured logbook compared to a structure logbook alone. The project found that the checklist-integrated shift log that provided information subcategories to prompt operators to acknowledge each detail even if there was nothing to report lead to better shift handover communications:

- Higher-quality log entries compared to model entries generated by operations experts (+18.6% improvement compared to the non-ASM solution)
- Second shift operators provided more accurate and comprehensive account of the unit situation (+9% improvement)
- Operator's accuracy in answering questions without need to consult other team members (+8% improvement)

First Line Leadership

Examination of the top 10 root causes associated with situation awareness failures found three root causes related to first line leadership (26% of SA-related root causes):

- Crew team needs improvement (12%)—poor teamwork within shift teams contributed to the failure to establish effective situation awareness
- No supervision (9%)—lack of a reasonable level of supervision at the work site contributed to poor situation awareness
- Standard, policies and administrative controls not followed (5%)—failure to adhere to established formal practices contributed to incomplete situation awareness

The first line leadership or supervisor role is a rostered and back-filled position on the shift team. The operations team recognizes the supervisor as the leader and director of work activities, particularly abnormal situations. The supervisor is available for consultation and maintains a presence around the operations team work areas. The supervisor ensures that individuals' behaviors are compliant with site policy and formal work practices.

Key ASM solution elements for effective situation awareness include:

- First-line leadership competency model
- Leadership training
- First-line leadership quality audit checklist

In 2011, an ASM study investigated the root-cause manifestations associated with ineffective first line leadership operations practice failures (Bullemer & Laberge, 2011). The study generated an audit checklist for monitoring leading indicators of the quality of the first line leadership. Some of the audit checklist items included:

- The supervisor maintains a presence in the control room and field areas with face-to-face contact periodically throughout a shift to ensure good situation awareness of Operations and Maintenance activities
- The supervisor is easily accessible via radio contact by any team member to answer questions and respond to problems
- The supervisor assigns a stand-in responsibility when leaving the job site
- The supervisor enforces clear guidelines on when and how to conduct pre-job briefings

- The supervisor ensures that individuals' behaviors are compliant with site policy and work practices, and does not allow individuals to operate in the presence of known hazards without taking adequate precautions

Operator Interface Design

Examination of the top 10 root causes associated with situation awareness failures found one root cause related to operator interface design:

- Displays need improvement (9%)—inadequate or unclear instrumentation, gauges, alarms, DCS displays or other types of computer-based display systems contributed to the failure to establish effective situation awareness

The operator interface framework provides a comprehensive and user-centered set of applications and tools that enables the console operations a single point access to their information needs to support team situation awareness and abnormal situation management.

Key ASM solution elements for effective situation awareness include:

- Integrated information access
- Perceptual display objects
- Console-wide overviews
- Rationalized alarms
- Alarm Trend Summary displays
- Console view of field activities

In 2008, the ASM Consortium conducted a study on the effective design of Span-of-Control Overview displays to enable console operators to maintain situation awareness across their area of responsibility (Reising & Bullemer, 2008). The study compared operator situation awareness using two different types of Span-of-Control Overview display designs: (1) Schematic Layout with Numeric Indicators and (2) Functional Layout with Qualitative Indicators (see Figure 4).

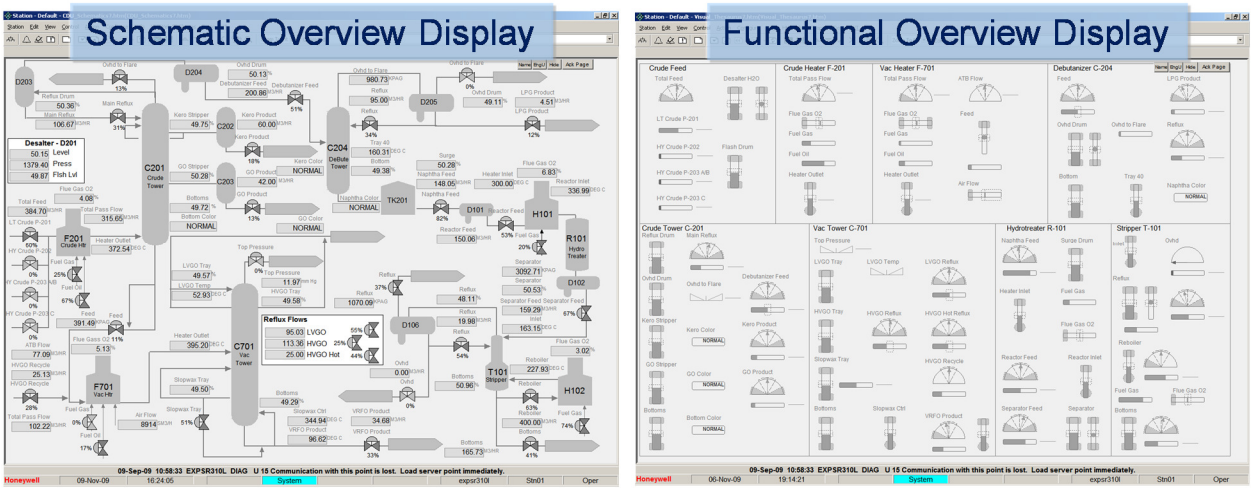


Figure 4 Illustration of two types of Span of Control Overview display designs: (1) Schematic Layout with Numeric Indicators and (2) Functional Layout with Qualitative Indicators (From Reising & Bullemer, 2008).

The simulation-based performance found that operators were able to detect significantly more process changes with the Functional Layout with Qualitative Indicators that highlighted when and where the process deviated outside of normal operating ranges. Consequently, the specific design of the Span-of-Control Overview display was shown to impact the extent and accuracy of the console operator situation awareness (Tharanathan et al, 2010).

Operator Development and Training

Examination of the top 10 root causes associated with situation awareness failures found two root causes related to operator development and training (14% of SA-related root causes):

- Crew team needs improvement (11%)—poor teamwork within shift teams contributed to the failure to establish effective situation awareness
- Learning objectives need improvement (9%)—lack of comprehensive set of training program objectives for operation personnel contributed to poor situation awareness

The training program for knowledge and skill development of operations personnel is based on the establishment and maintenance of a comprehensive set of competencies including those required for abnormal situation management. The learning process is a continuous process supported by a performance evaluation framework that identifies training opportunities and sustains operator performance over time.

Key ASM solution elements for effective situation awareness include:

- Common mental model development
- Problem-solving & troubleshooting
- Team-based abnormal/alarm response strategies

Based on the analysis of the root-cause manifestations associated with the operator development and training failures, the study team identified a strong need to improve upset response training. The following elements were identified as important elements for an effective upset training program:

- Define clear roles and responsibilities that emphasize value of team work
- Assign a team member with responsibility for maintaining the big picture during upset responses, startup or other major procedure-based activities, i.e., what has happened, what is now going on, and the risks of specific actions or inactions
- Learn common functional models of plant/process operations
- Learn common cause/effect troubleshooting strategies
- Conduct team-based training exercises such as the periodic review of procedures to identify potential risks associated with human reliability and periodic unplanned red-tag drills to assess team communication and collaboration competencies

Conclusions

The analysis of 32 major process industry incidents found that 50% of the common operations failure modes were associated with ineffective individual and team situation awareness. Further

analysis of these failures in terms of root causes indicates successful mitigation of these failure modes should focus on ASM solutions in four operations practice areas:

- Communications and Collaboration – communication protocols such as structured shift handover checklists
- First-line Leadership-leading indicator metrics with periodic leadership quality audits
- Operator Interface Design—Span of control overview display design
- Operator Development and Training—upset response scenario training

Human performance that can lead to plant upsets and incidents is not changed by the mere exposure to data and technology (Cochran and Bullemer, 1996). Many companies in the process industries seek to improve operations reliability through operator performance improvements. Effective solutions need to go beyond the delivery of more data and advanced technology for the operator. Establishing effective operations practices that enable high individual and team situation awareness are important to effectively preventing and responding to abnormal situations and improving process safety performance.

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