Paper presented at the Mary Kay O'Connor Process Safety Center 2015 International Symposium, College Station, TX, 27-29 October 2015.

Managing Human Reliability: An Abnormal Situation Management Historical Perspective

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Abstract

In 1993, five companies initiated a project to better understand the problem of managing abnormal situations. A study team was formed to visit several operations facilities to better understand the abnormal situation management challenge and identify the requirements to improve operations team's ability to prevent and respond to abnormal situations. The 1993 project team's findings were powerful enough to motivate several industry competitors to form a research and development consortium to work together to develop solutions to plant safety. This paper summarizes the key findings of this foundational 1993 study that lead to the founding of the Abnormal Situation Management (ASM) Joint Research and Development Consortium, which is commemorating its 20th year working together. More importantly, this paper examines the progress made over the past 20+ years against the ASM requirements identified in that foundational study in terms of (i) industry's understanding of the contribution of human reliability to major process safety incidents and (ii) the implications for operations practices to effectively manage human reliability in reducing risks that may contribute to process safety incidents. The ASM historical perspective is intended to show where progress has been made and where there are still gaps in effective solutions to improve human reliability and process safety.

Introduction

In 1992, Honeywell formed an alarm management task force with representatives from several of their customer organizations who had and were making the transition from pneumatic panel control boards to distributed control systems (DCSs). These individuals discussed alarm management problems with Honeywell and suggested potential improvements to the alarm system functionality of the TDC3000 DCS. During the discussions, some of the customer representatives told Honeywell that some of the alarm management problems were a manifestation of a larger problem. Some of the influential individuals on the task force included Ken Emigholz (ExxonMobil), Mike Clark (Amoco), Roger Humphrey (Chevron), Doug Rothenberg (BP) and Ed Huestis (Shell). They referred to the larger problem as the abnormal situation management challenge. The problem was characterized as a human reliability challenge wherein there is a disturbance in the process and the control system cannot cope with the disturbance requiring human operators to intervene to bring the process back to the normal operating regime and preventing an escalation to a process safety incident.

The challenge was that during normal, steady state operations the available control system functionality was quite good but once the process became abnormal, operations team members had significant challenges in detecting the abnormal condition, understanding the source and the implications and taking appropriate actions in a timely manner. In some of these situations, the significant number of alarms (i.e., alarm flooding) contributed to failures to detect and understand the nature of the abnormal situation.

The industry tendency was to try to solve this human reliability issue with more automation. However, the increase automation leads to more sophisticated process that are more complex for human operators to understand. Consequently, the more sophisticated processes have a tendency to reduce human reliability. This phenomenon has come to be known as the paradox of automation (Wiener, 1989; see also Bainbridge, 1983; Wiener & Curry, 1980).

At the conclusion of the alarm management task force activity, Honeywell and a few of the customer representatives agreed to establish a research project to better understand the abnormal situation management challenge and identify the key solutions requirements. In 1993, a study team was formed to conduct visits to plant facilities to better understand the abnormal situation management problem and identify the requirements to improve operations team's ability to prevent and respond to abnormal situations.

The 1993 project team's findings were powerful enough to motivate several industry competitors to form a research and development consortium to work together to develop solutions to plant safety. The key findings of this foundational 1993 study led to the founding of the Abnormal Situation Management (ASM) Joint Research and Development Consortium, which recently celebrated its 20th year working together.

In the remainder of this paper, we present the key findings from the 1993 study (Bullemer, 1994) and examine the ASM Consortium research progress in addressing the ASM requirements identified in that foundational study in terms of (i) the industry's understanding of the contribution of human reliability to major process safety incidents and (ii) the implications for operations practices to effectively manage human reliability in reducing risks that may contribute to process safety incidents.

1993 Foundational Study

Peter Bullemer led the Honeywell Abnormal Situation Management (ASM) Study Team on five plants visits in North America and Europe between September, 1993 and February, 1994. The team interviewed plant personnel to understand their concerns regarding current limitations facing industrial plant operations during abnormal conditions. The team spent five days at each site conducting structured interviews of plant personnel including operators, supervisors, engineers, managers, maintenance specialist, and automation specialists.

These plant visits were conducted with the following objectives:

- Identify problems by interviewing site personnel and observing operations personnel in their work environment
- Identify potential changes in methodologies, practices, and operations and the technical solutions to achieve best practices

Abnormal situations were found to occur almost on a daily basis in most large process industrial plants. Most are relatively small and are adeptly handled by the operating, maintenance and engineering staff in the plants with perhaps minor impact on the unit. An example of a small event might be a controller pushed beyond its limits and placed in manual to stop cycling, or an operator entering the wrong set point value for a controller. However, some situations may result in poor quality product or reduced production. A smaller percentage may result in situations that mandate a process shutdown. An even smaller fraction causes significant equipment damage, release of undesirable materials into the environment, and even human injury or death.

Although individual perceptions of abnormal situation management varied, there was consensus that normal and abnormal represent two distinct modes of operation. Furthermore, abnormal operations were more likely during transition events such as startup, feed change, product grade change, and shutdown. Errors in situation assessment could be a source of abnormal situations because personnel do not understand the plant or the software system and make erroneous interventions. Furthermore, the current interface design of the DCS led to predominately a reactive rather than a proactive mode of intervention.

Based on these findings, it was clear that a common definition of the nature and sources of abnormal situations and the problems associated with their management was the critical first phase in developing solutions. The next section presents a general overview of sources of abnormal situations and their average rate of incidence in the plant visits.

Sources of Abnormal Situations

The study team examined the plant incident reports to identify sources of abnormal situations. Root and contributing causes may have appeared in isolation or in combination with each other. However, in most cases, the abnormal situation was a result of the interaction among multiple sources. For example, a frequent plant practice was to extend the process to its limits to maximize production. In purposely pushing to the limits of the process, the probability of the equipment failing, the process becoming less resilient, and/or personnel making errors greatly increases; the equipment's original design limits are challenged, the process is operating very near or at its original design constraints, and personnel are being asked to monitor and interact with a process that is complex and reaching the limits of their cognitive and physical capabilities. At any point in time, one or more of these factors may contribute to the onset and escalation of an abnormal state. The resulting abnormal situations vary in their complexity and effect on the process.

The study team characterized the sources of abnormal situations in terms of three basic types of sources or causes of abnormal situations. Figure 1 shows the average percentages for each type of source.

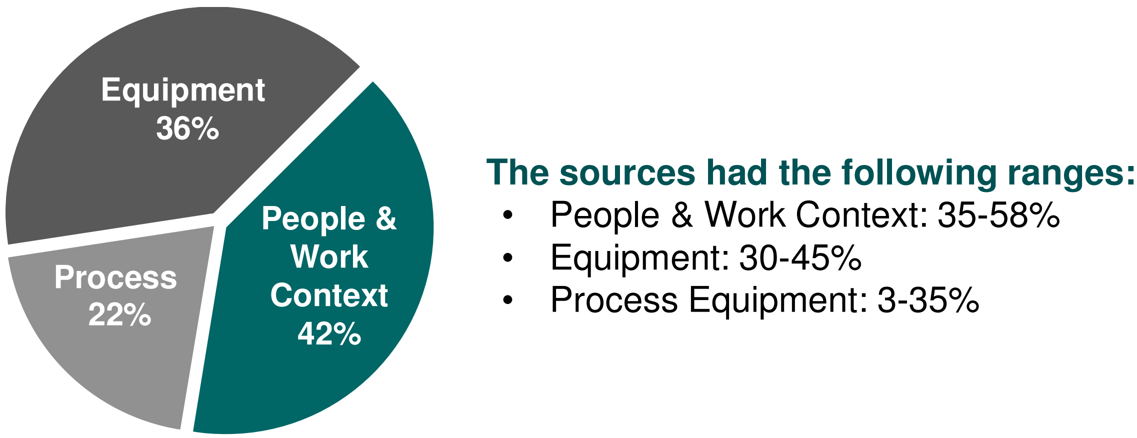

Figure 1 Average percentages and ranges for the 3 types of sources of abnormal situations identified in plant incident reports.

The data was obtained from 1992-3 incident reports at each of the five sites. Of all the incidents reports, the study team selected only those events that had an impact on process operations, i.e., did not include slip, trips and fall reports. These findings differed from a contemporary industry report at the time from the Chemical Manufacturers Association (CMA; Lorenzo, 1990) that indicated up to 80-85% of human errors contributed to process safety incidents. The study team identified a general reluctance of plant personnel to report people as the cause of an incident. Hence, the study team concluded that the available data was probably biased towards reporting equipment and/or process sources rather than people or work context.

For the incidents involving People & Work Context factors, the following root causes were reported:

- Inadequate or no procedure (27%)
- Fail to follow procedure (24%)
- Inadequate or incorrect action (24%)
- Inadequate work practices (15%)
- Fail to recognize problem (5%)
- Defective installation (5%)

Hence, the reported root cause indicated a significant contribution of ineffective procedural operations to the occurrence of the reported process safety incidents.

Human Reliability Influences

Based on the interviews with site personnel, the study team identified the following human reliability influences that contributed to the perceived abnormal situation management challenge:

- Minimal understanding of the source of the problems and their impacts
- Operating close to design limits
- Ineffective use of procedures
- Inadequate communication
- Inadequate training methods
- Ineffective access and presentation of information

In this section, a summary of these human reliability influences is provided along with a list of some of the recommended high priority solution requirements.

Minimal understanding of the source of problems and their impact

In general, the reporting and record keeping functions provided limited support for understanding the impact of ineffective abnormal situation management in the early 1990s. If sites were capturing impact of abnormal situations on plant performance, the safety incident reporting system was used. Consequently, most incident reporting captured major upsets that had safety implications and not abnormal situations (i.e., near-miss events). Consequently, the causes of abnormal situations (operationalized as the impact on the inability to control without operator intervention and subsequently, impact on profit) were not well understood.

Operational and system changes were often a daily occurrence in response to abnormal situations. The current documentation systems were unable to keep pace with changes. Reportedly, the plants were able to keep on top of the changes because the knowledge existed as corporate memory within collection of individuals working at a plant. However, in the economic climate of the early 1990s, with many plants reducing work-force along with normal turnover of staff, the reliance on corporate memory was perceived to be less dependable and involved more risk.

The alarm logging mechanisms at that time were found to not handle alarm flooding adequately. Consequently, important information for incident analysis was often not available.

Lack of integration and ease of access limited effective use of reporting and record keeping capabilities in the early 1990s. For example, chronological sequence information was a fundamental aspect of identifying root causes and contributing causes. However, the information available was not at the right level of detail for accurate identification. Furthermore, the information that was available must often be obtained from multiple systems and reports.

The study team identified the following high priority solution requirements to address this influence on human reliability:

- Need better techniques for recording event logs to prevent inadvertent data losses: *e.g. chattering inputs, buffering history*
- Need to archive more data, and essential data at higher resolution
- Need access to PLC information currently unavailable
- Need more powerful data visualization and analysis tools that can integrate all the available information and expose relationships

Operating close to design limits

A common problem across plants was that abnormal situations tended to arise as a result of operating close to the original design limits of the system. The strategy to maximize plant productivity frequently led to more manual intervention by the operator.

Abnormal situations occurred, oftentimes unexpectedly, when a disturbance or event was severe enough to make the DCS in its typical configuration unable to cope with disturbances. Consequently, the operator had to intervene quickly to supplement the control system. Instrument failure was a perceived to be a leading source of abnormal situations, and was often reportedly hard to distinguish from process upsets. For these reasons, correct manual interventions were most difficult in abnormal situations.

Interviewees reported that manual interventions were a contributing factor to the escalation of the problem for the following reasons:

- Failure to assess the situation correctly
- Inability to respond quick enough
- Failure to choose of the correct intervention
- Entry of the wrong commands

The most significant issue confronting effective manual interventions appeared to be the extremes of the process dynamics and process interactions. The process dynamics and process interactions could at times require extremely quick responses and at other times, disciplined paced interventions that allowed the changes to propagate through the system.

Insufficient time to check work, resulting in human error in command entries, was reported as a contributor to abnormal situations. Furthermore, the control system allowed entry of values that were clearly out of range of acceptable values. In some situations, inappropriate entries were reported as causing major incidents.

The study team identified the following high priority solution requirements to address this human reliability influence:

- Need to improve support for situation assessment activities and check appropriateness of manual interventions in current context
- Need automation techniques to accelerate interventions and reduce the need for operator manual intervention
- More reliable/redundant sensors and communications with on-line assessment of sensor's current validity

Ineffective use of procedures

One explanation for why some plants operated better than others accepted at the time was that people followed instructions in a more disciplined manner, i.e., through use of procedures and/or daily instructions, in the better plants. There was a common concern about compliance with plant policy on use of procedures. Compliance problems were attributed the current form, medium and content of the procedural documentation during the early 1990s. Some of the content problems reflected a more general issue with maintaining updated documentation to keep pace with rapidly changing plant configurations and operations regimes.

Some of the challenges in getting effective use of procedures included:

- Procedures existed in too many diverse locations which made it difficult for operations to access them in appropriate situations
- Procedure manuals and reference documents were not clearly and legibly marked
- Procedures did not adequately address execution contingencies
- Operators may not have followed procedures because of known or perceived undocumented exceptions, or a desire to simplify a complex procedure
- Procedures assumed that the operator knew the system well enough to make the correct quantitative adjustments

The study team identified the following high priority solution requirements to address this human reliability influence:

- Need procedures that operators could use within their working environment, and appropriate to their time constraints
- Support construction, maintenance and use of on-line procedures to support emergencies as well as startups and shutdowns
- Provide mechanisms to assist and track procedure execution to enhance compliance
- Need to provide operators with activity reminders for ongoing procedures

Ineffective communications

At every site visited, the study team observed that coordination practices and communications between and within operations teams had a significant impact on the ability to manage abnormal situations due to the process flow interactions across and within operating units. During upset conditions, multiple operators needed to coordinate their movements, which could be difficult with the current communication technology and integration systems of the day.

In these production facilities, the interconnectivity and dependencies across units required a high level of coordination and cooperation across and within operational and technical support teams. Teaming structure, control room design, process configuration, staff organization and work practices were contributing factors.

The main tool for communicating the day-to-day status between teams was the daily shift log and the daily instructions. Information in the shift logs was limited in its usefulness due to lack of structure and legibility. Inadequate communication between shifts often led to operators in the next shift undoing what the operators in the previous shift just did. Inadequate information sharing between operational and non-operational personnel (maintenance, management, system planners), led to inefficient/incorrect actions.

In the best instances, coordination was facilitated by regular periodic coordination meetings with other plants or production areas, shift rotations that maintained operator familiarity with each job, and direct communications with other plant control rooms.

The study team identified the following high priority solution requirements to address this influence on human reliability:

- Need to improve capability of using information contained in shift logs
- Need for reliable real-time mechanisms for multiple operators to exchange messages and synchronize actions during upset
- Need to make it easy for personnel to share information across functional boundaries

Ineffective operator training

Training was an area, in addition to alarm management, that was a concern to a majority of individuals. There was a concern at that time with the current methods of training on new applications as well as refresher training to keep skills up to date as people rotated through job positions.

Operators, universally, commented that they did not feel comfortable operating under abnormal situations given their level of training on the DCS. Whereas shift job rotation improves the distribution of knowledge across the crews, it reportedly limits individuals who were learning a new system from getting a strong foundation of knowledge. The time constants in which the console operator had to respond in abnormal situations required quick and automatic responses. Operators reported that they did not have time to think about what steps to take or search for operating displays. Console operators stated they needed more console experience and training.

The finding that operators lacked of familiarity with functionality of the new schematics indicated a need for training when introducing new functionality. In addition, several operators commented on the difficulty in remaining knowledgeable on how to control the process when advanced control applications were in place. Although help displays were provided to them, users needed to acquire experiential knowledge on how to perform manual interventions while these advance control applications were running.

In general, there was a need for more cost- and time- effective methods of providing training for both operations and non-operations personnel. Alternative training techniques and the use of dedicated simulators were seen as resolving some of these problems.

As with all sites visited, there was a strong perceived need for a unit-specific, on-line, simulation-based training. Simulation-based training was identified as the method to develop the experiential knowledge. Existing simulation techniques were found to be neither time- nor cost-efficient. It was found to be both difficult and expensive to keep simulators up to date.

The study team identified the following high priority solution requirements to address this influence on human reliability:

- Need to improve personnel readiness to handle infrequent abnormal situations with increase “hands-on practical components of training and adequate refresher training techniques and schedules
- Need to develop innovative, low-cost simulation technologies and automated links to update simulations when changes are made to the process or DCS.

Ineffective access and presentation of information

Quick access to operating displays for the current problem situation is critical to effective abnormal situation management. The default mechanisms and navigation speed in the DCS environments at the time tended to limit operator effectiveness. The specific access requirements could be difficult to anticipate with the implementation of a single schematic operating display. Abnormal situations could impose multiple simultaneous task demands.

Engineering and management commented that the DCS functionality made it difficult to design effective and flexible navigation paths, which led to situations where the operator had to navigate through a number of displays to access appropriate information or controllers. Several individuals commented that operators had difficulty accessing specific point information and controllers associated with alarms directly from the annunciation of the alarm.

Several operators commented that accessing a trend for a point could be tedious because they needed to go through a series of steps and either look up or remember information as part of trend specification.

Multiple systems used in- and outside of the control room were poorly integrated. Hence operators had to learn to use multiple control and information systems to access all the required information.

A general consensus from several sources was that operations lacked an adequate area-level status overview display (i.e., at a level compatible with the extent of console operator's responsibility including critical upstream and downstream parameters). Operations, management, and engineering agreed that the major impact on ability to understand the health of the plant at a glance in the transition from the panel board to the DCS was the loss of area-wide overview of process status. Situation assessment and coordinated actions within the operations team were hindered by lack of status overview that had been available on the previous hard panel control boards. An appropriate status overview provides the user with an immediate indication of the problem locations, as well as indications of where problems may be developing.

A major limiting factor to the extensive use of information presentation techniques for overview displays was their impact on DCS system memory and performance.

Abnormal situation management activities were significantly hampered by the limitations of the existing alarm management functionality. The DCS alarm annunciation and management functionality both obstructed and contributed to the abnormal situation management problem. As with all sites visited, alarm flooding under abnormal situations was the phenomenon that caused widespread concern. This phenomenon imposed limitations on the ability to assess the nature of the problem as well as the ability to react or manage the problem. Too many instrumentation alarms in the control system was also identified as a contributing factor.

In general, it was observed that engineers and supervisors understand how alarm flooding and nuisance alarms impacts the ability of the console operators to respond. However, the lack formal methods for identifying and implementing alarm notifications contributes to the alarm flooding problem.

The study team identified the following high priority solution requirements to address this human reliability influence:

- Need to improve capabilities to coordinate use of multiple, unintegrated systems – multiple data types and media types
- Need to improve system performance characteristics to handle demands for graphic displays
- Need to improve ease of specifying initial and default setups for displays, specifically, ease of specifying and retaining trending setups
- Need to improve interface design conventions and techniques to meet differing information needs for various situations (e.g., normal versus abnormal modes of operation)
- Provide more flexibility in specifying navigation paths between displays
- Need for alarming philosophy and design methodology to achieve effective situation annunciation including conducting alarm objective analysis, implementation techniques to achieve objectives, and sample templates for common system configurations
- Need to assure that alarms are reported in the true order of occurrence
- Need to be able to selectively view alarms based on:
  - recency
  - priority
  - area of plant
  - operator's current responsibilities
  - state of suppression
- Need to be able to easily, condition alarm activation to the state of the plant
- Need to detect abnormal process trends and alert operators prior to upset
- Need to improve error avoidance capabilities on data entry for set points and outputs as well as in keyboard layout design

Not by Technology Alone

A significant conclusion from this initial study of the abnormal situation management challenge was that the effective human-machine system solution involved more than developing the right technologies (Cochran & Bullemer, 1996). While the capabilities of technology can impact human performance, it is not the only factor that needs to be considered when organizations seek to improve human reliability. Effective solutions involve addressing the work culture, organizational structure, work processes, user acceptance and adoption, as well as appropriately designed technology.

The key to successful technology deployment requires understanding the problems that need to be solved and designing solutions that fit the work context. This means that organizations need to refrain from *only* identifying applications of the latest technological advances just because the technology is available.

Human Reliability and Process Safety Incidents

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.

In an effort to improve on the understanding of the impact of ineffective operations practices and management systems on safe plant operations, the ASM Consortium conducted a series of studies between 2008 and 2012 involving the root cause analysis of existing major incident reports. An initial study examined fourteen public and private incident reports to determine the impact of communication and coordination practice failures (Laberge, Bullemer & Whitlow, 2008). Based on the results of the initial study, a follow-on study was established to analyze an expanded set of incidents reports for failure modes of operations practices in general (Bullemer and Laberge, 2010; Bullemer & Reising, 2012). Additional studies focused on particular problem areas, a study used the same methodology to examine the impact of procedure execution failures during abnormal situations (Bullemer, Kiff &Tharanathan, 2011) and a fourth study examined incident reports involving heater operations (Bullemer & Reising, 2014).

This section presents the combined root cause analysis results across a total of 42 major process safety incidents reports. The methodology used to analyze these incident reports was developed by the ASM Consortium research team to investigate the impact of operations practice failures in major process safety incidents (see Bullemer & Laberge, 2010 for detailed description of the methodology).

Incident Analysis Methodology

The purpose of the incident analysis technique is to generate information to enable an understanding of why the incidents occurred and develop improvement programs and corrective actions to address weaknesses in operations practices or management systems. The focus is to eliminate common and systemic problems.

The project team conducted a search to identify potential public incident reports from sources world-wide sources and private incident reports from ASM Consortium member companies. The details of the method for identifying and selecting incident reports are available in the initial study report (Laberge et al., 2008). In the selection process, priority was given to recent refining and chemical incident reports with severe consequences (where recent is in the last 10 years) and the reports had sufficient detail to conduct a root cause analysis. In addition, the ASM Consortium wanted the analysis to represent operations practice failures from a global perspective so there was an attempt to get a global distribution. Table 1 shows the selection distribution results in terms USA versus non-USA incident reports as well as type of industry.

Table 1 Location, source and industry type for the 42 incident reports

Location	Public	Site	Total
USA	21	8	29
Non USA	6	7	13
Total	27	15	42

Industry	Public	Site	Total
Refining	9	10	19
Chemical	16	4	20
Oil & Gas	2	1	3
Total	27	15	42

The project's analysis methodology was based solely on the content of what was provided to the team in the way of documentation, such as the formal report and supporting analysis documentation, when available. The project team did not conduct any interviews or additional incident investigation as part of the project's analysis. Figure 2 illustrates the seven steps in the work process used to analyze the heater incident reports.

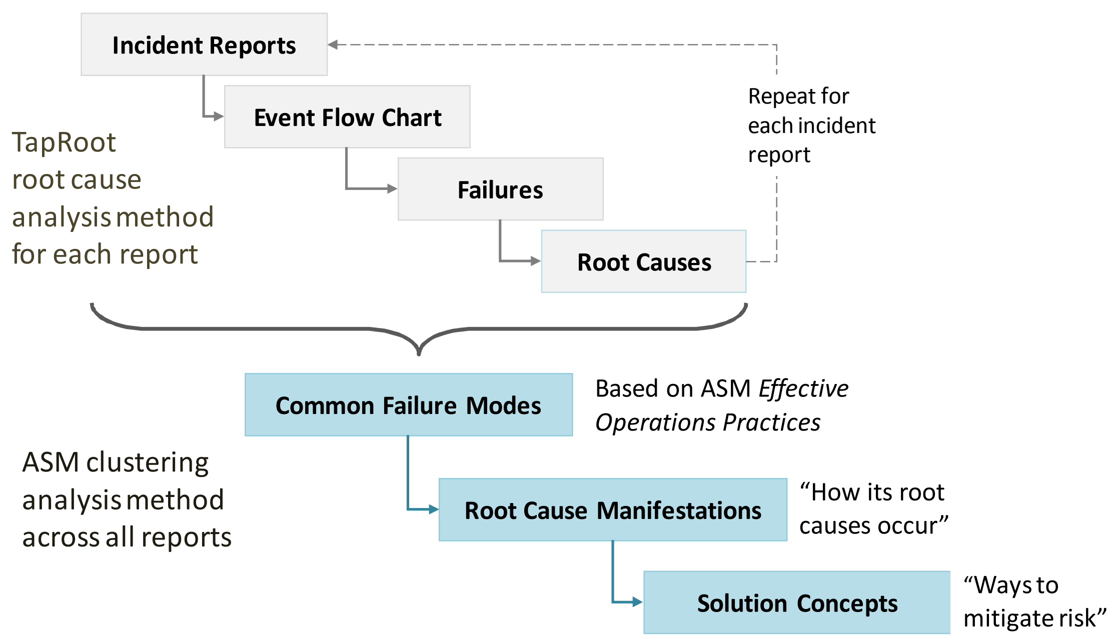

Figure 2 Work flow for the failure analysis methodology

The output of these initial steps is a list of operations practice failures in the language of respective the incident investigation teams and the associated root causes per the TapRoot classification scheme:

- **Operations practice failure** is any failure that, if corrected, could have prevented the incident from occurring or would have significantly mitigated its consequences. An operations failure describes 'What went wrong' in the specific incidents and is typically in the investigation team's own language/terms. An example of an operations failure is *Ineffective supervision of procedure execution*.
- **Root cause** is the most basic cause (or causes) that can reasonably be identified that management has control to fix and, when fixed, will prevent (or significantly reduce the likelihood of) the failure's (or factor's) recurrence (Paradies & Unger, 2000, p. 52). A root cause describes 'Why a failure occurred.' In the research project, the team used the root cause tree available in the TapRoot methodology. Two root cause examples are *No Supervision* and *No communication* which can both result in the *Ineffective first line leadership* common failure mode.

In a previous ASM research study of 32 major process safety incidents (Bullemer & Laberge, 2010), the project team found that additional analysis was valuable to identify the systemic failures across incidents, so as to better understand how to address the operational risk indicated by the operations failures and root causes with ASM solutions that would have the broadest impact. The second half of the methodology clusters the initial findings into common operations practice failures and common root cause manifestations to indicate where ASM solutions may reduce the apparent operational risks identified in the incident analysis:

- **Common operations practice failure** is a description of multiple operational failures that appeared across incidents. A common failure mode represents a common problem across industry sites. The project team characterized these common failures using language from their *Effective Operations Practices* (Bullemer, 2014). If a common failure mode did not map to one of the Effective Operations Practices, the project team created a new failure mode description. An example of a failure mode is *Ineffective first-line leadership roles*.
- **Common root cause manifestation** is the specific expression or indication of a root cause in an incident. The root cause manifestations describe 'How' operational failure modes are expressed in real operations settings. The root cause manifestation characterizes the specific weakness of an operations practice failure mode. *Supervisor not in accessible to control room to discuss problems* is an example manifestation for the *No Supervision* common root cause and the *Ineffective First Line Leadership Role* common failure mode.

Common Operations Practice Failures

Table 2 shows the top common operations practice failures in rank order. The top ten operations practice failures account for 78% of the operations practice failures.

Table 1 below shows the number of operations practice failures identified as a function of the seven ASM Operations Practice categories. The most common operations practice failure category is Organizational Roles, Responsibilities, and Work Processes (46%) accounts for almost half of all of the failures indicating management systems is a significant source of human reliability failures. Communications is the next most common category (16%) followed by Process Monitoring, Control & Support Applications (9%), Procedures (8%) and Knowledge and Skill Development (7%).

Table 2 shows the top common operations practice failures in rank order. The top ten operations practice failures account for 78% of the operations practice failures.

Table 1 Summary of operations practice failures as a function of the seven categories of ASM operations practices as defined in the *Effective Operations Practices* guideline document (Bullemer, 2014)

Rank	Operations Practice Category	Total Failures	% of Failures
1	Organizational Roles, Responsibilities, and Work Processes	288	46%
2	Communications	101	16%
3	Process Monitoring, Control, and Support Applications	54	9%
4	Procedures	53	8%
5	Knowledge and Skill Development	43	7%
6	Understanding Abnormal Situations	21	3%
7	Work Environment	5	1%
	Other	59	9%
	Total	**624**	**100%**

Table 2 Top Common Operations Practice Failures shown in rank order of most frequent to least frequent

Rank	Top Failure Common Failure Modes	Total Failures	% of Failures
1	Lack of a comprehensive hazard analysis and communication program.	92	15%
2	Ineffective first line leadership roles	74	12%
3	Ineffective continuous improvement program	72	11%
4	Poor safety culture	37	7%
5	Ineffective task communications	35	6%
6	Lack of a comprehensive Management of Change (MOC)	34	5%
7	Failure to establish initial and refresher training based on competency models for all modes of operation	32	5%
8	Ineffective cross-functional communications	24	4%
9	Failure to ensure compliance with an explicit policy on the use of procedures	23	3%
10	Lack of effective design guidelines and standards	17	3%
	All other failure modes	184	29%

	Total	624

An earlier ASM Consortium research project investigated operations practice failures in 32 major process safety incidents (Bullemer & Laberge, 2010). A comparison to the top ten operations practice failures in the previous study found the same list of failure modes. Hence, the addition of ten additional incident reports did not change the overall finding from those reported by Bullemer & Laberge (2010).

Common Basic and Root Causes

To better understand the nature of the operations practice failures, the common basic and root causes were analyzed for each of the operations practice failures. Table 3 Table 3 shows the basic associated with the operations practice failures.

Table 3 Common basic 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%
Totals	**964**	**100%**

Eighty-two percent of the basic causes were human performance-related with the top category indicating ineffective management systems. Eighteen percent of the basic causes were associated with equipment related sources:

- Design review (11%)
- Design specification (5%)
- Preventative maintenance (2%)

Hence, the basic cause findings are consistent with the 1990 CMA report indicating 80-85% of the contributing causes of major incidents is related to human reliability.

Table 4 shows the top 17 most common root causes in rank order from most frequent to least frequent

Root Causes (42 incidents)	#	%	Rank
No communication	76	7.9%	1
Crew teamwork NI	65	6.7%	2
Hazard analysis NI	54	5.6%	3
Management of change (MOC) NI	44	4.6%	4
Corrective action NI	41	4.3%	5
No supervision	41	4.3%	5
Displays NI	40	4.1%	7
Confusing or incomplete	38	3.9%	8
No SPAC	37	3.8%	9
SPAC not followed	36	3.7%	10
Top 10 Root Causes	**472**	**49.0%**	**10**
Specs NI	33	3.4%	11
Comm system NI	27	2.8%	12
Situation not covered	26	2.7%	13
Employee communications NI	25	2.6%	14
Correction action not yet implemented	25	2.6%	14
Procedure not used	24	2.5%	16
Pre-job briefing NI	19	2.0%	17
Top 17 Root Causes	**651**	**67.5%**	**17**

The root causes provide some addition information regarding how the operations practice failures manifested themselves in the operations environment.

Implications for Operations Practices

The information obtained through the analysis of 42 major process safety incidents provides a much richer source of information than was obtained in the 1993 foundational study of the abnormal situation management challenge. The initial study was limited both by the comprehensiveness of the reported human-related contributions to incidents and the reluctance of individuals to report human reliability sources.

This analysis indicates many of the practice areas identified in the 1993 foundational study of abnormal situation management challenges still persist today and contribute to major process safety incidents. The good news is that in many of these practice areas there are organizations in the industry that have established effective practices to address these process safety risks. The challenge is getting the entire industry to improve the quality of their abnormal situation management practices to reduce the overall industry risk to process safety incidents.

Reducing Process Safety Risk with Effective Operations Practices

The vision of the ASM Consortium is operating teams empowered and enabled to proactively manage their plants to maximize safety and minimize environmental impact while allowing the process to be pushed to their optimal limits. To deliver on the vision, the ASM Consortium conducts research, tests and evaluates solutions that develop and advance the collective knowledge of the members, and facilitate the conversion of ASM knowledge into operations practices.

In this section, the historical perspective is characterized on the ASM Consortium mission to conduct research and development to address the abnormal situation management challenges in terms of the progress that has been made and where there are still some gaps in providing effective solutions. Progress and gaps are characterized in terms of the following seven ASM practice areas:

- **Understanding ASM**—all site personnel have a shared understanding what abnormal situations are, how often they arise, why they occur and the impact on plant performance.
- **Organization roles, responsibilities, and work processes**—management proactively influences the work culture through the formal definition of work processes, staff roles and responsibilities, and the definition of valued behaviors to ensure a safe, productive and resilient work environment.
- **Knowledge and skill development**—operations personnel receive continuous training to acquire and sustain the necessary technical and nontechnical competencies for all modes of operation.
- **Communications**—all personnel exchange information effectively on an appropriate periodic or situational basis to establish effective team situation awareness for normal, abnormal, and emergency situations.
- **Procedures**—operations personnel use and comply with an effective procedure management system that provides consistent, effective formal work instructions where appropriate for normal, abnormal and emergency operations activities.
- **Work Environment**—the design of the work environment effectively supports 24/7 shift operations enabling alert and effective team member interactions.
- **Process monitoring, control and support applications**—the lifecycle development activities for the operations hardware and software platforms reliably and effectively meet the operations team needs for interacting with the process equipment and other personnel across their scope of work activities.

Understanding ASM

A key to human reliability and safe operations is a shared understanding of the risk (or safety) envelop at any given moment. Learning from past lapses in human reliability has implications for technology, training, communications, procedures and system design. The ASM Consortium, therefore, defined the foundation for effective operations practices as establishing a shared understanding of past abnormal situation causes and impacts through effective reporting, analysis and communications across functional roles within a production facility.

Almost every plant has a language for describing safety related incidents; however the foundational 1993 study found that this language was not necessarily effective for describing abnormal situation causes and impacts. The typical gap was limited characterization of human reliability causes from a management system basis, i.e., Organizational factors and local work place factors, as well as an individual contributor basis, i.e., unsafe acts (Reason, 1997).

In recent years, more organizations have created reporting systems for monitoring abnormal events that impact product quality and production. From a progress perspective, most organizations have transitioned from a blaming culture to at least a fact finding culture and in some cases even a learning culture with respect to how personnel and information is treated in response to incident reports. Consequently, there has been significant improvement in the level of operations personnel participation in the incident reporting work process as well as the number of near-miss events reported.

However, these reporting systems are often separate from the safety incident reporting systems with different reporting mechanisms and language to describe causes. Abnormal situations can be viewed as near-miss process safety events and hence precursors to process safety incidents. The existence of multiple reporting systems does not lead to a common shared understanding of causes and areas to improve operations practices.

There are incident analysis methodologies available that have a fairly comprehensive list of human-related causal categories that reflect organizational factors, local work factors as well as unsafe acts (Paradies, 2000; Weigman, Rich & Shappell, 2000).

In summary, key remaining gaps in typical understanding ASM operations practices include:

- Combining reporting systems across departments (e.g., HSE, production planning) to better understand sources of abnormal situations
- Conducting periodic analysis to identify repeating and systemic problems
- Establishing a comprehensive set of basic and root causes appropriate to tracking human reliability problems

Organization roles, responsibilities, and work processes

Management proactively influences the work culture through defining: plant processes, staff roles and responsibilities, and valued behaviors. Work culture consists of the values and beliefs that explicitly or implicitly determine acceptable behaviors. These values are consistently imparted to new members through war stories, rules of thumb, and observation of actions by veteran members.

Work cultures exist at many levels within a production facility. Typically, cultures of the operations teams are the most influential in teaching new employees acceptable behaviors in a particular process unit. To the extent that a management team treats all operations teams the same, there will be some common cultural themes across the operations teams within a site. Once all levels of the organization have agreed on the valued behaviors, the management structures and processes can be established to shape the work culture to be consistent with the valued behaviors.

There were three challenges identified in the root cause analysis of major incidents reported above that were not identified in the foundational study (See top 3 failure modes in Table 2), although these challenges probably existed at the time. First, the lack of effective communications of hazards to the operations team was the most common operations practice failure mode. Based on the ASM Consortium research findings as well as recommendation from other industry experts, it is important that the results of the hazard analysis is regularly communicated to site personnel and that an audit of practices is developed to periodically check compliance with the program (Bullemer & Laberge, 2010). Effective communication is important because a single, non-permanent source of communication of hazards leads to poor awareness and memory by the organization at later points in time. Consequently, regular and effective communications is more than a practice of sending out an e-mail to plant personnel following a process hazard review. In addition, organizations need to obtain evidence that a comprehensive hazard analysis was the basis for the hazard information provided by suppliers.

Second, a significant challenge was establishing effective first-line leadership roles to direct personnel, enforce organizational policies and achieve business objectives. Contributing factors included lack of accessibility, poor enforcement of organization policy and procedures, and failure to develop appropriate leadership competencies.

The third challenge was the lack of a comprehensive continuous improvement program to address the impact of people, equipment and materials on plant productivity and reliability. This challenge is related to the Understanding ASM practice area discussed above. The input to a comprehensive continuous improvement is findings from a periodic analysis of abnormal situations that indicates repeating or systemic problems. Moreover, the continuous improvement program needs effective methods to track and evaluate the impact of corrective actions and improved solutions.

In summary, key remaining gaps in typical organization, roles, responsibilities and work process practices include:

- Better communication of hazards and risks during start-up and non-routine operations
- Effective first-line leadership
- Establishing effective and comprehensive continuous improvement programs

Knowledge and Skill Development

Effective knowledge and skill development is required if plant personnel are to keep pace with the continuous changes to process unit design and performance. A program that achieves this result provides continuous learning, not just initial general operator and basic unit training.

The foremost priority is establishing and maintaining the base competencies of operators with respect to their individual job roles and responsibilities, as defined by the competency models for each position. Each operator is formally qualified for the jobs to which they are eligible to be assigned. To maintain their knowledge and skill levels, continuous training activities provide updates on temporary and permanent changes in the process, equipment, control applications, or other products that impact appropriate operator response.

In terms of the state of the industry, most plant organizations have established effective initial training programs for operation personnel that are structured with training materials, on-the job training and evaluation methodologies. A significant challenge that remains for many of these organizations involves keeping the materials and training up to date with plant changes. A second challenge is ensuring that the personnel providing the on-the-job training have effective mentoring skills as well as motivation because they are doing the mentoring in addition to their normal duties.

The second priority, an area often overlooked in many training programs, is to develop collaborative competencies in the operations team that address interactions with other operators and other supporting disciplines. Effective abnormal situation management training includes instruction on individual and team member roles and responsibilities under different plant operating conditions. Moreover, process control operators are trained on the processes upstream and downstream of their scope of responsibility to allow them to fully understand how their process changes impact processes not under their control. In particular, process control operators must learn the information requirements of operators of connected units during process upsets.

In a recent study of ASM member training practices for abnormal situation management found many of them have established simulation training platforms. These simulation training platforms are typically used to train console operators on startup, emergency response and some routine operations activities. A few organizations have developed team training exercises to improve coordinated response to upset and emergency events. One knowledge gap with respect to simulation training is how to effectively use generic or low fidelity simulators when high fidelity simulators are not feasible or available.

The biggest gap was found to be training on non-technical skills for operations personnel such as:

- Situation awareness
- Decision making
- Communications
- Teamwork
- Leadership
- Understanding stress & fatigue

Recent Crew Resource Management publications are now available with detailed course curricula and behavioral competency descriptions for these nontechnical knowledge and skills areas (CAA, 2003; EI, 2014a, EI, 2014b, FAA, 2004; JAA, 2006; OGP, 2014a, OGP, 2014b).

In summary, key remaining gaps in typical knowledge and skill development practices include:

- Training for abnormal situation management

- Use of generic or low fidelity simulators for training
- Training for team- and individual- Situation Awareness support

Communications

Communications between plant personnel is fundamental to effective operations under normal, abnormal, and emergency situations. It is often taken for granted that people know what, when, and how to communicate effectively. In fact, as abnormal plant conditions evolve effective communication often makes the difference between success and failure in the intervention.

Successful communication involves the transmission of a message between at least two parties, where the receiver of the message correctly comprehends the intended meaning of the sender and the sender knows that the message was received and understood. In critical situations, this requires that those involved share the same assumptions about the plant conditions, their goals, and their options. A failed communication can contribute directly to the initiation of an abnormal condition as well as to an unsuccessful intervention via an inappropriate response, slowed response, or no response.

As opposed to when the foundational study was completed, most organizations today have adopted some form of electronic shift team logbooks for reporting important process and activities status. Some electronic logbooks remain unstructured like the old paper logs but most have some structure on the types of information to be reported. A recent ASM Consortium research study found that providing an electronic shift handover checklist improved outcomes over a structured electronic logbook (Plocher, Yin, Laberge, Thompson & Telner, 2011).

A significant challenge remains in communicating to operations personnel Management of Change (MOC) information. Often the form of the communication is an e-mail or a paper document that is circulated to the operations personnel. In this form, the operators are made aware of the upcoming changes and the potential impact. However getting access to this information at later time when they may need to know because of work related activities is often difficult or challenging.

In today's work environment, the console operators are often located in a control room remote from the process equipment and field operations staff. The field staff have primary responsibility for overseeing the work permitting and maintenance activities. Most organizations have not found an effective communication mechanism to ensure console operations knows what maintenance activity is ongoing and the status of the field equipment.

In summary, key remaining gaps in typical communications practices include:

- Structured shift handover reporting
- Effective communication of MOC activity and impact
- Better communication between maintenance and operations

Procedural Operations

Effective operations practices associated with procedures address the delicate balance between guidance and prescriptive (recipe) work processes. Many incidents have been directly attributed to failures of procedural systems. Failures typically are associated with not following procedures, procedures not fully covering all aspects of operations, inaccurate procedures, confusing procedures, and too much detail in the procedure. This is a difficult subject and has many variables such as experience of the person doing the task, what other activities are being done in the unit at the same time, and how the procedure is split between team members, which may vary across all shifts.

Compliance with company policy on use of procedures is still a significant challenge in the industry. Some contributing factors include a persistent work culture for not using procedures along with a failure of management to establish effective formal policy.

A common practice in the industry is to have explicit policies that require operators to use all procedures in a similar manner, that is, to access the procedure and reference it while executing it. However, in many cases the implicit company policy communicated by supervisors and colleagues is to leave it up to the individual to decide whether to actually access and use a procedure document when performing a task. The widespread noncompliance with this type of explicit company policy stems from the common belief of operators and supervisors that is unreasonable to expect this type of in-hand use behavior for all procedures. Along with an explicit policy on the use of procedures consistent with the frequency, risk and complexity of the procedure, there should be an audit process to ensure compliance.

Not all procedures are created equal. Procedural instructions can vary in frequency of use, complexity and potential impact if not followed correctly. Consequently, depending on the combination of these factors, some procedures should be in the operators hand during execution, some should be reviewed prior to or following execution, and other should be learned during initial and refresher training activities. In the typical plant today, there is generally a single format used for all procedures regardless of the procedure specifics. A more effective approach would be to design the procedure format to be consistent with the expectations for use.

The detailed study of procedure execution failures found that the majority of failures involved execution failures during abnormal situations (Bullemer et al. 2011). This study reported that procedure content needs to be improved to address the failure manifestations.

In summary, key remaining gaps in typical operations practices include:

- Address the work culture of not using procedures
- Develop procedure formats specific to the use requirements (e.g., in-hand vs. reference)
- Improve procedure content to support execution during abnormal situations

Work Environment

During the foundational study, the observation was made that the control building work environment was rarely considered anything more than a place to accommodate equipment. First, the equipment was suitably located, and then people were added to monitor the control system. Little consideration was given to the needs of the people over and above basic facilities such as lunchroom, showers, and toilets.

Recent industry regulations and standards have identified that people working 12-hour shifts need additional support to address fatigue and maintain alertness (49 CFR 192.631; ANSI/API RP 755, 2010; HSE, 2006). The industry documents provide strategies for improving alertness that include: managing work schedules including overtime and rest time; designing work activities throughout a shift to address the negative influence of vigilance tasks such as console "rounds;" recognizing the nature and problem of the human body's circadian rhythms by designing appropriate lighting and temperature controls; and incorporating alertness recovery practices in the control room environment, including exercise and rest periods away from the console.

Formal methodologies and standards, i.e., ISO 11064, are available to control room designers that give consideration to ergonomic factors that impact operator performance such as:

- Adjacencies for collaboration
- Lighting
- Noise abatement
- Traffic flow

Despite the available standards and guidance documents, many control room environments remain dark. The initial DCS screens were deployed in the late '80s and early '90s with dark backgrounds and fully saturated foreground colors for text and schematic drawings. Because of the dark backgrounds, operators turned the lights down to minimize the luminance contrast of the ambient light with the illuminance of the console computer screens and to reduce glare on the monitors. However, since that time, new technologies have enabled lighter-colored backgrounds with more foreground color choices. Despite the opportunity to create lighter backgrounds on displays to reduce luminance contrast and allow for brighter room lighting to address workplace alertness, the work culture in many control rooms still prefers to keep control rooms dark (Bullemer et al, 2011).

A control room environment with multiple consoles tends to be a noisy environment, particularly during upset situations. During upsets, the console operators have a high level of radio communications with field operators at the same time that alarms annunciators are activating to alert them to abnormal conditions, all while interested parties gather in the control room to find out what's going on and carry on discussions behind the operators. There are known solutions to address the noisy environmental problems such as noise abatement treatments on surfaces, arrangement of consoles, devices to localize sound and alarm sounds to minimize distraction. Many organizations are beginning to deploy these techniques but the industry in general is still catching up.

In summary, key remaining gaps in typical work environment practices include:

- Implementing effective alertness and fatigue management practices
- Addressing a work culture that turns the lights out
- Providing effective noise abatement for multi-console control rooms

Process Monitoring, Control and Support Applications

Process monitoring, control and support applications comprise the software and hardware platforms used by the operations team such as operator graphic displays, alarm system configuration, regulatory control systems, advanced control, safety-instrumented systems, programmable logic controllers, SCADA, communications, equipment diagnostic and monitoring applications, procedure, and logbook applications. Process monitoring and control applications provide console operators the primary means of maintaining situation awareness through visualizing and interacting with the plant process. Operations support applications are becoming more pervasive as many paper-based functions are migrating to electronic-based solutions such as training, lab reporting, logging, procedures, communications, and diagnostics. As the number, complexity and importance of monitoring, control and support applications increase, there is a corresponding need for more formal, consistent work processes for engineering and IT functions to ensure that these applications deliver the intended benefits and do not make the operations task more difficult.

Since the foundational study, the ASM Consortium has conducted extensive research and development in this practice area (e.g., Bullemer, Reising & Laberge, 2011; Bullemer et al., 1997; Bullemer et al., 2014; Bullemer & Zapata, 2009; Elsass et al., 2002; Errington et al., 2005; Guerlain & Bullemer, 1996; Guerlain, Jamieson & Bullemer, 2002; Hajdukiewicz & Reising, 2004; Jamieson, Ho, & Reising, 2003; Reising, Laberge, & Bullemer, 2010; Reising & Montgomery, 2005) and produced two guideline documents (Bullemer & Reising, 2015; Errington, Reising & Burns, 2007).

One of the initial visions for improving the console operator HMI (Human Machine Interface) was to integrate data sources for the operator into a single window on their information to reduce the complexity of accessing and using the data. While there are demonstrated HMI design frameworks that enable this outcome (Bullemer & Reising, 2015), there has not been wide spread adoption due to perceived challenges with current DCS HMI technology, the prevalence of 'like-for-like' DCS HMI and architecture migration, as well as the underlying architecture for data bandwidth, for data integration across business and control networks, and for addressing cybersecurity concerns.

To support effective operator situation awareness, ASM research has found that having displays built with different levels of detail (i.e., creating a display hierarchy) can improve operator performance (Reising et al., 2010). In the foundational 1993 study, the lack of a span-of-control overview display was identified as a console operator requirement and this remains a solution gap today. There is a tendency to build the same type of schematic displays based on P&ID drawings that are at the lowest level as was done initially when organizations started providing DCS schematic operating displays (Reising & Bullemer, 2014).

Alarm flooding is still a significant challenge for the console operator. The industry has improved its understanding of the alarm flooding problem and improved the capability of the DCS HMI for alarm handling as well as rationalization methods (Errington et al, 2007; EEMUA, 2013; ISA, 2009; Rothenberg, 2009). However, despite improved alarm system configuration techniques and rationalization methodologies, the alarm flooding problem persists (Laberge, Bullemer, Tolsma & Reising, 2014). As a result of this finding, the ASM Consortium conducted a series of studies to investigate alternative techniques for presenting alarm data that improve the operator's ability to manage abnormal situations that cause alarm flooding (Bullemer et al., 2014).

In summary, key remaining gaps in typical process monitoring, control and support applications practices include:

- Provide a single, seamless HMI system for data and information the operator requires for their roles and responsibilities, regardless of the control or application system from which it originates
- Avoid single-screen, single-display design methods and leveraging 'windowing' capabilities to support the operator's required interactions driven by their designated work processes
- Address operator information overload due to alarm flooding

Conclusions

The ASM historical perspective is intended to show where progress has been made and where there are still gaps in effective solutions to improve human reliability and process safety. Since the 1993 foundational study on the ASM challenges, there has been significant progress in improving ASM operations practices. However, there remain significant gaps for the industry as a whole in achieving effective ASM operations practices. In the previous section, the key remaining gaps were characterized for each of the seven ASM operations practices areas. Since

Figure 3 illustrates the authors' subjective rating on the progress made over the past 20+ years and the opportunity gap for the industry as a whole for achieving known effective best practices available today. The figure purposely leaves room to the right of this effective practice achievement to illustrate that the bar will continue to move as the industry lessons are learned and technology evolves.

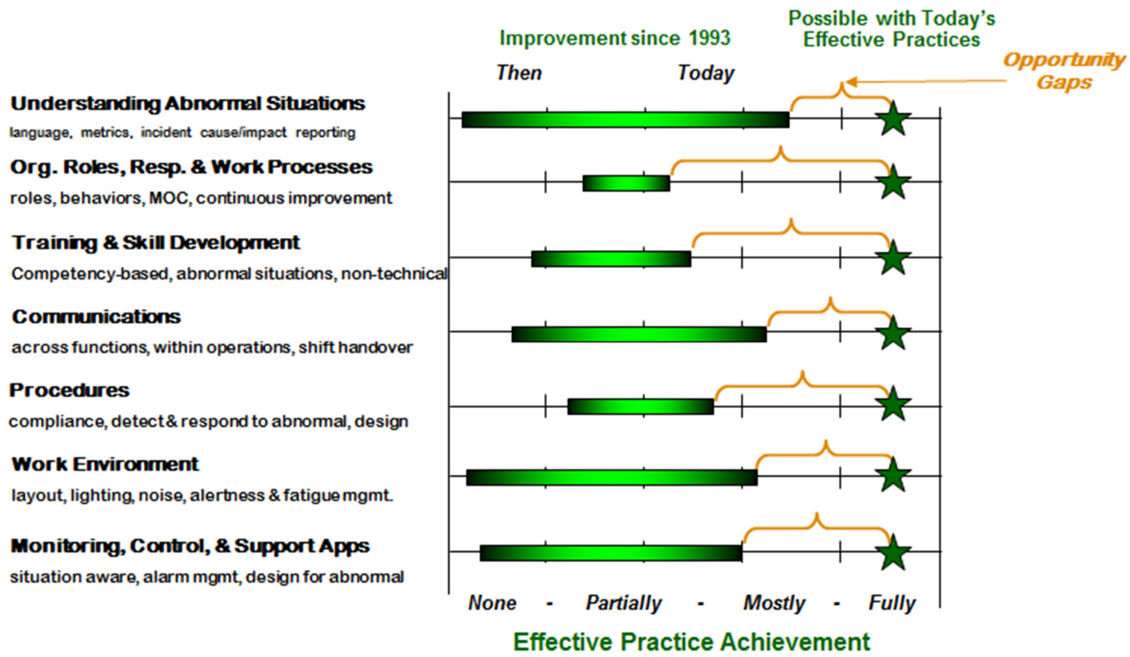

Figure 3 Illustration of the authors' subjective assessment of the industries progress on achieving effective ASM operations practices over the past 20+ years.

The practice category with the largest opportunity gap is in the organizational roles, responsibilities and work processes. The ASM Consortium root cause analysis of 42 major process safety incidents identified five specific practices in this category in the top 10 most common failure modes (see Table 2). The other two practice areas that round out the Top Three categories for largest opportunities are Training & Skill Development and Procedures.

An important learning from the 1993 study was that effective abnormal situation management solutions need to address not only the technology component but also the work culture, organizational structure and work processes associated with the use of the technology (Cochran & Bullemer, 1996). Consequently, the ASM Consortium has established a research methodology that starts with problem definition before developing solution concepts. This approach has contributed to the ASM Consortium success in closing the gaps on the abnormal situation management challenges.

Acknowledgements

This study was funded by the ASM® Consortium, a Honeywell-led research and development consortium. The Abnormal Situation Management® (ASM®) Consortium (www.asmconsortium.com) is a long-running and active research and development consortium of 16 companies and universities concerned about the negative effects of industrial plant incidents. The consortium identifies problems facing plant operations during abnormal conditions, and develops solutions. Deliverables from the collaboration among member companies include products and services, guideline and other documents, and information-sharing workshops; all incorporating ASM knowledge.

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