Common Procedural Execution Failure Modes during Abnormal Situations

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The Abnormal Situation Management® Consortium[1] funded a study to investigate procedural execution failures during abnormal situations. The study team analyzed 20 public and 12 private incident reports using the TapRoot® methodology to identify root causes associated with procedural operations failures. The main finding from this investigation was the majority of the procedural operations failures (57%) across these 32 incident reports involved execution failures in abnormal situations. Specific recommendations include potential information to capture from plant incident to better understand the sources of procedural operations failures and improve procedural operations in abnormal situations.

Introduction

Process industry plants involve operations of complex human-machine systems. The processes are large, complex, distributed, and dynamic. The subsystems 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, Ramanthan, & 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.

In 2007-8, the ASM Consortium funded a study to analyze the impact human reliability in terms of operations practices failures with an ad hoc analysis of 32 public and private incident reports. The results of this research was presented at the 2009 Mary K O'Conner Process Safety Symposium with an emphasis on the specific incident analysis methodology that revealed the opportunities for reducing abnormal situations associated with human reliability (Bullemer and Laberge, 2009). This paper presents the results of an analysis of the same 32 incidents from the perspective of procedural execution failures during abnormal situations. The research study objective was to develop an understanding of common failure modes in the application or execution of procedures, either manual or automated, during or in response to an abnormal situation.

For purposes of understanding the focus of this research study, the reader should be aware of the ASM Consortium's definition of an abnormal situation. An abnormal situation is defined as a situation where an industrial process is disturbed and the control system cannot cope, requiring the operations team to intervene to supplement the control system. 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. Typically, in a well rationalized alarm system, a process alarm is an indication of an abnormal situation in which the operations team needs to respond to return the plant to steady-state operations and avoid triggering emergency shutdown systems that are designed to prevent a release or catastrophic failure of process equipment.

From a procedural perspective, a procedure developed for an emergency response was outside of the scope of this study. In addition, a procedural execution failure that leads to an abnormal situation or emergency situation was outside the scope of this study. However, a procedure developed for a temporary plant configuration or temporary operation (i.e., avoidance of an emergency response situation) was considered relevant to the scope of this study.

Root Cause Analysis

The study team examined root causes related to procedural operation failures across a data set from 32 incident reports (Bullemer and Laberge, 2009). Per the prior study definition, a 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 prior research project, the team used the root cause tree available in the TapRoot® methodology.

The initial analysis examined all procedure related root causes from the prior analysis to identify those specific failures that were associated with execution during an abnormal situation. That is, for each identified procedure-related root cause, the study team assessed whether the procedural failure occurred prior to or during an abnormal situation. If it was determined that it was prior to an abnormal situation, the failure was classified as not relevant to procedure execution under an abnormal situation. The results of this initial analysis are shown below **Table 1**.

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Table 1   Root cause analysis results summary of procedure related root causes relevant to execution in response to abnormal situations (Note: NI is abbreviation for Needs Improvement).

Procedure Root Cause Summary Table			
Root Cause Category	**Subcategory**	**Count**	**ASM Relevance**
Procedure Followed Incorrectly	**Format confusing**	1	1 of 1; 100%
	> 1 action / step	0	No
	Excess references	0	No
	Mult unit references	0	No
	Limits NI	0	Yes
	Details NI	2	0 of 2; 0%
	Data/computations wrong or incomplete	0	No
	Graphics NI	0	No
	No Checkoff	0	No
	Checkoff Misused	3	1 of 3; 33%
	Misused second check	0	No
	Ambiguous instructions	0	Maybe; No examples found
	Equipment identification NI	0	No
Category Subtotal		9% 6	**Somewhat: 2 of 6; 33%**
Procedure Wrong	Typo	0	No
	Sequence wrong	0	No
	Facts wrong	3	2 of 3; 66%
	Situation not covered	25	20 of 25; 79%
	Wrong revision used	0	No
	Second checker needed	0	No
Category Subtotal		40% 28	**Mostly: 22 of 28 (79%)**
Procedure Not Used/Not Followed	**Procedure not used**	19	9 of 19; 47%
	No procedure	15	7 of 15; 47%
	Procedure not available or inconvenient for use	1	0 of 1; 0%
	Procedure difficult to use	1	0 of 1; 0%
Category Subtotal		51% 36	**Moderate: 16 of 36 (44%)**
All Procedures		100% 70	**Majority: 40 of 70 (57%)**

The first two columns of Table 1 show the root cause categories and subcategories used in the analysis based on the TapRoot® methodology (Paradies and Unger, 2000). The second column shows the total number of all root causes identified related to procedure failures. The last column shows how many of the identified procedure-related root causes were relevant to the execution during abnormal situations, i.e., relevant to the scope of this study's objectives.

For example in the first row, there was one observation of a root cause of *Procedure Format Confusing*. A closer examination of this failure revealed that the failure to execute due to this root cause occurred during an abnormal situation. Hence, the last

column, *ASM Relevance,* shows 1 of 1 or 100% of the occurrences of this root cause subcategory was related to failure to execute during an abnormal situation.

The bottom right corner of the table shows the result of classifying each root cause as ASM Relevant or not. The summary of the analysis shows that of the 70 identified root causes 40 are related to procedure execution failures in abnormal situations, i.e., 57%. Hence the surprising finding of this investigation was that the majority of the procedural operations failures across these 32 incident reports involved execution failures in abnormal situations.

Common Manifestations

To better understand the context of these execution failures, the study team examined the specific occurrence of the ASM relevant root causes in terms of their manifestation. Bullemer and Laberge (2009) argue that the manifestations of the root causes provide better insight into how to make improvements in operations practices than the more generic root cause classifications.

A **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 accessible to control room personnel to discuss problems* is an example manifestation for the *No Supervision* common root cause. Each root cause manifestation was classified into a set of common manifestations. A **common** manifestation is an abstraction of the individual root cause manifestations to characterize common element expressed across the incidents in a sample. The following common manifestations represent the common elements across the root cause manifestations identified in the 32 incidents:

- Fail to detect abnormal condition
- Fail to detect an abnormal situation
- Unaware of process or equipment hazard
- Lack understanding of impact of actions
- Execute inappropriate action

These five common manifestation types were based on the ASM Intervention Model of the operator supervisory control activities shown in **Error! Reference source not found.** for preventing and responding to abnormal situations (Bullemer, Hajdukiewicz and Burns, 2010).
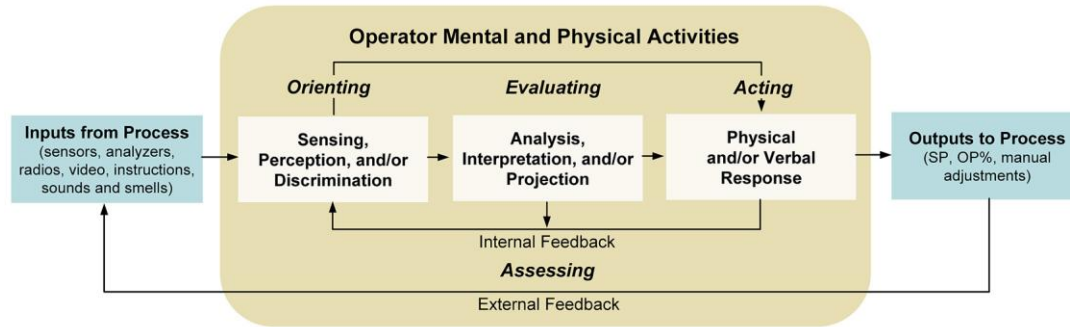
Figure 1   ASM Operations Intervention Model of human operator supervisory control activities for preventing and responding to abnormal situations.

The ASM Intervention Model has four stages of activities: Orienting, Evaluating, Acting, and Assessing. In the first step of the analysis all root cause manifestations were categorized as a failure of one of the stages of the ASM Intervention Model. In the second step, the root cause manifestations were clustered in terms of specific ways in which the intervention phase was ineffective. The two detection failures, *Fail to Detect Abnormal Condition* and *Fail to Detect Abnormal Situation* are both manifestations of breakdowns in Orienting. Evaluation breakdowns are represented by *Lack of Understanding Impact* and *Unaware of Hazards*. Finally, the last failure type was Inappropriate Action which represents a breakdown in the Acting stage.   The analysis did not identify any failures associated with the Assessing stage.

Table 2   Frequency of common manifestation types associated with the root causes related to procedure execution in abnormal situations shown in rank order from most frequent to least frequent.

Common Manifestations	Frequency	Definition
Inappropriate action	15	Failure to know what the appropriate response should be to the occurrence of an abnormal situation in the execution of the procedure
Fail to detect abnormal condition	12	Failure to detect whether equipment or process is abnormal mode; or whether there are any latent abnormal conditions
Lack understanding of impact	8	Failure to understand the correct impact or effect of a procedural action or failure to know the impact of not following procedural instruction
Fail to detect abnormal situation	4	Failure to know when normal operating range is exceeded; or know the indications of the occurrence of an abnormal situation
Unaware of hazard	1	Failure to know about the existence of a hazard or the potential of a hazardous situation if a step or steps are not followed as specified

Total	40	

Table **2** presents the results of the examination of the root cause manifestations in terms of the five common manifestations with their relative frequency across the 40 identified root causes.

The summary of findings show that the most common manifestation was associated with lack of knowledge about appropriate responses to the occurrence of an abnormal situation while executing a procedure. The second most common manifestation was the failure to detect the presence of an abnormal equipment or process mode while executing a procedure. And the third most common manifestation was the lack of understanding the impact or effect of a procedural action or failure to execute a procedural action. In total, these top three common manifestations account for 35 of the 40 (87.5%) procedural execution failures under abnormal situations.

These five common manifestations of execution failures are shown in

Table 3 associated with the root cause subcategories. Together the information aids in understanding the potential mitigations for these types of procedural execution failures.

Table 3   Rank order of root causes for common manifestations of procedure execution failures in abnormal situations.

Root Case Subcategory	Frequency	Common Manifestations (Count)
Situation Not Covered	20 of 25	Inappropriate Action (7) Fail to Detect Abnormal Conditions (7) Lack Understanding of Impact (5) Fail to Detect Abnormal Situation (1)
Procedure Not Used	9 of 19	Inappropriate Action (4) Fail to Detect Abnormal Conditions (3) Lack Understanding of Impact (2)
No Procedure	7 of 15	Inappropriate Action (4) Fail to Detect Abnormal Situation (2) Fail to Detect Abnormal Conditions (1)
Facts Wrong	2 of 3	Fail to Detect Abnormal Situation (1) Lack Understanding of Impact (1)
Check-off Misused	1 of 3	Fail to Detect Abnormal Conditions (1)
Format Confusing	1 of 1	Unaware of Hazard (1)

In addition, the team examined what types of procedural operations were most prone to these types of procedure execution failures. Further examination of this data as shown in **Table 4** shows three procedure types are most likely associated with procedural execution failures in abnormal situations.

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Table 4   Percent of procedure execution failures as function of procedure type shown in rank order of most to least.

Procedure Type	% of ASM Failures
Startup	**19%**
Operating: Batch	**18%**
Operating: Continuous	**12%**
Emergency Response	6%
Transfer	1%
LOTO/PTW/Maintenance	1%
Shutdown	1%

The data in **Table 4** suggest that the procedure types most relevant to mitigating procedure execution failures associated with abnormal situations are Startup, Batch Operations and Continuous Operations.

Corrective Actions

Finally, the study team looked at the corrective action recommendations in the incident reports to understand what types of mitigations were most often recommended.

Table 5 shows the frequency of corrective action recommendations in rank order from the most frequent to the least frequent.

Table 5   Frequency of corrective action recommendations from incident reports shown in rank order of most frequent to least frequent.

Incident Report Corrective Action Recommendations	Frequency
Improve procedure content by addressing abnormal situations	**19**
No procedure mitigation strategy recommended in report	**13**
Improve procedure coverage	**10**
Improve procedure content	4
Improve policy enforcement	3
Improve procedural training	3
Improve development method	2
Improve procedure format	1
Improve review work process	1
Improve status documentation	1

Of the incident reports with procedure related root causes, 13 did not contain any recommendations for corrective actions on the procedure management system. A total of 19 incident reports had the recommendation to improve procedure content to address

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abnormal situations. In addition, 10 recommendations were made to improve procedure coverage. A take-away message from this finding is that **in 59% of these incident reports (19 of 32), the incident investigation team observed a strong need to address abnormal situations in the development of procedures.** With the additional analysis of common manifestations, the specific requirements for improving procedure content become more evident.

Conclusion

The post hoc incident analysis of 32 public and private incident reports indicates a process industry-wide need to improve human reliability in execution of procedures during abnormal situations. The incident investigation found that the majority of the procedural operations failures (57%) across these 32 incident reports involved execution failures in abnormal situations. Moreover, 19 of the 32 incident reports (59%) included a corrective action recommendation to improve procedural content for abnormal situations.

As recommended in an earlier study, an examination of root cause manifestations provides additional information to the root cause information to better understand potential corrective actions (Bullemer and Laberge, 2009). In this study, the analysis of root cause manifestations suggests that improvements to procedural content in the following areas should improve operator reliability:

- Know what the appropriate response should be to the occurrence of an abnormal situation in the execution of the procedure

- Detect whether equipment or process is abnormal mode; or whether there are any latent abnormal conditions

- Detect when normal operating range is exceeded; or know the indications of the occurrence of an abnormal situation

- Understand the correct impact or effect of a procedural action or know the impact of not following the procedural instruction

Ultimately, organizations need to improve the incident reporting system to include metrics that enable a better understanding of opportunities to improve their procedure management system. To the end, the study team is now developing a conceptual framework to enable the comprehensive representation of failure modes and root causes associated with breakdowns in procedure execution, in both normal and abnormal situations.

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