# A STUDY OF EFFECTIVE PROCEDURAL PRACTICES IN REFINING AND CHEMICAL OPERATIONS[1]

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Significant investments have been made in the process industry in procedural practices and supporting technology with a focus to improve safety, reliability and efficiency in operations. Despite these efforts, many plants have not yet realized the full, expected benefits of procedural operations for a variety of reasons. A field study was conducted to understand some of the factors impacting the success of procedural operations and to develop recommendations for improved practices and tools. During the study, the team visited five refining and chemical sites, and interviewed key personnel on their experiences with procedures and the use of supporting technologies. Objectives of procedural operations were noted and ranked. Root causes of procedural breakdowns were assessed through incident reports and through surveys. Effective practices were also identified in the areas of procedure content, policy and process, technology aids and development.

## INTRODUCTION

Procedural practices involve the use of a set of explicit guidelines and instructions that, when followed by the operations personnel will minimize deviations from design or operating intent and will avoid hazardous conditions and other undesirable outcomes. The U.S. Federal OSHA Process Safety Management (PSM) regulations [Standard 29 CFR 1910.119 (f)] on operating procedures specifies that employers shall provide written operating procedures for distinct operating modes including startup, normal operations, temporary operations, and shutdown.

Consistent with the U.S. government regulations, there has been a significant focus in process plants on developing robust and reliable operations through effective procedural practices and the use of support tools (Jamieson & Miller, 2000). Despite these efforts, many plants feel they have yet to realize the full potential benefits of procedural practices. Being compliant with the broadly stated OSHA regulations does not necessarily lead to effective procedural practices. Plant personnel have expressed a need for better guidance in generating reliable and usable procedures as well as improved tools for the development and deployment of procedures.

The purpose of this study was to understand the current challenges and successes in the development and use of procedures in the industrial process plant operations environment. This study was conceived within a broader mission to identify opportunities to improve procedural practices generally within the industry.

## STUDY APPROACH

The project team visited two chemical plants and two refining sites, and one site was interviewed by phone. These sites are later identified as A, B, C, D, and E in random order to protect their identity.

This study focused on the use of startup and shutdown procedures, operating procedures, and emergency response procedures. The team investigated the range of continuous and semi-continuous process operations in refineries and chemical plants. Moreover, the team investigated the scope of procedural operations with an examination of the key aspects of the management system including the creation, use, and maintenance of the procedures.

Data collected for this study comprised of field observations, interviews with plant operations personnel, and review of documentation. The outputs were analyzed by looking at patterns across sites. From these patterns, the drivers behind procedural operations, root causes of procedural breakdowns, and effective practices were identified.

## DRIVERS FOR PROCEDURAL OPERATIONS

The motivation for procedural operations is multifaceted and grounded in improved safety and plant profitability. The top drivers, in order of perceived importance were:

1. ***Employee and Public Safety***. Use of operating procedures can reduce the number of personal injury or deaths due to operating error. Estimates from

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several sources indicate that 40 to 70% of accidents are due to operating error (Sutton, 1997).

2. ***Regulatory and Standards Compliance***. Use of operating procedures is required by governmental agencies such as OSHA (Process Safety Management standard 29 CFR 1910.119), EPA (Risk Management Program) and H&SE. International industry standards organizations also establish quality guidelines for procedural operations such as ISO 9000 and Responsible Care Program from the Chemical Manufacturing Association. Use of operating procedures to meet government regulations protects a company from negligence lawsuits in the event that an incident or accident impacts public or employee health and safety. Use of industrial standards to establish procedural operations practices enables a company to leverage the knowledge of the industry in defining quality practices.
3. ***Operational Effectiveness***. Use of operating procedures can lead to more efficient work processes and effective operational strategies. The effort to explicitly define operating procedures can lead to the identification of inconsistent or ineffective operational practices. In some cases, modifications or automation of procedures can improve operational effectiveness through faster start-ups, avoidance of human error, and longer equipment life.
4. ***Loss Prevention and Environmental.*** Use of operating procedures can reduce the unexpected costs to operations caused by abnormal situations such as damaged equipment, wasted raw materials and energy, process downtime, inferior product quality and unplanned overtime. Estimates from ASM studies indicate that at least 40% of abnormal situations are due to human error (Soken et al., 1995). The estimate of the cost of abnormal situations that do not lead to major accidents is at least $10B annually in the U.S.
5. ***Knowledge Management and Training***. Use of operating procedures can enable plant management to capture process operating knowledge gained in the experience of starting, running and shutting down a plant. This knowledge evolves over time with changes in the actual configuration of the plant equipment and materials as well. The explicit capture of this knowledge in the form of operating procedures makes it available to all plant personnel and other interested parties at any time. Moreover, the formalization of the operating knowledge enables its use for training employees. However, the operating procedure itself may be insufficient to meet the employees' training needs. Typically, an operating procedure assumes that an individual has prior training in general aspects of plant safety practices and operations.

## IMPACT OF PROCEDURAL BREAKDOWNS

From site incident reports and interviews with Process Safety Management, the following results show the impact of procedural breakdowns:

- **Site A** (1997-2001): 14% of all reports were attributed to procedural breakdowns; 10% of serious events; $12MM impact (8% of total incident losses).
- **Site B** (1998-2001): 31.2% of all reports were attributed to procedural breakdowns; impact was not easily traceable from the systems in place and information provided.
- **Site C**: Data was not accessible in incident database.
- **Site D**: Data was not readily accessible.
- **Site E** (1998-2001): 10% of reported incidents were attributed to procedural breakdowns; human error causes accounted for 6% of all capacity losses included maintenance, technical and operations.

For the few sites that actually captured data on procedural operations breakdowns, evidence shows up to 30% of all reports had procedural operations as one of the causes and an impact of up to 8% of all reported financial losses. Based on the limited nature of these reports, the typical impact is probably significantly greater than 8% of losses.

## CAUSES OF PROCEDURAL BREAKDOWNS

Again, from a review of site incident reports and surveys from plant personnel, evidence shows that procedural breakdowns have produced significant negative impacts on plant safety and profitability. The top root causes identified are noted below in order of frequency. Effective practices and tools to mitigate these problems can minimize incident risks associated with procedural operations and improve plant performance.

From the incident reports, we identified the reported root causes when a procedural breakdown was specified as well as its relative percentage of occurrence. For example, 42.7% of the reports containing a procedural breakdown had incomplete coverage by the procedure as the root cause.

| **Root Cause Description** | **%** |
|---|---|
| 1. Incomplete Coverage | 42.7 |
| 2. Procedure NOT Followed | 29.0 |
| 3. Flawed Reasoning | 13.7 |
| 4. Incorrect Procedure | 6.1 |
| 5. Incorrect Use of Procedure | 3.8 |
| 6. Inadequate Coordination | 3.1 |
| 7. Incorrect Data/Facts | 1.5 |

To ascertain operator's perceptions of the relative frequency of possible root causes, we asked them to subjectively rate the root causes of procedural breakdowns when they happened (Frequent, *once a month or more*=9; Occasional, *about 4 to 12 times a year* =3; Infrequent, *3 per year or less*=1).

| **Root Cause** | **Rating** | **Frequency** |
|---|---|---|
| Procedure NOT Referenced (2) | 3.58 | Occasional |
| Poor Coordination/Communication (6) | 3.08 | Occasional |
| Action Executed Wrong (5) | 2.83 | Occasional |
| Shortcut to Save Time (2) | 2.75 | Occasional |
| Misperceive Information/Data (7) | 2.42 | Occasional |
| Lack Knowledge/Experience (3,5) | 2.00 | Infrequent |
| Flawed Thinking/Reasoning (3) | 1.96 | Infrequent |
| Incomplete Coverage (1) | 1.75 | Infrequent |
| Lack of Time (?) | 1.75 | Infrequent |
| Misremember-Distracted–Fatigued (?) | 1.58 | Infrequent |
| Incorrect Procedure (4) | 1.50 | Infrequent |
| Incorrect Data (7) | 1.42 | Infrequent |
| Infrequent Unauthorized Override (2) | 1.25 | Infrequent |

The root causes in this table were slightly different from those found in the incident reporting systems. We selected this set to give us a better understanding of the nature of procedural breakdowns from a human error perspective. The number in parentheses indicates how the perceived root cause maps with the objective results from the incident analyses above. Note the discrepancies in perceived and actual root causes as documented in the incident reports. Reporting based on personal experience and awareness can differ from reported data for a number of reasons. Two highly likely reasons in this situation are:

1. Ineffective communications of root causes summaries to operations personnel
2. Unwillingness of operators to report human error as a root cause in an incident report

## EFFECTIVE PROCEDURAL PRACTICES

From the interviews and review of procedures, a number of common practices were observed:

- The policy requires following procedures at all times.
- If the procedure is non-routine or complex, operators are expected to use the procedure for planning and execution, and initial the steps as they are completed.
- If the procedure is routine, operators are expected to know and follow the procedure.
- If the procedure is an emergency type, operators are expected to know the initial steps and then reference the procedure in completing the remaining steps.
- There is a management of change process for deviating from procedures; temporary procedures need approval (typically, a team leader or supervisor has approval authority).
- Learning to perform procedures is a fundamental part of initial training program and in some cases, re-qualification.
- Use the procedure in hardcopy format, even if it is accessible on personal computers.

These common practices provide an understanding of the typical industry practice. To identify opportunities to improve the standard of practice, we identified unique practices that were reported to address past challenges in the success of using procedures. We labeled these as *effective* practices based on our expert judgment as to whether these practices were addressing significant challenges reported at other sites and the literature (e.g., Jamieson & Miller, 2000), as well as the reported impact of management and operations staff that used the practices. Unique practices were identified in the areas of procedure content, process and policy, technology aids, and procedure development.

### Procedure Content

*Overviews for lengthy procedures or activities involving multiple procedures.* The complexity of a procedure can vary depending on the number of process units involved, the extent of integration of the units, and the number of manual field activities. At times, plant operators struggle to understand what is happening during complex procedures. During training sessions, one site decided to develop a graphic to provide the plant operators with a high level overview of the startup of the units on the site. The graphic showed the operator roles, high-level step sequences, interdependencies and expected timeline for the startup activities. The operators reported that it was easier to identify how elements of the procedure impact each other and coordinate activities in a more efficient manner.

*Pocket checklist for routine procedures.* One site created a pocket checklist for routine operations that were performed on a weekly basis. The routine activity has a high level of manual activity performed simultaneously by operators in the field on the process equipment and operators in the control room on the control system console. This potentially hazardous operation had a history of frequent errors due to omission of steps, and poor coordination and communications. The checklist could easily fit in the field operator's pocket. Each high level activity was listed with color coding to indicate which operator had responsibility for the action. There was a check-off area to keep track of the current status of the procedure by equipment components. Often the procedure would be partially completed when the operators shift ended. The checklist provided a formal handoff at shift change to communicate the status to the operators coming on shift. After putting the checklist into practice, the number incidents due to procedural failures on this routine activity went from frequent to zero.

**Policy and Processes**

*Risk-based assessment criteria for procedures classification.* Operator compliance with a plant policy to “always follow procedures” has been found to be interpreted broadly and followed inconsistently within and across sites. In some situations, operators intend to follow procedures but do so from long-term memory without looking up the procedure prior to execution. If the procedure requires check-offs or sign-offs on steps, operators will typically pull the procedure after performing the task and complete the check-offs in a perfunctory manner.

The site with the best reported compliance by both operators and management was using a corporate effective practice called Risk-Based Assessment for Procedure Classification. The methodology used a numerical rating scheme to classify procedures as one of three types based on frequency of use, complexity and consequence:

- ***Critical.*** (1) In-Hand Use of Checklist Required, (2) Verification with initials and sign-offs (15-20% of procedures)
- ***Reference.*** (1) Review Procedure prior to Performance, (2) No checklist required on task, (3) Sign-offs optional
- ***Guidelines.*** General use for information or guidance on task performance; recommended for novices or training

In addition, the plant had a management practice to hold operators accountable for compliance with the stated policy. After a couple of reported situations in which operators were disciplined for failing to comply with the policy, the site culture for following procedures was dramatically improved. It appears that the success at this site was achieved by the combination of the clear, explicit criteria for classifying procedures based on potential risk and the management policy for individual accountability. Where only the management policy for accountability exists, there are still occasional failures due to the *perceived* unreasonableness of having a procedure in hand for every situation.

*Metrics to track the impact of procedural operations.* Understanding how plant practices impact plant reliability and profitability is a key element to making continuous improvements in effectiveness. Only one site out of five was able to provide data on the relationship between procedural operations, plant incidents and cost to plant operations. At this site, we found a comprehensive incident reporting system that captured data on the sources of procedural operations failures and their impact on plant profitability. The causes went beyond reporting that there was no procedure or the procedure was not followed, and included:

- No procedure
- Incomplete coverage
- Procedure not followed or used
- Flawed reasoning or computations
- Incorrect procedure
- Incorrect use of procedure
- Not available or inconvenient to access
- Inadequate coordination
- Incorrect data or facts
- Ambiguous instructions
- Difficult to use

With this type of data, a site is able to identify specific aspects of the procedural management system that influence human performance and justify making appropriate improvements.

**Technology Aids**

*Automation to assist in operations.* There are some procedural activities that require the operator to make several control system changes in the proper sequence at the right level within a short period of time. The time to perform the procedure could make a difference in profitability or the risk of an abnormal situation occurring. At two sites, we witnessed the use of automation to assist operators in getting more consistent execution of procedures with the elimination of negative impacts such as equipment stress, unplanned safety shutdown or environmental release. With the exception of one application, the operators are in control of when the procedure is initiated, have manual actions to execute in coordination with the automated actions, decide whether the automated actions are executed and monitor the overall effectiveness of the procedure. The use of automation for these time critical applications requires an understanding of the appropriate use of computer and human resources in the execution of procedural operations. Because of the dynamic behavior of the process at various stages of the procedure, it may be important to keep the operator in a supervisory role with adequate information and controls to oversee the proper execution of the procedure.

*On-line procedures in HTML format with links to reference materials.* Key elements of usable procedures are accessibility, freshness (up-to-date) and size. All sites we visited are moving away from procedure manuals to delivering procedures through the plant intranet on PC platforms in the control room and field houses. The site with the best practice in online formats converted the procedure to HTML format with links to reference materials available on other location in the intranet. The advantage of this approach is that the content was formatted better for online viewing. In addition, the size of the base procedure was kept small by inserting links to supporting information. The kinds of information in the links included digital images of equipment and/or equipment in location, drawings, equipment specifications, and safety information. In this particular setting, the operators were willing to use the procedure online rather than printing hardcopies.

**Procedure Development**

For procedure development, the study team identified common triggers for procedure changes: engineering changes, operations changes, PHA or HazOp reviews, environmental requirements, incident investigations, effective practices at other locations, and operator recommended changes. Typically procedure changes are implemented using standard word processing tools (e.g., Microsoft Word) and databases with revision controls.

*Comprehensive guidelines document for procedural development*. A challenging task for procedure developers is to develop usable and effective procedures that contain the right level of detail, are understandable to an appropriately trained operator, and present information in a consistent format. A procedure development guideline document has the potential to assist developers in achieving these results. While most of the sites had guidelines documents, the site with the most consistent implementation of procedures in a usable format also had the most comprehensive guidelines for developers.

The comprehensive development guideline had the following sections: Introduction, Drafting Guidelines, Human Factors Guidelines, Appendix A: Procedure Criteria Checklist, Appendix B: Word Usage, Sample Text Procedure. A number of good references to help you develop your own or to assess the adequacy of the guidelines developed by a third party are available in the literature (e.g., Sutton, 1997; Center for Chemical Process Safety, 1996).

## CONCLUSIONS

The results of this study indicate that even though there are large investments in procedural practices for plant operations, there is evidence that these efforts may not be delivering the desired benefits, due primarily to breakdowns in human performance.

Despite the keen awareness of the importance of procedural operations to business objectives, only a few sites could actually report the financial impact of breakdowns in procedural operations on operator and plant performance. Historically, the plant incident reporting systems have been designed primarily to monitor and track events with safety and environmental impacts. Hence, the typical incident reporting system provides only a general indication of the extent of the impact of procedural operations performance.

The investigation of root causes examined the relative contribution of various kinds of breakdowns in human performance. The evidence obtained in this study indicates human error is a significant source of failures in the procedural system. Combined with the plant management's lack of awareness of these sources, human factors methodologies and solutions are not being used to address shortcomings in procedural operations. Instead, there is a tendency for organizations to respond with more procedures or more training on the few occasions when procedural operations is implicated in an incident investigation.

The examination of effective practices unique to a few sites illustrates the potential value of addressing the key challenges to human performance such as apparent reasonableness of plant policies, awareness of sources of human error, physical and mental limitations, ease of use, and adequacy of information. In most cases, these effective practices were designed intentionally to address specific human performance breakdowns.

While these findings are from only five sites, the results are consistent with general observations the authors have made in visits to a number of plants in the industry over the past five years. The nature of the effective, unique practices highlights the potential for industry-wide improvement from applying human factors to the design of plant procedural operations systems.


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