Best Practices for Writing Operating Procedures and Trouble-Shooting Guides

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Abstract

There is no complete, best practice guideline or textbook for writing operating procedures and trouble-shooting guides. This paper presents the proven, best approach for developing accurate operating procedures and for ensure the format of the page and steps are optimized to reduce human error rates. This approach and the 35 rules established in this paper are based on the foundations set by Swain and others in the 1970 for control of human error rates, but uses experiences from more than 60 sites where this approach has been successfully followed. The approach and rules for developing procedures for responding to process deviations (such as those needed for Human IPL) are again the best approaches found and have been applied successfully since the early 1990s; these are many times called operational trouble-shooting guides. The paper also discusses how and when to integrate trouble-shooting guides into distributed control systems. Several case studies are provided that show the gains from following this approach. The guidelines in this paper build upon ones presented in 1999 at CCPS.

Background

Operating procedures have always been crucial to the safety, quality, and productivity of process systems. And with the advent of new safety and quality standards such as OSHA's process safety management (PSM) regulation, OSHA's personal protective equipment (PPE) regulation, EPA's risk management program (RMP) regulations, and the ISO 9000 quality standard, many companies are facing the daunting task of developing or upgrading their procedures to satisfy varied and sometimes complex or conflicting requirements.

Although there are overlapping characteristics that the various regulations and standards share, each approaches the procedure-writing process from a somewhat different perspective (e.g., quality or safety, protection of workers or protection of the public/environment), and the required level of detail for documenting the procedures differs greatly between these regulations and standards. For instance, the ISO 9000 quality standard advocates documenting procedures and work instructions that impact quality and suggests keeping the procedures as simple as possible, while the OSHA PSM regulation requires detailed procedures that address all operating modes (startup, shutdown, etc.) and that address operating limits, consequences of deviations, means to avoid hazards, safety and health considerations, and safety systems and their functions. How can companies develop and maintain procedures that ensure productivity and simultaneously satisfy the different regulations and standards? The key is to remember that the ultimate goal of the regulations and standards is consistent: reduce human errors that can impact quality, productivity, and/or safety.

Procedure-related errors are errors that occur because some characteristic of the procedure caused task performance to fail. ***This is currently the most critical human factor at most sites since 90% of accidents have at least one root cause related to mistakes within procedures.*** Reducing these procedure deficiencies can reduce human error rates by a factor of 2 to 10, normally. [1, 2]

The concepts and rules presented in this paper are applicable to all industrial settings. Most importantly, this approach **is effective in satisfying both safety and quality concerns.** With this approach, procedures can and have been developed that provide a sound basis for training and that provide the users and supervisors with an understanding of what can go wrong and how it can go wrong. This approach also provides management with an understanding of the inherent risk (to quality, productivity, safety, etc.) of an activity (i.e., the activity addressed by the procedure) and an appreciation of the safeguards that are being relied upon to mitigate this risk.

An extensive case study is presented by REC Silicon, which illustrates this approach, along with supporting the benefits of the accurate and clear procedures. But the same is true at more than 60 sites where the same approach has been followed.

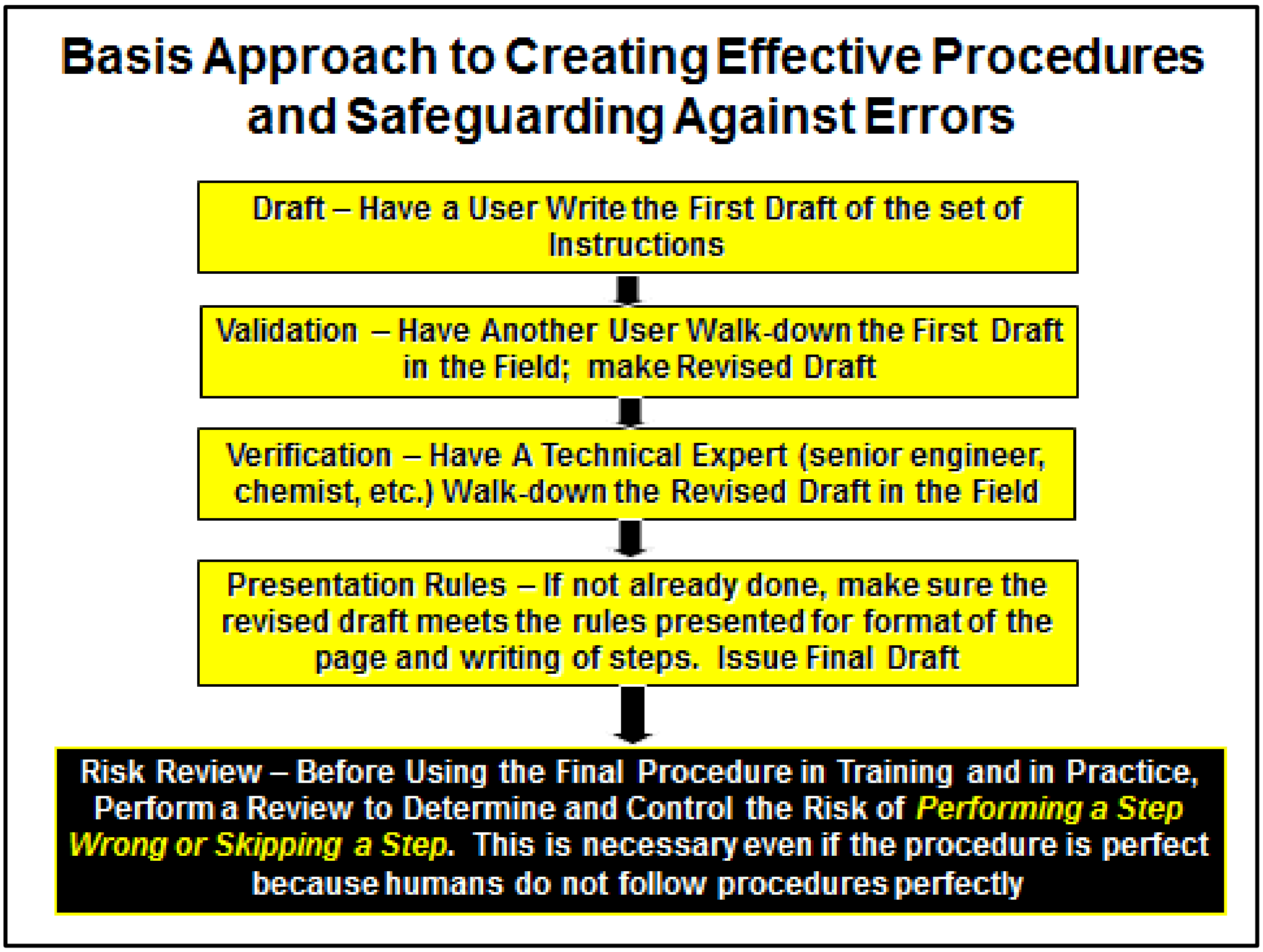
Fundamentals of Writing Effective Procedures

When developing procedures, or any written material, always remember that the burden of written communication is on the writer, not on the reader. It should never be up to the reader to decipher the meaning of a message. Engineers who write procedure manuals may "tend to include information that is more relevant to them than it is to the operators actually running the unit" [Sutton, 1992].[3] When writing procedures, your guiding principle should always be: if the written procedures are difficult to read, difficult to locate (e.g., if titles are do not have a clear meaning), or inconvenient to use, they will seldom be used [Swain, 1983].[1]

Deficient Procedures are the most prevalent problem in process industries since procedures have not traditionally been developed from the perspective of optimizing human factors; instead, procedures have been traditionally developed to meet a compliance requirement to have written procedures. Examples of procedure deficiencies (inaccuracies) include:

- Incorrect/incomplete/nonexistent (most procedures we have audited have been only 70-75% accurate – the inaccuracies include missing critical steps, steps as written are not what needs to be done, or the steps are out of sequence)
- No/misplaced warnings (for a example, a warning should Never **contain** the action to take; it should instead **emphasize** the action to take)
- Poor format and presentation rules

Figure courtesy of Process Improvement Institute, Inc. (PII), copyright 2003-2016[4]



The flowchart above describes the basic sequence of steps for writing effective procedures. Note that the some basic rules are contained in the flowchart, such as "Operators writing operating procedures" and "Maintenance craft-persons write maintenance procedures" and "Lab technicians write lab procedures." Procedures are Not written by engineers or department superintendents. This is a critical rule because it ensures the procedures are written in the common language of the users and is written at the right level of detail.

Universal Purposes of a Procedure[4]

1. A written guide to accomplish initial training of employees
2. A quick reference manual for experienced (trained) employees

The Right Information to Write – Content is KEY[4]

The Content of the procedure controls the human error related to "procedure-based" error – if and content is wrong, the trainee is very likely to learn the step wrong (if the trainer is using the procedure as a basis or when the trainee refers the to the procedure step that is wrong). So:

If the content of the step is wrong it does not matter if the presentation is clear; but if the content is perfect, you can reduce error rates a further 50 to 70% by presenting the information properly.

Ask experienced mechanics or operators to describe a simple task that they perform. You will quickly see that even simple tasks can involve many steps.

You should consider the following questions when writing each procedure step:

- How is the step performed? Does the action involve interacting with a computer terminal, an automatic controller, or simple devices (gauges, valves, micrometers)?
- Can the actions be performed as written and in the sequence written? Can the equipment be operated as specified? Can the steps be physically performed? Does the user have the training or experience to understand and carry out the action using the information available, or is additional information needed?
- Does the user need to be alerted of any potential hazards (Cautions or Warnings) or need any supporting information (Notes) before performing the action?
- Does the user need to know specific operating ranges or limits to:
    - Perform this action
    - Recognize the successful completion of the action
    - Recognize an actual or potential problem
    - Make a decision

For example, does the user have to verify temperature or pressure visually? Is the user waiting for a computer command or verification? How should the process react? Will exceeding a limit result in an accidental chemical release, personal injury, or quality concern? What is the chance of not operating within safe *operating limits, and what would be the consequences? If operation of the component is critical and a deviation will probably cause a failure, state the corrective actions. If failure is unlikely, keep going.*

- Is needed information found on an instrument, panel, or monitor or is it in the procedure or another source such as a graph, table, drawing, or specification sheet? Should this information be included in the procedure or be referenced?
- What is the next logical step? How is the next step affected by what is performed in the current step?
- What are the results of improper task performance? If an action is critical, spell it out in detail. For example, when starting a special pump that may bind or cavitate if not vented and primed properly, the procedure may require more information than simply stating "start the pump."
- Is the action frequently performed? Is it an action that is easily overlooked? Is this a complex piece of critical equipment that has a low frequency of use? These questions can help determine the level of detail in your procedure.
- Is the action performed so infrequently or is it so complicated that the user is not sure how to do it? Is the action so complicated that nobody is ever certain it's done right the first time?
- Is the decision point clearly defined if a decision is required? Unclear decision points can cause arguments and delays in performing actions.

To address the concerns listed above, a few simple rules are needed for developing content:

- The procedures should be written at the level of someone who has just completed the basic training for that task. Do not write the procedure for someone just hired or for the 10+ veteran.
- Clearly identify ahead of time what activities need procedures to help ensure error rates or controlled low enough, and identify which activities are considered common “skills” of all of the staff.

  Example: Starting a pump is typically considered a “skill.” This means a procedure step can simply be “Start the benzene recycle pump (P-119).” The procedure does not need to explain how to start the pump. But, starting a pump is a skill that nonetheless must be learned; it requires doing several sub-steps related to positioning of intake and discharge valves, how the discharge pump is throttled at startup, checking local pressure gage, etc. So, a training module is needed for starting pumps of various types, and the operator needs to learn this necessary skill. Once the skill is learned, it will be applied to so many various cases and so often, that a procedure is no longer needed as a “refresher” on how to do “start the pump.”

- The first draft of the procedure must be walked-down in the field by another user. (Simply reading through the procedure does not catch the enough of the mistakes.)
- The revised draft should be reviewed in the field by a technical staff person, such as a process engineer (for operating procedures).

Next:

- The procedure needs to follow the page format and step writing rules described in the next section. This ensures the accurate steps are clearly presented.

The target is to reach an accuracy of 95% or better (so, no more than one wrong or missing step out of 20 steps). The following have been observed in the field by PII staff by direct data collection at more than 110 sites/plants around the world, based on walk-down review of several to dozens of procedures at each unit/plant:

- At 95% accuracy or better and when the same procedures follow 80% of the rules for procedure clarity (presented next), then most users will follow the written procedures and will try to keep the procedures up-to-date.
- At about 85% accuracy or less, about half of the users stop using the procedures
- At about 70% accuracy or less, less than 10% of the users will refer to the procedure or will try to keep it up-to-date. ***So, the written procedures are useless.***
- Unfortunately, the typical Operating procedure walked down by PII staff (accompanied by senior operators, a process engineer, and a shift supervisor) is about 75% accurate (so one step in four is missing or wrong). Usually these inaccurate procedures also follow less than half of the best practices for procedure format, presented next.

PHA/HAZOP of procedures

Just as critical as getting the content accurate and presenting the steps clearly, is performing a PHA/HAZOP of the written steps to determine if you have enough independent protection layers (IPLs) against errors that the "imperfect" operators will eventually make when using the "near perfect" written procedures. This analysis is described in detail in Chapter 9 of the *Guidelines for Hazard Evaluation Procedures*, 3rd edition, 2008[5]. **For an update on the methods for such analysis and for a discussion of the extra emphasis on PHA of procedures by US OSHA, refer to the more recent paper (Bridges, Marshall; 2015).**[6 and 7, 8]

Procedure Clarity

The importance of the accuracy of the procedure steps were discussed above. The clarity of the procedure steps (how they are written and how the page is formatted) is also important. Following best practices for step and page format reduce human errors by a multiplying factor of 3 to 5.[1, 9]

The best practice rules for writing and validating procedures have been published for many years *(see Bridges & Williams, 1997).*[11] These rules include best practices for formatting of the pages and steps; these have been gradually improved over the past decades and now are incorporated into PII's training materials.[4]

The Table on the next is a checklist (in auditing format) based on the current set of best practice rules for developing accurate and clear operating, maintenance, and other work-instructions (procedures).

PROCEDURE QUALITY CHECKLIST *(courtesy PII, copyright 2003-2016)*[4]

#	Issue	Response
	Procedure Content Checklist	
1	Is the procedure drafted by a future user of the written procedure? (Engineers should not author procedures to be used by operators or maintenance staff.)	
2	Is the procedure validated by a walk-down in the field by another future user of the procedures?	
3	Is the procedure reviewed and commented on by technical staff (engineers or vendors)?	
4	Is the procedure checked versus the Page and Step format rules below?	
5	Is a hazard review of step-by-step procedures performed to make sure there are sufficient safeguards (IPLs) against the errors that will occur eventually (when a step is skipped or performed wrong)?	
6	Is the content measured using "newly trained operators" to judge the % of steps that are missing, steps that are confusing or wrong, and steps that are out-of-sequence? (A score of 95% accuracy of content is good; 98% should be the targeted average.)	
	Page Format Checklist	
1	Is the title of the procedure the largest item on the page?	
2	Is the procedure title clear and consistent with other titles, and does it uniquely describes the topic?	
3	Are the document control features the smallest items on the page?	
4	Are temporary procedures clearly identified?	
5	Is white space used effectively? • Is there one blank line between each step? • Does indentation help the user keep their place? • Are the margins large enough to reduce page congestion?	
6	Is type size is 12 pt font or larger?	
7	Is mixed case used for words of steps, with ALL CAPS used only for special cases (such as IF, THEN, AUTO, and WARNING)?	
8	Is the step number very simple (single level of number used)? Only an integer?	
9	Have sections or information not necessary to performing the steps been moved to the back or to another part of the manual or training guide?	
10	Are section titles bold or larger than the text font? Do sections have clear endings?	
11	Is the decision on electronic presentation versus hard copy correct? Are electronic linkages to procedures clear and accurate and easy to use? If paper is chosen, is the color of the paper appropriate?	
12	Is the overall page format (such as Outline format or Two-Column [T-Bar] format) appropriate to the use of the procedure?	
13	Are play script features added for tasks that must be coordinated between two or more users? • Play script is normally used when there are two or more hand-offs of responsibility for steps.	
14	Are rules followed for formatting of Warnings, Cautions, and Notes? (See annotated rules, such as Warnings are for worker safety and Warnings must clearly standout from rest of page.)	
	Step Writing Checklist	
1	Is each step written as a command?	
2	Is the proper level of detail used throughout? This is judged based on: • *Who* will use the procedures • Same level of detail used in similar procedure steps	
3	On average, is there only one implied action per instruction? Best practice is to average 1.2.	
4	Does the procedure indicate when sequence is important? • If sequence matters, each step should be numbered (with an integer or letter) • If sequence does not matter, bullet lists should be used	
5	Are only common words used? Apply "education" level test (5 grade reading level is best)	
6	Do all acronyms, abbreviations, and jargon aid understanding? • Develop a list of such terms for use in procedures *and* communication. • Use terms that users use (within reason)	

7	Is each step <u>specific</u> enough? No room left to guess/interpret: • The meaning of a word or phrase (Check vs. Make sure) • The intent of a step or series of steps • A desired quantity or value • To what equipment the step applies	
8	Is the procedure free of steps that require in-your-head <u>calculations</u>? • Values expressed as ranges rather than targets with error bands • Conversion tables, worksheets, or graphs provided where needed	
9	Are graphics to the user's advantage? • No explanatory paragraphs or lengthy instructions that could be replaced by a picture • No impressive graphics that provide no real advantage	
10	Are references to the user's advantage? • No lengthy explanations or instructions that could be replaced by branching to a reference • No references to a procedure that references still another • No gaps or overlaps between this procedure and a referenced document • If branching, must branch to a procedure, not to a specific step in a procedure	
11	Are rules followed for writing warnings, cautions, and conditional steps? • No more than 2 per page • No actions within a warning or caution (actions must always be numbered steps) • Warnings and Cautions contain descriptions of potential consequences	

Each of these rules is explained in detail in the course *Writing Effective Operating and Maintenance Procedures*, by PII.[4] (Visit www.piii.com for more details.) Each rule is backed by experimental or observed data that indicates there is a clear advantage in error reduction by using the rule. Below are a couple of examples from others on procedure writing rules.

> ***Proper Page Format:*** *In one study, Haney took a procedure presented in narrative format and converted it to column format. He then asked experienced technicians who had been completing the procedure using the narrative format to complete it as presented in the column format. He found that when the technicians used the column format, their errors were reduced by a factor of 3 compared with the narrative format [Haney, 1969].*[10]

> ***Including Supplemental Checklists:*** *Checklists can be effective aids to performance and often should be used to supplement procedures presented in any format. Checklists can be particularly effective in terms of preventing errors of omission. Some of the literature supports using checklists only for simple procedures that do not need to be performed under time or other constraints [Sutton, 1992].*[3] *However, there is also support for using checklists for emergency procedures in which a core set of steps is used to respond to emergency situations, particularly when the actions follow a simple sequence of steps for shutting down a process [Connelly, 1992].*[12] *Overall, experimental data have shown that the probability of errors of omission and commission can be reduced by a factor of 3 to 10 when checklists are used as reminders of key steps in a work instruction [CMA's A Managers Guide to Reducing Human Error, 1990].*[9]

For more data on the history and development of these rules, see Bridges & Williams (1997)[11] and especially refer to originating data and discussion for most of the rules (Swain, 1983).[1] **The procedure on the next page follows the rules**; this is a T-Bar format. Several other page formats are also valid.

PII CHEMICAL COMPANY
Unloading Monomer from Tanker to Storage

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Revised 11/4/02, Printed 2/21/16

Unloading Monomer from Tanker to Storage

STEPS	DETAILS
1. Wear standard PPE, plus rubber gloves and full-face organic respirator.	Standard PPE includes hard hat, safety glasses with side shields, and steel-toe shoes.
2. Weigh in the tanker.	Record weight on GROSS line of form.
3. Check bill of lading.	... to verify correct type of material is in tanker.
4. Sign in tanker driver.	Driver must sign in as a visitor and be escorted at all times.
5. Take Certificate of Analysis to QC.	***CAUTION: To avoid contamination, DO NOT unload until you receive approval from QC.***
6. Spot tanker.	A) Direct driver to location. B) Verify brake is set. C) Chock the wheels on at least one side between the two rear axles. D) Ground the tanker (attach grounding strap to an unpainted metal surface).
7. Have the storage area operator make sure the storage tank can hold contents of tanker.	***WARNING:*** *Failure to perform this step can result in an overflow and spill of hazardous Monomer.* Perform **Tank Gauging Procedure (SOP-01-804)** or check the storage tank load cell readout. Storage tank operating limits are stenciled on the control panel.
8. Place 5-psig nitrogen pad on tanker.	A) Connect from local 5-psig nitrogen drop to aft bottom nitrogen connection on tanker. B) Open nitrogen supply valve. C) Then open valve at tanker.
9. Connect Monomer unloading hoses.	A) Verify hoses and gaskets are in good condition. (Hoses are normally stored on hose rack at unloading spot.) B) Connect from tanker to air pump. (Use aft bottom connection on tanker. Remove cap.) C) Connect from air pump to storage tank. (Connect to storage tank line labeled "from TW.")

Trouble-Shooting Guides (Procedures for Responses to Critical Deviation Alarms) [13]

Trouble-shooting guides are a special form of operating procedure; they are written for the actions that we want the operators to take to recover from a process deviation, *before an emergency situation occurs.* They are called guides since rarely can we predict the process conditions at the time the action is required. Trouble-shooting guides (and training and drills of the action) are required for any action that is considered a Human IPL. The Action Limit is what we show as the Min or Max in a Trouble-Shooting Guide. The action limit triggers the demand to use the trouble-shooting guide.

- The response is typically still possible, but it is time dependent. The time available is called the process safety time (PST). The operator must complete the diagnosis, make the necessary change(s), and make sure they are out of harm's way by the end of the Maximum Allowable Response Time (MART). [13]
- We usually set an alarm or a pre-alarm to trigger this action.
- This is usually before the shutdown triggers (ESD occur automatically) or release points (PSV set points) are reached
- The Min and Max shown in the Trouble-shooting Guide table is not the absolute safety limit for a system, but is instead some value that leaves us some time to take action to prevent from reaching the absolute limits.
- There is still time to prevent or avoid the final consequence that could occur if we reach the ultimate limits of the process. Usually, we want the MART to be ½ or less of the PST, and we want MART > 10 minutes for trouble shooting in the field/plant and MART > 5 min for trouble-shooting only from the control room. [13]

If the unit has a good PHA/HAZOP, then it is best to extract information from the HAZOP (or What-If) analysis tables to start the development of each guide. The guide is then finished with input from the process experts.[4]

Examples of Creating a Trouble-Shooting Guide from a HAZOP Table

HAZOP Table Entry	**Trouble-Shooting Guide Entry**
Cause: *Bypass valve is open or passing*	Make sure the bypass is tightly closed
Safeguard: *Isolation valves for the vessel*	Isolate the vessel, if necessary
Safeguard: *Relief valve*	Make sure the relief valve block valves/relief path are open

The key categories of information needed in a trouble-shooting guide are:[4]

- IMMEDIATE ACTION (by system or by operator)
- DECIDE IF ALARM is REAL
- FINDING and FIXING the CAUSE
- FIX or BYPASS PROBLEM

The example below is of a trouble shooting guide for one critical alarm/action.

Trouble-Shooting Guide

Alarm or Indicator:	**PAL 4446 – Low Pressure Alarm for Suction of Organic Feed Pump 40-PM-18.445**

Action Limit:	5 kPa		
Consequence:	Possible pump seal failure, releasing or spraying organic waste into the berm.		
Process Area:	FB&D Incinerator; Liquid Organic Liquid Feed	**Oper. Mode:**	Normal
Drawing #s:	D-400-PI-013		

IMMEDIATE ACTION (by system or by operator)

- DCS should shut down the organic feed pump (40-PM-18.445).
- From the DCS display, MAKE SURE the organic feed pump is shutdown.
- HAVE the field operator check for leaks near the organic feed pump.
- IF there is a large leak/release, THEN use the ESD switch to shutdown the unit and then follow/complete the shutdown and isolation procedure, OPS-ESD-117.
- IF there is a minor leak or no leak, THEN:
    - COMPLETE the rest of the trouble-shooting,
    - and DECIDE how to contain the leak for now,

DECIDE IF ALARM is REAL

- From the DCS, CHECK the pressure and feed tank level trends. IF the trends indicate the alarm if valid, THEN continue with finding the cause or fixing or bypassing the problem.

FINDING and FIXING the CAUSE

- CHECK valves upstream of the organic feed pump to see if any are closed too far, including checking ESD valves.
- CHECK, by feel with hand, if the heat tracing is on; IF Not, then TURN ON or open heat trace valves
- MAKE SURE nitrogen to the pump seal is at the normal operating pressure.
- CHECK if the line if plugged or frozen (skill)

ABC Chemical Company Prepared by: *Printed copy of this procedure is good for one job task duration.*	OPS-76-TSG-233	Incinerator Unit Revised 8/24/2015 Printed 2/21/16 Page 1 of 2

Trouble-Shooting Guide

Alarm or Indicator:	**PAL 4446 – Low Pressure Alarm for Suction of Organic Feed Pump 40-PM-18.445**

- CHECK if the line if plugged or frozen (skill)
- CHECK if the level is actually low, use the Organic Feed Tank.
- IF the cause is low level in the feed tank, THEN resolve the problem if necessary based on cause that is found (skill)

FIX or BYPASS PROBLEM

- IF necessary, SHUT DOWN the Unit to allow fixing of the problem.
- FOLLOW the proper procedure to resolve problems (repair procedure, line clearing procedure, etc.)
- IF the decision is made to continuing operation without all equipment in normal condition, THEN:
    - FOLLOW Temporary Operating mode, if there is a temporary procedure already written for this possible problem/condition
    - FOLLOW MOC procedures to obtain approval for any non-standard temporary operating procedure or mode

END

Optimal presentation of trouble-shooting information.

Ideally (or ultimately) such trouble-shooting information should be imbedded in the basic process control system (DCS) so that the operators can access the information on demand, with the click of mouse or key.

Comments on Current Industry Consensus Guides for Writing Procedures

None of the consensus textbooks available for procedure writing cover all of the major points of this paper. The best "guidelines" for writing procedures currently exist in the course notebooks used by PII (and likely in the course notebook used by ABS Consulting, as they had similar origins).

Notably, the AIChE/CCPS textbook, *Guidelines for Writing Effective Operating and Maintenance Procedures*, 1996[14]:

- has NO description at all on the development and use and format of Trouble-Shooting Guides. This should have been a major chapter in the textbook.
- mentions only about half of the rules listed in this paper (and the related PII course notebook) for formatting of pages and steps
- emphasizes technical staff or professional procedure writers writing procedures, rather than the Users themselves writing the procedures (it violates the first rule of procedure writing)
- Fails to cover the competency needed by procedure writers.
- recommends and emphasizes having subsections in each work instruction/procedure (between the Title of the task and Step 1) rather than relegating such information either to other sections of the operating manual or rather than turning this information into steps.
- fails to mention the need for a PHA of procedures that focuses on hazard review of deviations from the steps; this is required by best practices and by US OSHA for PHAs under PSM.

This guideline textbook is not worth the investment.

As a better example, but one that nonetheless still falls short of what is needed, the ASM Consortium *Guidelines for Effective Procedural Practices*, 2010[15]:

- has good discussion on the need and thought processes related to handling abnormal situations (trouble-shooting or response to critical deviations), but there is little description on the format and detailed content of the trouble-shooting guides; in fact, the guideline fails to differentiate between routine procedures for startup, shutdown, and online maintenance, and those used for response to critical alarms (trouble-shooting)
- mentions only about half of the rules listed in this paper (and the related PII course notebook) for formatting of pages and steps
- mentions that experience users themselves should write their own procedures, but it does not emphasize this rule and leaves the authorship open to engineers or a committee. And it specifically mentions use of retired senior operators for writing operating procedures. While this is one good way to write the procedures (while also capturing the knowledge from this experienced group is prior staff), we have found that the current users do a better job overall, once they have achieved competency in how to write procedures.
- mentions the competency needed for procedure writers in general.
- mentions the need for a PHA of procedures, but does not reference the method for this in Chapter 9 of *Guidelines for Hazard Evaluation Procedures*, CCPS/AIChE, 3rd edition, 2008,[5] or other related papers on the topic. Also, the description of the PHA is misleading because it focuses on how PHAs should be used in writing procedure content (which is fine for trouble-shooting guides) but fails to emphasize that a step-by-step analysis of deviations from the steps are needed to ensure that the process has enough IPLs against mistakes that can occur when imperfect humans use the procedure.

Though this guideline has deficiencies, it is worth the investment and provides useful insight not found elsewhere. Just be sure to address the deficiencies noted above.

Implementation of this approach

PII staff has helped more than 60 sites implement the approach above. The typical approach for successful implementation is:

1. Perform a gap analysis to determine the average accuracy of procedure content, average clarity (as judged versus the procedure format rules, and identify any examples of excellent procedure writing.
2. Convince management of the problem and get their buy-in on the solution.
3. Train (1.5 to 2 days for operators; 1 day for lab or maintenance staff) and coach the users of procedures (normally for 3 to 8 days, to have them achieve full competency) so they can be effective authors. Normally, 20 to 25% of the users (hands-on operators, hands-on maintenance and inspection staff, lab staff) need to be trained as authors. Not all of those trained will make good writers; the organization needs to judge who does the best jobs. About 15 to 20% of the staff should end up being authors.
4. Get organized, like a project, for tracking and scheduling of the effort. Use master spreadsheets such as those used at REC Silicon (shown later).
5. Use a Traveler form (described later) to make sure each new procedure gets a proper amount of review by other users and by technical staff (such as engineers)
6. Reward procedure writers for their efforts. Especially ensure there are no disincentives for taking the extra effort to write procedures.
7. Track the progress on the effort; fix problems as they arise; enforce schedules (to show management cares).
8. Perhaps use to specialized software make it easy to output the content of procedures into different user-friendly formats such as training tools, training competency records, and field checklists. WordPerfect (formerly from Corel) made this relatively easy with the use of Primary and Secondary merge files; MS Word makes this more difficult. As a result, some specialized software have been developed to help keep formats consistent and to help reformat the content, on demand.
9. Issue procedures through a document control system that does not add extra workload.
10. Of course, ensure there is JSA performed for procedures that have "personal injury" potential and perhaps a PHA of the steps in the procedures whenever there is "process safety" potential.
11. Train all affected workers in the new procedures.
12. Identify the best writers to become the trainers of new authors, over the long run.

Overview of REC Silicon

REC Silicon is one of the world's largest manufacturer and suppliers of

- Silane Gas and specialty silicon gases.
- Granular Polysilicon from Fluid Bed Reactor technology for solar photovoltaic applications
- Ultra-pure float zone Polysilicon for the electronic industry

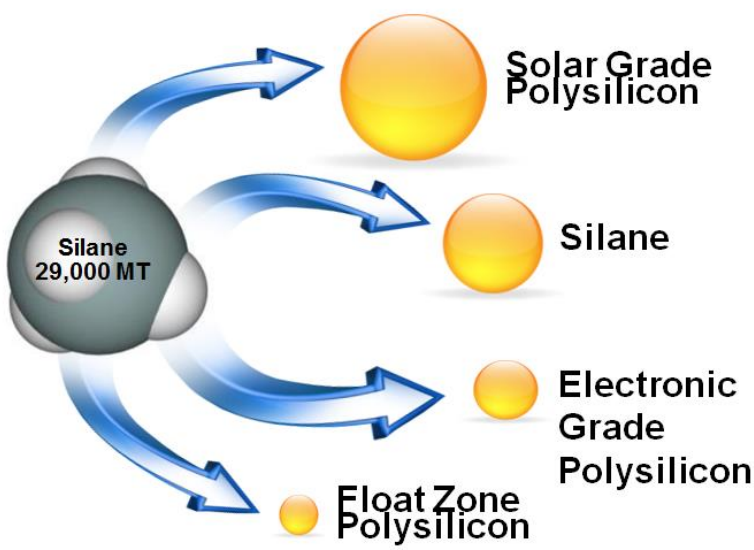
REC Silicon's Product and Service Offerings

Solar Grade
Polysilicon with various applications for the solar industry

Silane Gas
Product used in production of semiconductors, flat panel displays & thin film technologies

Electronic Grade
Polysilicon delivered to the semiconductor industry as well as other electronic market segments, such as optics & MEMS

Float Zone
High-purity polysilicon delivered to the power electronics industry



Moses Lake, Washington, USA 396 Employees	Silicon III, IV FBR	Silane gas: 22,000 MT Granular silicon: 16,300 MT
Butte, Montana, USA 255 Employees	Silicon II	Silane gas: 7,000 MT Siemens grade: 3,600 MT

Implementation at REC Silicon

REC production facilities in the USA have been actively implementing process safety for many years, with a renewed interest in 2013 in meeting industry best practices (which goes well beyond US OSHA PSM requirements). To that end, REC commissioned gap analyses versus best practices at both the Butte and Moses Lake production sites. One common finding was that the operating procedures and maintenance procedure for both sites needed improvement with respect to accuracy of the steps as well as clarity (page format and step format). The following were some of the issues with the procedures and related management systems, per the audit results:

- Procedure Inaccuracy
- Technical Staff (such as process engineers) were viewed as owners, not shop floor
- Annual review process ineffective
- Procedure formats needed improvement for reducing human error
- Inconsistent use of Warning, Caution, and Note
- Procedure Naming – not consistent
- Tried to take on all modes of operation in one procedure title
- Procedure accessibility was difficult in the legacy database; multiple searches needed to find tool for job
- Procedure Safety Reviews – did not utilize recognized methodologies for procedure safety reviews; i.e., there were no PHA of procedures with process hazards or JSA of tasks with personal hazards

Procedure Author Training – *the first step in any procedure writing effort*

In early 2014, REC Silicon adopted Process Improvement Institute's (PII's) procedure author training module (*Writing Effective Operating and Maintenance Procedures*[4]) with minor customizations. The training consists of 2 days of classroom lecture and about 6 exercises, followed by practical procedure development and field validation steps in the coaching phase. The classroom course covered all aspects of procedure writing with the focus on optimizing the aspects of the procedures that will lower the likelihood of human error when using the procedures. Topics included:

- human factors overview
- getting the content right
- page format rules and selection
- step format rules
- addressing operating limits (including creating trouble-shooting guides
- nuances of emergency shutdown and emergency operating procedures

- implementation guides and high level procedures for the task of getting all of the work instructions written
- examples/exercises on each topic

The coaching consisted of the instructors from PII, who are expert in organizing procedure writing efforts, helping the procedure writers organize and write operating and maintenance procedures, and trouble-shooting guides. Coaching was for 2+ days. About 20 staff from the Moses Lake and Butte sites attended the initial author training and coaching session.

REC Silicon has revised its management systems to require this competency for all personnel developing or changing procedures and to reach full operator certification. Operators must demonstrate an active role in the procedure MOC process to qualify for recertification every 3 years, otherwise they must repeat the classroom and field training. The unit trainers have taken over leading the procedure author training.

The benefits we have seen from these changes include transfer of ownership of procedures from the technical day staff to the operator since these are the people performing the work in the field. This is necessary to have accurate procedures. **The emphasis on intentional competency development for what is required to write effective operating procedures has greatly improved the quality of our procedures and our operator training and certification program.** The quality of the annual reviews and audits has improved tremendously with the rewritten procedure format and content changes.

Safe Operating Limits and Consequence of Deviation

REC Silicon has developed an engineering standard that governs the content and format for this type of special safety troubleshooting procedure. *CCPS Guidelines for Engineering Design for Process Safety*[16] is the basis for determining the safe operating limits. Production engineers are the owners of these procedures. Engineering competency is required to develop the safe operating limits table based on the available process safety information. A consequence of deviation is then developed by the Process Hazard Analysis team. Finally involvement of certified operators is required to develop steps to correct or avoid exceeding the safe limit. This combined effort produces the safety troubleshooting guide, which complies with the approach listed earlier in this paper.

REC silicon has risk ranked its process areas and is focusing on developing safety troubleshooting guides for high risk process first. To date, for the Moses Lake Facility, thirty six (36) guides have been developed. These have been developed in conjunction with PHA updates to the safe operating limits. We have not yet implemented the formal training and competency testing of these safety procedures. This is planned for the next phase of the initiative.

How REC Silicon approached the re-write effort:

To begin this initiative, each operating department listed all of the existing operating procedures into the procedure development tracking form. Each department also developed a list of “skills” that are used across multiple procedures and that operators or maintenance staff are required to attain before using the written procedures that were developed for more complex tasks (such as starting a pump, or hookup of a chemical transfer hose).

The workers (users) then screened each procedure for safety, equipment damage, or quality risk. This assisted in determining whether 2, 3 or 4 peer walk-downs were required on the validation traveler workflow. Since most of the REC Silicon procedures covered more than one mode of operation, the term "parent" was developed for the original procedure and each procedure was rewritten and broken out into a separate "child" procedures. The procedure re-write assignments were divided up between all four rotating shifts and the superintendent assigned certified authors (e.g., operators trained/coached as procedure writers) from their pool. Each department is managing their pool of qualified authors. For example, our fluidized bed reactor (FBR) unit has 11 qualified authors. Silane, which is a much larger department with 3 production units, has 56 qualified authors. Cross shift validation was utilized to ensure all operating approaches were considered. The assigned author was responsible for consolidating red line comments.

The traveler process introduced by PII was customized to consider information that is marked for removal from the parent procedure. **A Traveler form shown to the right accompanies each new or revised procedure through the writing and editing/review process.** When complete, the traveler form is then kept in the QA file for the procedure to validate long-term how the initial procedure was developed.

Procedure Development Traveler - Moses Lake			
New Document Number:		Area:	
Procedure Title:			
Procedure Type:			
Author:			
Initial Draft Completion Date:			
Author Walkdown Date:			
Author Revision 1 Completion Date:			
Peer 1:		Shift:	
Peer 1 Walkdown Date:			
Optional Peer 2:		Shift:	
Peer 2 Walkdown Date:			
Optional Peer 3:		Shift:	
Peer 3 Walkdown Date:			
Optional Peer 4:		Shift:	
Peer 4 Walkdown Date:			
Author Revision 2 Date:			
Engineer/Verifier:			
Verification Completion Date:			
Author Revision 3 Completion Date:			
QA Person:			
Author Revision 4 Completion Date:			

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A color coding process has been developed to indicate if the content can be permanently deleted, or must be moved into the unit training manual. The unit trainers have been responsible for tracking and reporting weekly progress on the initiative. **See an example of the overall tracking form below.** A total of 184 Moses Lake procedures were tracked through the development, review, and revision process.

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Procedure Development Tracking Form - Moses Lake

							Initial Development			Validation				
Item	**New Doc #**	**Old Doc #**	**Area**	**Procedure Title**	**Proc Type**	**Author(s)**	**Initial Draft**	**Author Walkdown**	**Author Rev 1**	**Peer 1 Walkdown**	***Opt. Peer 2 Walkdown***	***Opt. Peer 3 Walkdown***	***Opt. Peer 4 Walkdown***	**Author Rev 2**
1	FBP.3.xxx	FBP.3.160	FBR	Hydrogen Booster Compressor Cleanup	Cleanup	LT/FG	3/19/14	3/19/14	3/20/14	3/21/14	3/21/14			
2	FBP.3.xxx	FBP.3.160	FBR	Hydrogen Booster Compressor Operation and Op Restrictions	Operation	LT/FG	3/20/14	3/20/14	3/20/14	3/21/14	3/21/14			
3	FBP.3.xxx	FBP.3.160	FBR	Hydrogen Booster Compressor LOTO	LOTO	BCA/OL	3/19/14	3/19/14	3/21/14					
4	FBP.3.xxx	FBP.3.160	FBR	Hydrogen Booster Compressor Standby	Standby	BCA/OL	3/20/14	3/20/14	3/21/14					
5			4.0	STC/TCS from Receiving Tank to STC/TCS Storage Transfer Through Metering Line	Transfer	ME/RR	3/19/14	3/19/14	3/20/14	3/20/14	3/21/14	3/21/14	3/21/14	
6			4.0	STC/TCS from Receiving Tank to STC/TCS Storage Transfer Through Bulk Line	Transfer	ME/RR	3/19/14	3/19/14	3/20/14	3/20/14	3/21/14	3/21/14	3/21/14	
7			4.0	H2 Recycle Compressor Switching to Standby	Standby	ME/RR	3/20/14	3/20/14	3/20/14	3/20/14	3/21/14	3/21/14	3/21/14	
8			4.0	H2 Recycle Compressor Cleanup	Cleanup	ME/RR	3/20/14	3/20/14	3/20/14	3/20/14	3/21/14	3/21/14	3/21/14	

From PII's procedure author training,[4] the Quality and Content checklist was modified and used as quick reference guide to make sure that all the content development and formatting rules are being followed during the re-write process. We used Microsoft Word and made templates for the Tbar, Flat and Consequence of Deviations.

Procedure Management of Change

Through this project REC Silicon has adopted formal safety review methods for procedures. These methods standardize the approach to determine if a procedure is safe to use as written or if revisions are required. These details are outlined in a completely new REC Silicon policy - Procedure Management of Change PSM.30.004.01. The REC Silicon IT department developed a custom tool to execute these requirements in an electronic workflow. The benefits from these changes are formally transferring competency to lead and document job safety analysis to the shop floor supervisors. Prior to this effort, JSA was traditionally a review lead by our safety specialists.

Overall Summary of the procedure writing initiative:

For the Moses Lake facility, 398 procedures (operating, maintenance, and trouble-shooting guides) have been developed through this project (new and rewrites combined.) We do not have any data yet for reduction in error rates or increase in production, quality or safety, however we have seen great improvements with the new formats with the ability to conduct job observations in the field. Our job observations assess accuracy of the work being performed, accuracy of the written procedures, and an opportunity for on the job operator training.

This type of project can seem overwhelming for a manufacturing site. It is essential to form a project team with key decision makers from all the correct disciplines and have a project sponsor that can remove barriers. The way REC Silicon was able to accomplish this type of effort was dedicating time to meet each week, setting short term goals, and tracking KPIs to meet those goals. The procedure writing initiative at REC Silicon is still very much "a work in progress". Leaders of the project have to make time to support the staff to keep the momentum going on this initiative and also on the related culture change, until it becomes "the way the work always gets done."

Quotes from workers involved in initiative:

- Operators are receiving better work instructions
- Sequence of steps is well understood
- Much easier to audit operator compliance to procedure
- Standardizes how we do work – protects our equipment from damage, protects our people, protects the environment
- No longer need 20 year operator tribal knowledge and interpretation to complete procedure
- Procedures are not cluttered anymore, they just have the necessary information
- Procedure element now requires involvement of many shop floor workers
- JSA technique is alive on the shop floor
- Procedure can be trusted
- Technical staff no longer doing all procedure work. Freed up to optimize processes and realize other cost saving benefits.

Conclusions

Having clear and accurate procedures is a must. Poor procedures show up as one of the root causes in 90% of the accidents. The approach described in this paper has worked for more than 35 years for one of the authors, and continues to work today.   Controlling risk is mostly about controlling human error rates, and having accurate and clear procedures are one key to this control. One other gain from the approach described in this paper that the users become the owners, and therefore they have a vested interested to keep the procedures up to date and clear.

No doubt, writing all of the procedures for a facility is a large task. But, it can be accomplish by site staff, with support from process safety or quality control leadership, after enough users become competent authors; attaining this competency takes less than 2 weeks of work, on average.

Acronyms Used

AIChE– American Institute of Chemical Engineers
ASM – Abnormal Situation Management consortium
CCPS – Center for Chemical Process Safety (a division of AIChE)
CMA – Chemical Manufacturer 's Association, now American Chemical Council (ACC)
FBR – Fluidized Bed Reactor
HAZOP – Hazard and Operability Analysis
IPL - Independent Protection Layer
JSA – Job Safety Analysis

LOPA – Layer of Protection Analysis
MART – Maximum Allowable Response Time
MOC – Management of Change
NUREG – Nuclear Regulation, US Nuclear Regulatory Commission
OSHA – Occupational Safety and Health Administration, US Department of Labor
PHA – Process Hazard Analysis
PII – Process Improvement Institute, Inc.
P&ID – Piping & Instrumentation Diagram
PSI – Process Safety Information
PSM – Process Safety Management
PST – Process Safety Time
SOP – Standard Operating Procedure

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