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Optimizing PHA-HAZOP while maximizing brainstorming

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OPTIMIZING QUALITATIVE HAZARD EVALUATIONS FOR MAXIMIZED BRAINSTORMING

(OR "HOW TO COMPLETE A PHA/HAZOP MEETINGS IN ONE-THIRD THE TIME CURRENTLY REQUIRED WHILE FINDING MORE SCENARIOS")

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Abstract

This paper discusses the lessons gleaned from more than 8000 qualitative hazard evaluations completed by the authors and compatriots over the past 34 years. The learnings were from project risk reviews, management of change (MOC) risk reviews, full unit process hazard analyses (PHAs) redos, and PHA revalidations. (All of these evaluations fall within the qualitative category of CCPS's "Hazard Identifications and Risk Assessments [HIRAs]," required in the Risk-Based Process Safety [RBPS] guide [1].) The experience covers all chemical and related industry. The paper shares secrets that will speed up your hazard evaluations while not sacrificing thoroughness. Issues covered include: Should you project your notes during the meetings? Should you use dedicated software? Should you have a dedicated scribe? Should you define the methods and make sections/nodes ahead of the meetings? What methods should you choose? What documentation rules speed up the meeting? What facilitation rules speed up the meetings without crimping brainstorming? What mistakes kill brainstorming and also slow the meetings? Data based on thousands of PHAs is presented, along with a condensed set of optimization rules.

Introduction

PHA optimization is executing the PHA analysis with practices that are thorough and efficient. One key to optimization is optimizing PHA Team Leadership – the PHA leader's ability through training and practice to run efficient meetings while driving the team to make sound engineering- and operationally-based risk decisions. In addition, developing, implementing, and maintaining a PHA management practice with detailed procedures and rules for conducting PHAs is necessary to ensure consistent and efficient implementation. However, PHA optimization is also very dependent on the strength of other process safety management (PSM) practices. The full implementation of these strong PSM elements, over time, will lead to better data needed to conduct better PHAs.

This paper presents PHA team leadership techniques and rules, discusses content of PHA management practice, policy, and procedures, and explains the relationship of PHAs with some other PSM elements where if those elements are weak, can impact the quality of the PHA and increase the PHA meeting or documentation time.

This paper is a significant update of the paper presented, with the same title, in the 5th Global Congress on Process Safety in 2009. [2]

Source of the Optimized Rules

The rules presented in this paper were developed through our efforts in conducting thousands of PHAs, each with slight variations (planned and unplanned experiments). The rules were established with the goal of minimizing the effort it takes to complete a thorough PHA.

The data set for these rules include:

- 34-years of PHAs
- More than 8000 PHAs performed under contract for more than 300 clients
- PHAs were performed by more than 70 leaders and 40 scribes
- Teams were all composed of excellent, required members and often some optional team members
- Leader and scribe used various commercial software packages

Optimized Rules for PHAs

The rules presented in this paper will be new to most of the readers. Some of the rules will be quite surprising (even controversial) and, so at first, may not be readily accepted. Since these rules have been difficult to develop and, until now, have been closely held by a few very experienced PHA leaders and instructors, we recommend that readers give these rules a try.

We also understand that some readers will ask: "Why optimize PHAs? Aren't more meetings and more documentation better for safety?" The answer is no, as will be explained in detail later. In short, inefficient PHAs can burnout teams (lower the brainstorming and causing accident scenarios to be

missed). Also, if a PHA takes 3-times longer to complete than it should, then company leaders will be reluctant to invest more in aspects of PHAs where they are currently weak.

Major gap related to PHA's scope

Many companies do **not** perform a thorough analysis of the risk for startup, shutdown, and on-line maintenance modes of operation; the reason normally given is that the analysis of these modes of operation takes "too long." Yet, actually the PHA of the normal mode is taking too long and so the company has no time left for the analysis of procedures for startup and shutdown modes of operation. If these PHAs for the normal mode of operation are optimized, the organization will have time for thoroughly analyzing the non-routine modes (typically discontinuous modes) of operation and the organization will still have a net savings overall! This point is critical since 80% of catastrophic accidents occur during non-routine modes of operation.

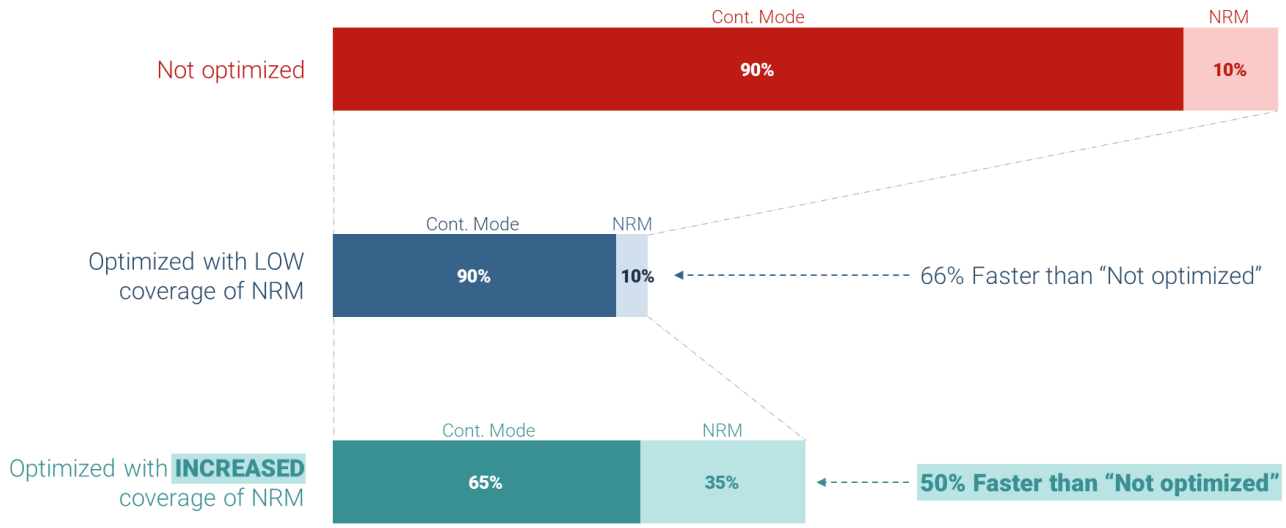

Figure 1. Meeting time (Continuous process)

General rules

This section list best practices for executing efficient PHA meetings.

The rules shown in **Table 1** are considered necessary for any team to be (1) compliant with government and industry standards or (2) are generally understood universally already, and therefore are considered a minimum requirement or common practice and so are NOT considered Optimization rules (but they are rules nonetheless).

There are opportunities for improvement and optimization in each of the the three phases of a PHA (Preparation, meeting and documentation):

- **Meeting Preparation** – Pre-populating the tables with the appropriate deviations will help the leader to quickly transition from deviation-to-deviation within a node, and also transition between analysis nodes or sections.
- **Leader Facilitation** – The PHA leader's ability to run efficient meetings requires training and practice. The Leader must be trained in best practices (not merely what guidewords to ask) and then must be coached through many sessions to practice what he or she has learned. The leader must have at least 10-years of hands-on experience in process operations and plant engineering. Other factors include the elimination of projecting meeting notes for the team to view, which tends to divert the team from brainstorming and instead focuses them on evaluating what the scribe is documenting. As a result, the leader tends to wait for the scribe to "catch up" (since the team members are reading what is projectetd) before leading the team into the next deviation analysis. Additionally, one important rule is for the leader to drive the team to make sound risk decisions as soon as possible in the discussion.
- **Scribing** – Having a separate person to scribe in the meeting (for analysis longer than 4-hours of meeting time) can help tremendously and easily pays for itself. While the scribe is completing the summary of the team's discussion, the leader can move on to the next topic of discussion.
- **Documentation** – Though not as important as the team meetings, documentation of the meeting results is nonetheless critical for the meeting results to be useful to others. There are many styles of documentation, but some styles are more efficient than others. **Table 1** and **Table 2** show the styles that have proven best.

Table 2 lists and describes the best practices for the three phases of a PHA.

Table 1. Regulatory required or universally understood practices (not optimization rules)

Best Practice Rule	**Typical of Current PHAs**	**More details on Best Practice** (i.e., how to optimize for efficiency and thoroughness)
Consolidate Studies – *From Risk Based Process Safety, CCPS 2007, page 230*	Sometimes large plants are broken into smaller units and the PHAs are performed separately for each unit; this reduces efficiency. .	Consider analyzing an entire unit instead of analyzing processes within a unit under separate PHAs. Efficiencies will be gained because the process safety information should overlap, the team members will be almost identical, except maybe for operators. Also, this allows more rapid linking of one discussion to other discussions in other nodes, thereby reducing repetition. Be mindful though that too many consecutive meeting days may require team member substitutions. Following this rule can take one-half of the time of separate, small PHAs that are difficult to link.
Standardize Checklists – *From Risk Based Process Safety, CCPS, page 230*	*Since the mid-1990s, many companies already follow this rule. Therefore, we have not included it in our estimate of potential savings.*	Saves time to have these tools available instead of requiring each leader to develop their own. This is especially true for checklists, such as Human Factors Issues and Facility Siting Issues; these two checklists have been shared across the industry since the mid-1990s. For best efficiency, use these checklists only at the end of a meeting to ensure you have not missed any issues during the pure brainstorming portion of the PHA; using them too early will overwork the checklist issues.

Best Practice Rule	**Typical of Current PHAs**	**More details on Best Practice** (i.e., how to optimize for efficiency and thoroughness)
Develop and use only a trained and experienced PHA Leader	A majority of team leaders do not know the rules below and therefore do not get the most from their meetings. *We have not included this factor in our estimate of potential savings; instead, we have assumed that each leader will have completed a minimum of 5 PHAs of one or more weeks of meetings, while. Applying the rules after reaching this threshold will give the gains listed.*	A new leader (those who have performed 0-2 PHAs on their own) will take 3-times as much time to cover the same issues and will not document the issues as well. Once a leader has performed 5+ PHAs (or one or more weeks of meetings for each PHA) using the rules below, they will be completing PHAs in one-third the time of other experienced leaders and one-third of a new leader, following the same rules. This gain is likely only possible is the new leader is "coached" during the 5 PHAs by someone who is already expert at using the rules listed in this paper. **See "Elaboration on PHA Team Leader Qualifications" later.**
Make sure you have ALL required team members – such as operations specialist from the area and the process engineer	Most teams are structured correctly, but this has not always been the case in the past. *Since this rule is mandatory for all PHA standards, we have not listed this as an optimization rule.*	The correct team members are critical (paramount) to a thorough meeting, and therefore thorough PHA. *Since this rule is mandatory for all PHA standards, we have not listed this as an optimization rule.* One rule we use in our meetings is: If the senior operator or process engineer from the unit leaves the team meeting (such as to respond to some urgent plant or personal need), the meeting is halted.

Best Practice Rule	**Typical of Current PHAs**	**More details on Best Practice** (i.e., how to optimize for efficiency and thoroughness)
Follow rules for meeting logistics	Most (but not all) teams tend to follow these rules already, so *we have not included this factor in our estimate of potential savings*	PHA teams have long been told (CCPS 1992, 2008) to meet no longer than 4-5 hrs per day and to take one week off before the next meeting (if possible). Leaders have also been taught to take frequent breaks (every 60-80 minutes) to allow the team members to get out of tunnel vision and refresh their minds and to allow the scribe to ask the leader about one or two confusing issues. It is also best to plan the breaks with hot and cold drinks and with fresh fruit (not pastries) and vegetables, since this will keep team energy higher.

Table 2. General PHA optimization rules

Best Practice Rule	**Typical of Current PHAs**	**More details on Best Practice** (i.e., how to optimize for efficiency and thoroughness)
Leader and scribe should develop nodes ahead of the team meeting	Many (perhaps more than half) develop the nodes during the team meetings.	A leader/scribe can develop the total nodes before the start of the first meeting. This provides all of the blank spaces for each possible issue, so the scribe can quickly document issues that come up ahead of time. This rule is mandatory if linking is used, as described later. **This rule can save 10% of the meeting time and saves a little after meeting time, as well.**
Make sure to follow node/section definitions that match LEADER or PHA Pro software (see discussion of software later)	Some teams use other software that requires manually choosing each deviation to use for each section/node. This is insanely wasteful.	**Pre-populating nodes with a standard set of deviations or what-if/checklist issues can save 10% of total project time and reduces meeting preparation time by 70%.** This type of optimization is what software should do for us.
Do not project/display (onto a screen) the analysis tables during PHA Team meetings	Some organizations, perhaps more than half, project/display all meeting notes "live" during the meetings.	Only project selected notes at the start of a new meeting-day to allow clarification of a confusing issue. Projecting P&IDs or procedures is fine. **Not projecting the scribe's live notes can save +30% in meeting time while increasing brainstorming.** The brainstorming increases because, if the notes are projected, the students are switching to the editor mode of their brain (while watching notes being typed). There are downsides with not projecting notes, but there are effective ways to overcome these downsides. **See "Elaboration on NOT Projecting Analysis Notes 'Live' during Team Meetings" later.**

Best Practice Rule	**Typical of Current PHAs**	**More details on Best Practice** (i.e., how to optimize for efficiency and thoroughness)
Leader should press for decisions as soon as the scenario is understood	Many teams overwork each moderate and major issue.	Pressing for an early judgment of risk can eliminate redundant discussion and can also help to eliminate unnecessary recommendations if the first decision pressed for is: "Is the risk tolerable?" **This can save 10-20% of the meeting time and greatly reduces burn-out, since most of team's energy goes into discussion of scenarios.**
Clarify which safeguards are candidate independent protection layers (IPLs)	Safeguards are a mix of IPLs, non-IPLs, and supportive management system layers.	Safeguards should be noted as either meeting IPL definition or not. This is a major advantage derived from introduction of layer of protection analysis (LOPA [3], [4]) in the late 1990s. **This does not save time, but does not take much if any extra time either.** You can view this as applying the "best" rules from use of risk matrices, which we recommend not using in PHA meetings (see later note).

Best Practice Rule	**Typical of Current PHAs**	**More details on Best Practice** (i.e., how to optimize for efficiency and thoroughness)
Perform a PHA of startup, shutdown, emergency shutdown, and certain online maintenance modes of operation	Not performed in nearly all refineries and in most petrochemical plants; the PHAs in these industries tend to focus on continuous mode of operation, even though 80% of the accidents in these industries occur in non-continuous modes of operation.	PHA of all modes of operation, with What-if and 2 Guideword (and rarely 7 Guideword HAZOP) being the methods of choice for non-continuous modes of operation. See section 9.1 of AICHE/CCPS, *Guidelines for Hazard Evaluation procedures, 3rd Edition, 2008* [5] for coverage of this requirement. **This does not "save time" but it does reduce the number accidents by ensuring the process is properly safeguarded for accidents that can occur during non-routine modes of operation.** This also improves compliance with PSM regulations and standards. **This will cost 50% more time than merely doing a hazard review of normal (e.g., continuous) mode of operation.** So, rather than being linked to "saving time," the optimization aspect here is to increase the allocation of time to these modes of operation and therefore find many more high-risk scenarios for the same or lower investment in PHA time (if the other rules are also followed). **So, the benefit of such scope change is a 500% improvement in risk identification and risk reduction.** Choose either 2 Guideword or What-If analysis methods (again, see Section 9.1 of CCPS 2008 for guidance). When documenting, list the data (causes, consequences, etc.) "by exception only" and show in the "deviation during startup," etc., if for a non-continuous mode of a continuous process. Or in a What-if style table of major procedure sub-sections (such as "preparation phase,") if for a batch process (a process that is normally step-by-step).
Use a dedicated Scribe, for meetings longer than 4-total hours	Most meetings do not have a scribe; the reason given is "cannot afford this luxury". However, the savings ratio in staff-hours for the whole team is about 2:1	Use a well-trained scribe to take the documentation load off of the team. **This rule can save 30-50% of meeting time and increases brainstorming** (because the team is not daydreaming as they wait for the Leader to complete the notes). Many junior and senior engineers make excellent scribes with about 1-week of coaching during actual PHAs; attending PHA leadership training can also improve scribe skills. Non-technical secretaries/clerks have been tried as scribes, usually with poor results. [6]

Best Practice Rule	**Typical of Current PHAs**	**More details on Best Practice** (i.e., how to optimize for efficiency and thoroughness)
Use efficient Software if you do more than 2-weeks of PHA per year. (Note: Software does not increase the quality of the PHA team meetings.) This is particularly true if you mostly use HAZOP method (versus What-If or FMEA methods)	Many organizations use PHA Works (Primatech), PHA Pro (Dyadem), or HAZOP Manager (Lihou); some organizations do not use PHA software (they instead use MS Excel applications or MS Word).	All of the software vendors are competitors of PII, and so we have no vested interest in any of the existing software packages; however, PII has many years experience with each of the listed commercial products. We recommend using LEADER (by ABS Consulting) if you do a lot of HAZOP of continuous flow processes. **This decision can save 25% in meeting time and can save 80% in preparation time.** Part of the savings is due to the predefined set of deviations for each node/section type (though PHA Pro 7 and above has the same capability of pre-defining deviations easily). Another part of the savings is due to the ability to link from one consequence to the cause of another deviation (even to a deviation in another section/node); LEADER is the only software with this option. Still another part of the savings is being able to decide to "turn off" cause-by-cause mode of documentation when the scenarios are simpler; again, LEADER is the only software with this option. If, however, you perform less than 2-weeks of PHAs per year, then likely MS Word or Excel are your best choices, since they are free and simple and since the benefits above will not be as apparent.
Do not use a risk matrix in the PHA meetings	Use of semi-quantitative risk matrices or even LOPA within PHA meetings.	Only use Risk Matrix within LOPA, and only use LOPA after the PHA meetings for issues that are very confusing to the PHA team (and possibly for multiple-fatality-potential events). **Eliminating forced use of risk matrices (and LOPA) from PHA meetings increases brainstorming and therefore increases the number of scenarios found by 10-20%, and saves 25% in meeting time.** **NOTE:** See the discussion later in this paper if your company forces the use of LOPA or a similar risk matrix tool for each scenario

Best Practice Rule	**Typical of Current PHAs**	**More details on Best Practice** (i.e., how to optimize for efficiency and thoroughness)
Use What-if (brainstorming with no guidewords) wherever you believe the risk and complexity is moderate, low, or well understood.	Many (most) organizations require use of HAZOP method in all cases (though a notable few require use of What-If in all cases).	What-If typically only takes 30-40% of the time (saves 60-70% of the time required) that HAZOP of the same system would take. Many see What-If as being too informal or less thorough that HAZOP, but experience of thousands of PHAs has taught us that What-if can be used for selected systems in nearly all PHAs, and in some cases (such as oil terminals and many utility systems), What-If is far superior. There are many PHA leaders who can lead a more thorough PHA with What-If than with HAZOP. **We tend to average a blend of 30% What-if in our PHAs, for a 10-20% savings in total meeting and documentation time.**
Use linking (especially for HAZOP of continuous modes of operation)	Less that 10% of the leaders/scribe use Linking. They instead either use repetition of causes, consequences, and safeguards; or they use "refer to" as a general statement and then attempt to list all safeguards for the entire scenario in one deviation.	Use LINKING to save time and increase speed (both). Use links from a consequence of one deviation to the cause of another deviation, to indicate the scenario path (if the ultimate consequence is of interest). The reader can follow the links forward or backward to find the related causes and safeguards elsewhere in the scenario path. This saves time by eliminating repetition of safeguards. We have also found that, typically, the quality of the final report is greatly improved, since it more accurately reflects how the scenario builds from one deviation to the next. Using linking allows using other clarity rules, such as "only show a safeguard in the deviation where it belongs." **Linking can save 20-30% of meeting time and after-meeting documentation time, and also increases thoroughness, if you doing a HAZOP-based analysis of continuous operation mode. If you are doing mostly What-If, then there is no savings.** Linking is illustrated in **Figure 2.**

Best Practice Rule	**Typical of Current PHAs**	**More details on Best Practice** (i.e., how to optimize for efficiency and thoroughness)
Use mostly deviation-by-deviation documentation instead of cause-by-cause documentation	More than one-half of the leaders (including all of the leaders who use PHA Pro, Lihou, and PHA Works) use only cause-by-cause documentation. Note that these three software packages only allow Cause-by-Cause style of documentation; though a power user of PHA Pro can change this at the start of a new PHA	**Cause-by-cause documentation takes 20-30% longer than deviation-by-deviation documentation, and, in most instances, provides little advantage, especially for HAZOP of continuous mode. If you are doing mostly What-If, then there is no savings since cause-by-cause is usually best.** We have found it is best to use a mix; using cause-by-cause documentation style only when absolutely necessary, such as in complex reactor nodes/sections or when LOPA (scoring) of many sceanrios is required by the company policy. Linking (described earlier) can be used in either documentation style. For more description of these styles of documentation, See section 5 of AICHE/CCPS, *Guidelines for Hazard Evaluation procedures, 3rd Edition, 2008;* or contact the authors of the paper. (As mentioned earlier, LEADER is the only software that automates Linking of one deviation to another deviation.)
Follow additional rules as outlined in **Table 3**	Most leaders/teams only follow a fraction of the optimization rules listed in **Table 3**.	**Following the additional rules (or clarification of earlier rules) in Table 3 will reduce meeting and documentation time by about 30%.**

Item Number	Deviation	Causes	Consequences	Safeguards	Actions
2.0 Line – Compressed Air System (dwg: 1)					
2.1	High flow		No consequences of interest		
2.2	Low/no flow	Air compressor failing to start or transferring off	Low pressure in the chlorine railcar (Item 1.6)		41
2.7	High pressure	Operator setting the pressure control valve incorrectly Pressure control valve failing to close or transferring open during unloading operations	High pressure in the chlorine railcar (Item 1.5)	Local pressure indication at the pressure control valve	04

Item Number	Deviation	Causes	Consequences	Safeguards	Actions
1.0 Vessel – Chlorine Railcar (dwg: 1)					
1.1	High level	Railcar overfilled by supplier Reverse flow in the chlorine unloading line soon after a new railcar is connected to the unloading system (Item 3.3) Misdirected flow to the idle railcar from the chlorine unloading line (if the idle railcar is already full) (Item 3.4)	High pressure as a result of liquid thermal expansion (Item 1.5)	Good supplier loading practices	01
1.2	Low level		No consequences of interest		
1.3	High temperature	External fire High ambient temperature	High pressure (Item 1.5)	Concrete crossties of rail spur Dike preventing any combustibles spilled nearby from reaching the unloading rack areas	02
1.4	Low temperature	Flashing of chlorine while using the eductor in the neutralization system to clear the chlorine from the line	Potential brittle fracture of piping, resulting in a loss of containment (Item 1.9)		03
1.5	High pressure	High level with subsequent liquid thermal expansion (Item 1.1) High temperature (Item 1.3) Violent reaction caused by a high concentration of organic contaminants (Item 1.7) High pressure in the compressed air system (Item 2.7) High pressure in the chlorine vaporizer (Item 4.5)	Potential loss of containment (Item 1.9)		04

Item Number	Deviation	Causes	Consequences	Safeguards	Actions
1.0 Vessel – Chlorine Railcar					
1.8	High	Backflow from the neutralization	Loss of containment resulting from	Closed dome on railcar	07
1.9	Loss of containment	Corrosion/erosion External impact Flame impingement Gasket, packing, or seal failure Improper maintenance Material defect Operator failing to close or inadvertently opening a valve to the atmosphere (e.g., a valve at a hose connection) Railcar inadvertently derailed Valve leaking to the atmosphere Low temperature (Item 1.4) High pressure (Item 1.5) Acid corrosion caused by a high concentration of water (Item 1.8)	Large release of chlorine to the atmosphere	Chlorine repair kit Limited vehicular access to area Maintenance/operator response as required, including isolation if needed Operator periodically monitoring the railcar valves while unloading Personal protective equipment in the area Plugs installed in all chlorine valves to the atmosphere when the valves are not in use Relief valve on each railcar for mitigating releases caused by overpressure Supplier maintenance of railcars Video monitoring of the unloading area	10 11 12 13 40

Figure 2. Example: Documentation using linking

Elaboration on PHA Team Leaders Qualifications

A PHA team must be led by a qualified leader. As mentioned, for comparison of gains, we have already assumed that each leader has already completed 5 PHAs of 1 or more meeting-weeks each. There is nothing magic about this number, but after completing a few PHAs, the leader is capable of using ALL of the rules defined herein. The leader may (should) have already learned these rules on the way to completing 5 PHAs. If the leader is NOT qualified, then it does not really matter what rules they follow; the PHA will be poor quality. The rules in this paper only apply to good PHA leaders. What does this really mean? Well, we know a good/bad leader and scribe when we see them, but to put some parameters around the answer, here are minimum criteria we use for qualifying PHA leaders:

Starting Suggested Qualifications:

- 10-years of hands-on experience in chemical or hazardous operations, with special emphasis on hands-on field or plant experience. This is critical to the leader being able to quickly understand the process under review and to be able to quickly understand the aspects of the accident scenario under review. Too many PHA leaders are "academic only" (i.e., their experience is engineering from an office or consultancy). Though we have seen some academic folks become effective leaders, its generally the folks with operations backgrounds that help a team find more of the subtle accidents scenarios during startup, shutdown, and abnormal operations.
- 10-years plus of technical background. This can include obtaining an engineering degree or equivalent experience learned in the field. Some of the best leaders we have observed have been non-degreed staff. With that said, engineers have a natural tendency for learning to be good scribes and leaders (as long as they also have some education in the school of hard-knocks: in the field or operating units).
- Quick learner – since the leader should be independent of the unit/process under review, they must have enough knowledge and experience to be able to quickly learn what the team's concern is for a specific What-If or Deviation and to help facilitate the team through the scenario development and judgment of risk.
- Good writer – the team will need a comprehensive, yet concise/clear record of the analysis, along with easy to understand recommendations. Much of this load can be pushed to a good scribe, but for hazard review of small changes (where the risk review lasts a few minutes or a few hours), a scribe may not be warranted. It is best if the leader serves as a scribe during their training and coaching to become a Leader.
- Inherent facilitator – We look for many traits, which include personable, reasonable, the ability to summarize issues quickly, good at conflict resolution; a good sense of humor is also important.

Once someone meets the Starting Qualifications to become a Certified PHA Leader, most organizations require the candidate to complete the following steps:

1. Attend a 4-5 day course that is approved by the company. There is a lot of bad training out there and many courses are not taught by expert PHA Leaders. The trainer (external or internal) should be carefully selected and approved by the organization. In some cases, the company will only approve

one or two individuals to be their trainers (rather than approving an entire consultancy or internal group). At the end of this first step, there is normally an exam of 30 minutes and, in some cases, a judgment by the instructors on the "potential" for leading a PHA in the near future. The course certificates will therefore say either that you completed the training and passed the exam, or that you are a Candidate PHA Leader. In our experience that only qualifies you for the next step (you are not a leader, yet).

There are exceptions: In one series of multiple PHA Leadership Courses for a client, we trained about 70 individuals, most of whom met the starting qualifications. At the end of the training sessions, each had passed the exam. Of the 70, we (the instructor and the client representatives who helped in the training) concurred that one student was ready to lead or scribe at the end of the 5-day session. This is a rare exception for a rare individual (we have found only 2 in 5000 graduates who could lead effectively after ONLY a 5-day class; even considering the 5-day class was 70% workshop). As a point of contrast, we believed that 30 of the individuals would never make good leaders, but might be good scribes and we believed some, with a little more coaching (1- or 2-weeks during actual PHAs), would make excellent leaders. Likewise, we believed that some would be good leaders eventually, but may never make good scribes. The training was excellent and the structure of the course was right (the client had tried many trainers and courses over a 10-year period before exclusively selecting PII trainers). But, the numbers above are fairly typical results after an excellent PHA Leadership course of 5-days duration.

2. The Next step at the Best organizations is for the "best graduates" to be tutored for their first few PHAs/HAZOPs; this tutoring can be by an already qualified, expert Leader internal to the company or by an already qualified Leader from outside the company. The tutoring can take 1 or 2 weeks or it can take many weeks, depending primarily on the selection of the new leader candidate and how quickly he/she can learn all of the subtle lessons of how to lead and how to scribe. (By the way, it is more difficult to produce a fast and thorough scribe than it is to produce a good leader-only.)
3. The final step is for the new leader to produce his/her first report and have it critiqued by a PHA expert (internal or external). The certifier should review this final report and, if it is good enough, the leader can be certified as a PHA leader; which means they can be trusted to lead and scribe (or work with a certified scribe) to complete a PHA in good and relatively efficient order.

With this background defined, PII staff has trained about 6000 PHA leaders around the world. Of those graduates, we have certified about 280 leaders. But, there are variations across the industry, and our standards may overlap or be different than our client's standards.

Example: In February 2008, we trained 8 candidate leaders from one chemical complex. They practiced on small risk reviews for 8-months. Then, in November 2008, they began to prepare for 4 large PHAs (two were revalidations, which would require significant redo). In January 2009, we completed step 2 of certifying 4 PHA leaders and 3 scribes during 2-weeks of hands-on coaching during actual PHA sessions of the large plants. The Final step will be completed in

the next few months, as reports are submitted for critique, revisions, and final issuance. In the meantime, the chemical company considers these individuals certified already because they have met the companies minimum requirement of completing training, passing the exam at the end, and being tutored by a qualified leader for a minimum of 1-week following training. Once the reports are approved, the 4 Leaders and 3 Scribes will also receive a certificate from PII. This approach has been followed at many companies in the past 18+ years.

Please refer to the paper "Building Competencies in Internal PHA-HAZOP Leaders" (2018, PII, presented at GCPS) for details on best practice for developing competent PHA leaders and scribes. [7]

Elaboration on NOT Projecting Analysis Notes "Live" during Team Meetings

Since many readers may be used to projecting meeting notes Live during PHA team meetings, we thought it would be beneficial to compare the pros and cons. (Note that CCPS HEP guidelines of 2008 [5] listed the pros of projecting but did not adequately cover the cons.)

Benefits of projecting notes live during a meeting:

- The team discussions can more easily be kept on track, since the team members can see exactly what checklist item, scenario, etc., is being discussed.
- All team members can see exactly what is being documented, so what is captured by the software can be truly considered as the consensus of the team.
- Documentation errors can be caught by team members and immediately corrected.

Drawbacks of projecting notes live during a meeting:

- Reduces brainstorming by drawing attention away from the discussion of accident scenarios and focusing attention of the text being typed (this causes more scenarios to be missed)
- Projecting the notes is boring for the team (the team's energy is reduced and therefore the team is much less productive)
- Overall, when equivalent teams were used, the teams that projected notes found 15% less accident scenarios for only a marginal improvement in documentation of the scenarios they did find.
- In comparing the speed of meetings with and without projection, the meeting with projection takes 30% longer meeting time, even if the drawbacks of projection are known and attempted to be overcome. This costs applies to all team members (including the team leader, scribe, and participants).

Benefits of projecting other information in the meetings:

- Key information such as P&IDs, procedures, the design intent (PSV specification sheet), plot plans, etc. can be displayed to help everyone focus on the same issue.
- The team leader can make a few notes on the drawing or procedure to highlight a key concept of the scenario, with adding the detail necessary for the scribe to add for the sake of the report.
- Previously completed work (such as during a revalidation, or during the 3rd or 4th phase PHA of a new capital project) can be displayed if it has a bearing on the current discussion or if revalidating results.

Conclusion of leading and documenting meetings with and without live projection of meeting notes:

- The reduction in brainstorming is significant is the team notes are project live during the meetings. All teams miss 10-20% of the accident scenarios (and miss 5-10% of critical, large impact scenarios) that another team will catch, but a team that projects the meeting notes live tends to miss as much as 15% more accident scenarios because they do so much less brainstorming during the same period of time. The teams that watch projected notes tend to digress to analysis and editor modes quickly, instead of fully brainstorming "what can go wrong?"
- The reduction in meeting speed costs more than just additional time for each team member (which takes time away from other critical tasks related to controlling risk). This extra meeting time also leads to more burnout of the team members, and burnout leads to missed scenarios or incomplete analysis of the scenarios found.
- The benefits of projecting can generally be recovered (while *not* projecting) by good and frequent *verbal* summarization by the PHA team leader and by good communication of the leader with a qualified and dedicated scribe. Also, the leader or scribe can, on exception, project the notes that are confusing to them; this seems to work best at the start of the next session (e.g., the next morning).
- Projection of meeting notes appears to speed up a revalidation of a previous PHA, if not much brainstorming is required, so for revalidations we are generally in favor of projecting notes live during PHA meetings.

Projecting of meeting notes may be necessary if the leader and the scribe are both lacking in experience or are not quick learners, because the team will need to compensate for their inadequacies; however, we have already stated that the efficiency rules shared in this paper are for experienced, "good" leaders (not poor, inexperienced leaders).

Other optimization rules

Table 3 summarizes these additional rules in a "simplified" PHA analysis table format to assist the reader in "seeing" the rule in context. These rules apply to analyzing deviations for a particular process section or node. They include specific documentation rules for certain deviations, as well as more general rules; again all of these rules are targeted as achieving high efficiency with little or no sacrifice of thoroughness. Following these rules will reduce meeting and documentation time by about 30%.

The Notes in the following subsections will help the reader understand the entries in each of the columns of **Table 3**. The Notes are presented in the order in which they should be filled:

1. **Deviation**
2. **Consequences**: Complete first for the deviation. **Go to consequences first and make sure the consequence is of interest to the organization** (not below the scope assigned to or agreed to by the PHA team). If the consequence is too low, then state "No consequence of interest" in the consequence column and do not list any causes or safeguards or recommendations. This rule alone can save 35% of the meeting time.

3. **Causes**: Complete second for the deviation, if there is a consequence of interest
4. **Safeguards**: Complete third after stating the consequence for the deviation and stating the causes
5. **Recommendations**: The last column to complete for a deviation, if additional protection against the scenario is necessary

Deviation column

A – Make sure you document each deviation that has a consequence of interest. For HAZOP, document even deviations that do not have consequences of interest.

B – Discuss Loss of Containment for each node; do this FIRST as stated above

C – Reverse flow is usually a credible scenario, even if there is a check valve in the line. (If there is a check valve, and if it is inspected and tested about every 4-5 years, and if it usually passes these checks, then it can be listed as a safeguard against reverse flow.)

Consequences column

D – Use LINKING to save time and increase thoroughness (both). Link from a consequence of one deviation to the cause of another deviation to indicate the scenario path (if the ultimate consequence is of interest). The reader can follow the links forward or backward to find the related causes and safeguards elsewhere in the scenario path (see also **Figure 2** above).

If high pressure links to loss of containment, and if one or more PSVs are safeguards against loss of containment, then one consequence listed in high pressure must be "PSV opens on demand, releasing _____ to _____".

Causes column

D – Use LINKING to save time and increase thoroughness (both). Link from a consequence of one deviation to the cause of another deviation to indicate the scenario path (if the ultimate consequence is of interest). The reader can follow the links forward or backward to find the related causes and safeguards elsewhere in the scenario path.

E – "Thermal expansion, if liquid blocked in" is shown as a cause in loss of containment (and not shown as a cause anywhere else).

F – Do not show external fire as a cause of high temperature; it is instead shown as a cause of loss of containment (since it is not a "process deviation" and since flame impingement is also a concern).

G – Tube leak/rupture cannot cause misdirected flow, but it can leak (and therefore link) to the node that relates to the "interchanged" stream, such as linking to high concentration of contaminants.

H – High pressure causes high flow (in a line) and not the other way around. So, "pump over-speed," if credible, is a cause of high pressure and then high pressure would be linked to high flow (assuming all of this leads to a consequence of interest).

I – Low pressure causes low flow (in a line) and not the other way around. So, "pump off," is a cause of low pressure and then low pressure would be linked to low/no flow (assuming all of this leads to a consequence of interest).

J – PSV opening is not a cause of misdirected flow.

Safeguards column

K – TRV (thermal relief valve, for thermal expansion) are only shown as safeguards in loss of containment and not in high temperature, since thermal expansion is almost never an issue during normal, process deviations (but instead is usually an issue during shutdown)

L – PSV is not a IPL if it is too small for the scenario listed, but can be listed in the Safeguard with a "non-IPL; not capable" tag.

M – Safeguards are only listed for the specific deviation and for the specific node to which they apply (flow safeguards for a line are only listed in a flow deviation; they are not listed in level deviations or pressure deviations).

N – Do not add the label "IPL" if a safeguardt is associated with a cause or another safeguard (in or linked to the same deviation). In other words, all IPLs must be truly independent of all other safeguards and of the causes of a scenario (we use the same definition as an independent protection layer (IPL) as in the LOPA and IPL guideline books).

> **Example:** If the flow control valve (FCV) failing closed is a cause, then you cannot use the flow indicator or low flow alarm (FAL) as an IPL for the same accident scenario, if all are from the same instrument loop, because they are not independent

O – Do not list any safeguard with the lable of "IPL" that has not been properly tested, maintained, and assured. For example, interlocks must be on a reasonable check/test plan; check valves must be on an inspection/text plan with 5 years of less test interval (in clean service); critical SOP steps must be emphasized in training and routinely practiced in the field.

P – A PSV is not a safeguard against high pressure, but instead is only listed in the safeguard column of loss of containment, and can be labeled "IPL" only if the PSV is sized large enough for the scenarios listed and only if it is inspected/tested according to industry standards.

NOTE: See the textbook on *"Guidelines for Initiating Events and Independent Protection Layers,"* 2015, CCPS for a deeper understanding if IPLs and see the paper by PII on *"Identifying IEs and IPLs During PHAs"* [4], [8].

Recommendations column

Q – Judge risk before moving forward to recommendations. Only list recommendations if, in the judgment of the team and/or by performing a LOPA, the risk is too high. If you ask your team "Do you have any recommendations?" then 9 out of 10times they will give you a recommendation. But, many times these are not necessary since the risk is already tolerable. The team should always first

answer the question "Is the risk tolerable or not?" and then, if the risk is too high, discuss recommendations.

R – Make one recommendation for ALL the minor corrections to the SOPs (but only for minor corrections, not for "changes"); have one person on the team (such as an operator) keep track of all minor fixes for a procedurr and reference in the recommendation who has the official copy on minor corrections (who has the procedure that was marked up with minor corrections during the PHA). Then, then PHA team leader can make notes for recommended "changes" to the SOP and forward this recommended markup along with the PHA report to the unit for resolution of the recommendation for procedure changes.

S – Make one recommendation for ALL the fixes/corrections (not the physical changes that may be recommended) to the P&IDs and other system drawings. Then, have one person on the team (such as an engineer) keep track of all fixes (on the drawings and referenced in the recommendations), and have that person maintain the official copy of the marked up drawings from the PHA. (Any necessary changes to the system must have their own recommendation.)

T – Make sure you designate which recommendations are Operability only.

U – Have a formal method for closing OPEN items before meetings (cycle) ends.

Table 3. Additional detailed rules for team facilitation and documentation

Deviations	Causes	Consequences	Safeguards	Recommendations
A – Make sure you document each deviation that has a consequence of interest.		Make sure you ask for consequences "first." If the consequence is not of interest, then state "No consequence of interest" and move to the next deviation or concern.		
B – Discuss Loss of Containment for each node	**D –** High Pressure **E –** Thermal expansion "if liquid is blocked in" **F –** External Fire		**K –** TRV **L –** PSV (do not list as a safeguard if the PSV is sized too small)	**Q –** Judge risk before moving forward to recommendations. **R –** Make one recommendation for all minor procedure changes.
High Flow	**H –** High Pressure			
Low Flow	**I –** Low Pressure	LINKING	**N, O –** IPLs must be independent and proven by testing; safeguards can support IPLs or be candidate IPLs (if gaps are closed) **P –** PSV are not safeguards against high pressure; they are safeguards against Loss of Containment	
C – Reverse Flow			Check Valves	**S –** Make one recommendation for all fixes/corrections to P&IDs.
Misdirected Flow	**G –** ~~Tube Leak/Rupture~~ **J –** ~~PSV Opens~~		**M –** In general, list safeguards for the specific deviations and for the specific node they apply	**T –** Make sure you designate which recommendations are operability.
High Temperature	**F -** ~~External fire~~			
High Pressure	**H –** High Flow **H –** Pump overspeed	**D –** Loss of containment **D –** PSV opens on demand, releasing (material) to (location)	**P –** PSV are not safeguards against high pressure; they are safeguards against Loss of Containment	**U –** Have a formal method for closing Open Items before meetings (cycle) ends
Low Pressure	**I –** ~~Low Flow~~ **I –** Pump off			

Specfic case: Optimization rules when use of Risk Matrix or LOPA is mandatory

As described in **Table 2**, the use of Risk Matrix or LOPA in a PHA is NOT recommended because it impacts negatively on the brainstorming and adds 2 to 10%% additional meeting time. However, there are some companies in which the use of a risk matrix or LOPA is mandatory on all or most of the scenario risk judgments. For those cases, there are some specific rules that can streamline the meeting while still using a Risk Matrix or LOPA:

- Use LOPA rules (for IPLs and their PFDs and Initiating Events and their Initiating Event Frequency (IEF) for the risk ranking of scenarios with highest consequences (Multiple and Single Fatality, and the equivalent in environmental and financial damage). Use qualitative judgement (with the matrix) for lower consequences. **Never use risk matrix scoring without using the rules of LOPA.**
- Repeat IPLs in the deviation where the final consequence (and the risk ranking) is recorded. In **Table 2** it was mentioned that Safeguards / IPLs are only recorded in the applicable deviation; however, if risk ranking / LOPA is performed, it is better to show all the applicable IPLs in the deviation / row with the final consequence (for clarity).
- Applicable Safeguards that do not meet IPL criteria should be clearly labeled as "Non-IPL" along with the explanation why it is not (not independent, not capable or big enough, not tested or documented, etc.)
- Use Deviation-by-Deviation documentation style and use Cause-by-Cause to group "equivalent" Initiating Events. Score (perform LOPA) on the the worst-case cause-consequence pair for a set of related sceanrios in the same deviation.

  Example: A vessel has two major causes for High Pressure leading to Loss of Containment: 1) Gas blowby from the vessel upstream, 2) runaway reaction. There might be several Initiating Events leading to Gas blowby (recorded in Low Level) or Runaway reaction (recorded in High Temperature), but the LOPA scoring will be performed to worst case cause-consequence pair for gas blowby and for the worst case cause-consequence pair for runaway reaction.

PSM implementation and its relation to efficient and thorough PHAs

The PSM elements are very dependent upon one another. These interrelationships determine the management of process safety risks. While some benefits are realized from implementing a single process safety management practice, the implementation of process safety elements is not intended to be ala cart. A missing PSM element or major weaknesses of one PSM element will most certainly weaken the implementation of other PSM elements; the overall impact is a weak PSM program. The relationship between some PSM elements are stronger (or more dependent) than others. Understanding the relationship between the elements is critical for optimization of any PSM program. Missing PSM requirements, for instance, if the MOC system and MI program are not fully designed and implemented,

will lead to unnecessary team discussions and a larger number of recommendations generated, which adds to meeting time.

While optimizing PSM will help to optimize PHAs, we realize this is global to all PHA leaders and scribes. There is nothing the Leader can do if the organization has a poorly implemented PSM system, but he or she will feel the effects in both less efficient and less thorough PHAs. So, for completeness we have included a summary (below) of the relationship of PHA to the rest of the organizations PSM (or RBPS) systems.

Identify weak management practices by analyzing types of PHA recommendations

One way to recognize weaknesses in the implementation of PSM elements is to categorize PHA recommendations from previous PHAs. After several cycles of PHAs for a given process, expect the number of recommendations to decrease as the process safety design is tweaked and PSM management practices are strengthened and fully implemented. **Table 4** summarizes some typical categories for PHA recommendations. If there are many across multiple PHAs, then the management practice warrants review.

Table 4. Typical categories for PHA recommendations

Category	Description
Process design	Indicates a possible weakness in engineering or process safety engineering standards
Standard Operating Procedures Changes/Updates	Indicates a possible weakness in the procedure writing process. If there are sizeable areas of weakness, a global recommendation to rewrite the operating procedures may be necessary. Poor procedures can greatly affect the quality of the PHA. If the weakness is widespread, the PHA of the procedures should be halted.
Admin/Policy/ Procedure Verification Items	Every PSM element, including PHAs, requires policies, authority, procedures, check and balances, and verification steps to work effectively. Weakness in these can lead to lower reliability of safeguards and impact the PHA.
Mechanical Integrity	These may simply indicate weaknesses in documentation or communication of these systems. But, perhaps critical tasks are missing or perhaps the frequency of a task is wrong.

Category	Description
Process Safety Information (PSI) Deficiencies/ Availability	These recommendations indicate that PSI is not up-to-date or available for the team to use to evaluate the safeguards and/or define the consequence of interest. Poor PSI can greatly affect the quality of the PHA. If the weakness is widespread, the PHA should be halted.

Process Design

Recommendations for process design changes may increase or decrease in number for a variety of reasons. As operational experience is gained, the reliability of safeguards and "lessons learned" from incident investigations could lead the team to make better risk evaluation decisions. This is related to quality of incident, near miss investigations, and documentation discussed elsewhere. Ultimately, recommendations related to improving designs indicate areas for improvement in engineering and design standards used by the organization; if these are amended to account for the recommendation, then perhaps the deficiency will not show up in the next (similar) design.

Standard Operation Procedures (SOPs) Update/Corrections Recommendations

Many PHA recommendations are the result of using incorrect SOPs. As a result, these inaccuracies slow the hazard evaluation process. As the team is analyzing procedures (all procedures for batch operations and non-routine procedures for continuous processes) the leader guides the team in understanding the consequences of not performing a step or performing the step incorrectly. The team reviews the process safety information, such as operating limits and consequences of deviation, which are stated in the procedure. If the procedures are incomplete, the team must then take the time to discuss the SOP inaccuracy and take the time to recommend, in general, how the SOP should be updated. Simple recommendations like "add a warning…" or "change the operating limit to reflect the current process…" are typical but would be unnecessary if procedures were written using best practices for procedure writing, SOP changes recognized as needing approval through the MOC system, and if the MOC system recognized the need to update SOPs as a result of a process change (if the change impacted the SOP content). One ultimate solution would be developing and implementing a system for writing effective operating procedures. See PII's paper "Best Practices for Writing Operating Procedures and Trouble Shooting Guide" for more details on best practices. [9]

Administration/Policy/Procedure Verification Recommendations

A PHA procedure is necessary to define roles and responsibilities, PHA leader qualifications, data to gather for the preparation of PHAs and for reference during the meetings, team membership requirements, and documentation requirements. Such a procedure should also include best practice rules, such as those stated in this paper.

Mechanical Integrity (MI) Recommendations

Many recommendations are the result of the team not having information on the reliability of engineered safeguards. Since the leader must drive the team to a risk decision for a scenario, the team should know or be able to reference certain information to help in deciding if the safeguards in place

are meet the definition on an IPL and if they collectively are adequate to control the risk at an acceptable level. Many recommendations are made to determine the frequency of a safeguard's inspection, testing, and preventive maintenance tasks, or to improve a safeguard by establishing an inspection, test, or preventive maintenance for the safeguard. Recommendations related to MI may simply indicate weaknesses in documentation or communication of these systems. Perhaps, though, critical tasks are missing or the frequency of a task is wrong. Many safeguards are not IPLs because of these deficiencies.

Process Safety Information (PSI) Recommendations/Verifications

Process safety information is necessary to identify valid consequences of interest for a process deviation and to evaluate the risks (the adequacy of the safeguards to prevent causes and mitigate/prevent the consequences). If the information is missing or is poorly documented, or otherwise unavailable for reference by the team, the team will not be able to fully analyze the hazards.

Inefficiencies also arise if there is an incomplete understanding of the scenario because of missing or incomplete PSI. As consequences are discussed, if the team does not fully understand the extent of consequences, they may understate or overstate the consequence or the safeguards needed to control the risk. For example, consider process chemistry. If the team does not fully understand the consequences of adding an incorrect amount of catalyst, then the consequence may not be fully documented (understood); however, there is the possibility of overstating the consequence and discussing a scenario that is not credible or has no consequences of interest. Information on reaction rates, operating limits, process chemistry, chemical properties, chemical volumes, equipment design, and others, assist in determining the consequences. **If information is missing on the safeguards, then the adequacy of the safeguards to prevent the cause or mitigate the consequence may not be properly evaluated**. Often, team members cannot recall the exact alarm set point or interlock trip. This results in an "open" item where the information is located over lunch or at the end of the day. The team must then re-examine the scenario, based on the information now available. If the information cannot be located, then a recommendation must be written to develop the PSI and to reassemble the team to evaluate the scenario using the PSI.

P&IDs – P&IDs are referenced throughout PHA to verify connections, valve locations, etc. As team members realize that the P&IDs are incorrect, a discussion begins, adding to the meeting time. **Ensuring that P&IDs are up to date prior to the PHA meeting helps to minimize meeting time.**

Management of Change

During PHA revalidations, MOC reviews can take considerable time. If MOC documentation is incomplete (key information the revalidation team needs to ascertain that the change process included a health and safety risk review) or is of poor quality, then the PHA team will have to spend more time discussing each process change. Designing the MOC system correctly will facilitate MOC reviews during the revalidations. Thorough documentation of the risk review – what questions are asked and what process is used to determine the level of risk review required for the type of change. Documentation of the risk review including the deviations, consequences, safeguards, and any action items will be necessary for the PHA team to incorporate the process change into the PHA analysis and

to allow the PHA tables to be updated to reflect the process change. Also, documentation confirming exactly what was installed and implemented is necessary so any design changes that are safeguards (or IPLs) can be added to the PHA tables.

In the past 15-years, while conducting PSM audits, assessments, and PHA revalidations, the MOCs reviewed at many of the 40+ sites did not include information on the risk review. Some MOC forms had only a checked box indicating that the risk review was required or not required. Some MOC procedures contained a short questionnaire to evaluate the risk category of the change, and depending on the category, determined the type of hazard evaluation method required to further evaluate the risk. In many of these risk categorizations there was no supporting documentation of the risk review. Were these risk reviews completed? Were the risk review teams of the same composition as a PHA team? If not, can these MOCs be reflected in the revalidated PHA without a new risk review with proper team composition? Obviously, the MOCs at the mentioned sites had insufficient risk review documentation and this will greatly reduce the efficiency of the PHA Revalidation system.

Certain risk-based questions must always be asked, so the reviewers can confidently say that the proposed change does not introduce a new risk or increase the current risk. That in itself is a level of risk review, and those questions, and their responses should be documented to help the PHA revalidation team when reviewing the MOC.

Incident Investigations

It is best practice and required by OSHA's PSM standard to evaluate previous incidents related to the process under review. Poor documentation of incident reports can add hours to a PHA meeting, depending on the number of reports under review. Inefficiencies can occur at the meeting preparation phase, as well as during the PHA meeting. Electronic incident report generation and storage can make it easier to retrieve reports, but can also be a timely process depending on how the system is designed and how incidents are categorized. Some companies have a "process safety" category, but typically process safety incidents are categorized under equipment damage, environmental, loss time/injury, operational, or fire. Having to go through each category, in search of process safety incidents, is time consuming. Having a clear definition of what a process safety incident is, and properly categorizing these incidents, will make the reports easier to access and will save preparation time.

In order for the PHA team to analyze incident investigations, the report must clearly describe the incident, the root causes, recommended corrective actions, and the status of the corrective actions. If the incident investigation management practice doesn't define investigative leadership and team requirements or, documentation and implementation requirements, then poor quality investigations can result.

If the root causes are missed or incorrectly identified, then incident investigation corrective actions will not adequately prevent the near miss or incident from recurring. (Some corrective actions are engineering/administrative controls and others are changes in the management systems to directly address the root cause.) Longer discussion times for poorly documented incidents, and most likely the generation of recommendations to address the causes or probable causes, will increase meeting time.

Conclusions related to PSM management systems and their impact on PHAs

When reviewing PSM management practices, think in terms of how the information generated from these management practices is used in PHAs and PHA revalidations, to ensure the policies and procedures are designed to facilitate efficient process hazard analyses.

Summary of savings and other benefits

Following the rules for PHA preparation, leadership, and documentation as described in **Table 1** and **Table 2** can result in PHAs meetings being completed in one-third the time of typical PHAs today. The improvements percentages listed in these tables is not necessarily additive and some rules are dependent upon others. However, we have watched some PHAs, conducted by "experienced" leaders, which took 5-6 weeks of meeting time using the wrong rules, and yet an identical unit with an identically structured team took only 6-days using the optimized rules presented here. When the documentation of the two analyses are compared, the one that took less time, but used the optimized rules, found more accident scenarios and documented them more clearly. We do not expect 80% improvement as typical. However, when all the rules are followed, we have seen dramatic improvements in both meeting speed and number of meaningful accident scenarios discussed.

For many highly experienced leaders, the meeting time may only be cut in half, instead of cut by two-thirds, if these rules are followed. All of the rules were learned through experiments (planned or unplanned), and in all cases we tried to hold the qualifying analysis and clarity of the results to the highest standards. In most cases, 15-20 deviations (or What-if questions) per hour average speed is achievable by the rules listed here for meeting facilitation. If all of the rules are followed, even slightly higher "per deviation" speed is possible. Additional efficiency gains are possible within meetings if the proper mix of hazard evaluation methods are used and the proper changes are made as to choice of software. Finally, the optimal efficiency and thoroughness for preparation, meeting, and documentation phases of a PHA is achievable if all of the rules are followed. **The typical reduction in overall PHA labor cost is two-thirds, when compared to typical, un-optimized PHAs**.

The tables below provide two comparisons of following the optimization rules to not following these rules. Comparison 1 is for the same scope, but following all optimization rules and assuming an average speed for what we have observed for well trained leaders who do NOT follow these rules. Comparison 2 (**Table 6**) is the same as Comparison 1 (**Table 5**), except analysis of operating procedures for uncovering accident scenarios during non-routine modes of operations has been added to Only the Optimized PHA column to provide comparison of un-optimized to fully-optimized PHAs. These tables provide a similar comparison to what was shown in **Figure 1** in page 4.

Both comparison are for a basis of 100 nodes of continuous HAZOP sections (and all related operating procedures for startup and shutdown, for Optimized case only) and consider 4 full-time PHA team members.

Table 5. Comparison 1: LOW coverage of Non-Routine Modes – Potential savings when following optimization rules

		Optimized (Using rules + dedicated Scribe)			**Un-Optimized** (No rules + No Scribe + No NRM)	
PHA Phase	**Use of optimization rules**	**Leader labor**	**Scribe labor**	**Team members** (4)	**Leader labor**	**Team members** (4)
Preparation	Predefining nodes and section Pre-populating deviations and What-If questions	10 h (**5%** of total time)	10 h (**5%** of total time)	-	30 h (**~15%** of total time)	-
Meeting	Not projecting the meeting notes live Pressing for decisions on risk soonest Use a dedicated scribe Use efficient software (must save time) – must support different documentation style and Linking (if you do HAZOP of continuous modes) Do not use risk matrix in qualitative PHAs Use What-if wherever possible Use linking for continuous-mode HAZOPs Use mostly D-by-D style of documentation Following detailed rules in Table 3 Clarifying which safeguards are candidate IPLs Performing analysis of startup and shutdown modes of operation	60 h (**50%** of total time)	60 h (**50%** of total time)	240 h	200 h (**~65%** of total time)	800 h
Documentation	After-meeting benefits directly relate to meeting optimizing rules, but when using optimization rules, more load is shifted to the after-meeting effort	50 h (**45%** of total time)	50 h (**45%** of total time)	-	40 h (**~20%** of total time)	-
	Total staff hours	440 h			1070 h	
	Accident scenarios found	**500**			**400**	

Table 6. Comparison 2: INCREASED coverage of Non-Routine Modes – Potential savings when following optimization rules

		Optimized (Using rules + Dedicated Scribe + NRM)			**Un-Optimized** (No rules + No Scribe + No NRM)	
PHA Phase	**Use of optimization rules**	**Leader labor**	**Scribe labor**	**Team members** (4)	**Leader labor**	**Team members** (4)
Preparation	Predefining nodes and section Pre-populating deviations and What-If questions	15 h (**5%** of total time)	15 h (**5%** of total time)	-	30 h (**~15%** of total time)	-
Meeting	Not projecting the meeting notes live Pressing for decisions on risk soonest Use a dedicated scribe Use efficient software (must save time) – must support different documentation style and Linking (if you do HAZOP of continuous modes) Do not use risk matrix in qualitative PHAs Use What-if wherever possible Use linking for continuous-mode HAZOPs Use mostly D-by-D style of documentation Following detailed rules in Table 3 Clarifying which safeguards are candidate IPLs Performing analysis of startup and shutdown modes of operation	90 h (**50%** of total time)	90 h (**50%** of total time)	360 h	200 h (**~60%** of total time)	800 h
Documentation	After-meeting benefits directly relate to meeting optimizing rules, but when using optimization rules, more load is shifted to the after-meeting effort	75 h (**45%** of total time)	75 h (**45%** of total time)	-	40 h (**~20%** of total time)	-
	Total staff hours	720 h			1070 h	
	Accident scenarios found	**600 – 700 (but the gain is risk reduction is 500%)**			**400**	

Some organizations may be reluctant to implement the changes to accommodate use of these rules. We encourage them to think through the potential savings for all team members time. Also, improvement in meeting efficiency improves brainstorming and increases the number of significant accident scenarios found. Finally, the savings obtained can be used to fully analyze hazards during non-routine modes of operation, finding even more scenarios and more importantly finding the scenarios that are likely least safeguarded.

Closing

Although more than a million PHAs have been performed, few organizations perform these in an optimized fashion. The goal of a PHA is to identify potential accident scenarios, describe the scenario fully, and qualitatively judge the risk of the scenario. A goal of any business practice is efficiency. Both goals are readily achieved if rules for optimizing the PHA effort are strictly followed. The rules in this paper are based on thousands of PHAs, with many variations across the set. Therefore, we believe these rules represent at least a first cut at PHA optimization. Following these rules can lower the labor costs significantly for completing PHAs and can, at the same time, improve thoroughness.

Acronyms

CCPS: Center for Chemical Process Safety
CM: Continuous Mode
COI: Consequence Of Interest
CSB: US Chemical Safety Board
EPA: U.S. Environmental Protection Agency
HAZOP: Hazard and Operability study
IE: Initiating Event
IEF: Initiating Event Frequency
IPL: Independent Protection Layer
L+S: PHA Leader and PHA Scribe
LOPA: Layers Of Protection Analysis
NRM: Non-Routine Modes
OSHA: US Occupational Safety and Health Administration
PHA: Process Hazard Analysis
PFD: Probability of Failing on Demand
PSM: Process Safety Management
RBPS: Risk Based Process Safety
SOP: Standard Operating Procedure

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