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Abstract

Incidents in complex oil and gas refineries and offshore platforms are usually the result of several interdependent events, although deviations from written procedures have often been credited as root causes. Semi-structured interviews were conducted with 72 operators in nine refinery and offshore sites to investigate the systemic factors that shape procedures usage behaviors at individual, task, cultural, organizational, and environmental levels. Our findings suggest large variations between the way procedures are operationalized, stored, and used within and between investigated organizations, a result of many interacting socio-technical elements. Lack of usage was shown to be attributable to experience and adherence in some cases was for fear of job security in punitive work cultures. A plethora of process control documents for differing tasks have emerged among the industry, perpetuating a general disconnect about what is meant by “the procedure”. Team communications, such as supervisor sign-offs, change processes, and collaborative work tasks can be streamlined to ensure safe completion of work. While several recommendations are offered, the intricate interdependencies among findings suggest the need for a paradigm shift in which change would focus on process effectiveness and work integration rather than blind enforcement of paper, written documents in all scenarios.

Keywords	process safety; procedures; oil and gas; interview analysis; grounded theory
Taxonomy	Safety Procedure, Safety in the Workplace, Oil Industry, Qualitative Methods, Offshore Engineering
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Texas A&M University
Industrial and Systems Engineering

Farzan Sasangohar, PhD
Assistant Professor

April 20, 2018

Dr. Georgios Boustras
Editor
Safety Science

Dear Dr. Boustras,

Uploaded onto the submission website is our manuscript titled "A Systems-Oriented Investigation of Written Procedures in Process Safety: Understanding Influences on Human Behavior." The research presented in this paper is original and has not been reported in a published article or contained in another paper that has been submitted or accepted for publication in print or electronic media.

The analysis work was conducted primarily at Texas A&M University, as part of the first author's PhD thesis work. I am the second author and his primary PhD advisor. The third and the fourth authors are from Environmental and Occupational Safety and Mary Kay O'Connor Process Safety Center (respectively) at Texas A&M University and were involved in supervision as well as the collection of data from nine sites. The PhD student was involved in all stages of the research: from idea generation and study design to data collection and analysis, and finally to reporting. Overall, all four authors meet the criteria for authorship and have approved the final article. Further, all those entitled to authorship are listed as authors.

The research was funded by an ExxonMobil, Chevron, ATR, Nova Chemicals and a contractor with NASA grant, as well as startup funds awarded to myself. The study sponsors were not involved in the conduct of this research. Further, none of us authors have conflicts of interest regarding this research.

While the manuscript is long, this is mostly due to inclusion of participant quotes which is essential to support our arguments. I strongly believe this large-scale study will be of interest to the Safety Science readership.

Thank you very much for your time and we look forward to hearing back from you.

Sincerely,

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A Systems-Oriented Investigation of Written Procedures in Process Safety: Understanding Influences on Human Behavior

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Keywords: process safety, procedures, oil and gas, interview analysis, grounded theory

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1.0 INTRODUCTION

Process industries such as Oil and Gas and petrochemical refineries are becoming more complex, a consequence of increasingly advanced technologies, organizational constructs, and business functions that interact and depend on one another so as to safely meet the demands of a dynamic world economy. Our abilities to understand the behavior of complex systems have been limited by a Newtonian-Cartesian worldview which relies on assumptions of linear cause-and-effect relationships (one way causality) and analyses emphasizing hunts for the single "root-cause" that is associated with the entire system malfunction (Dekker, 2016). Recent trends in systems-oriented problem solving Gharajedaghi, 2011) have sought to reframe inquiry into the behavior of complex systems by understanding that failure and disaster are, in truth, the result of many interdependent, context-specific variables. Historically, the

perception of such complexities and the struggle to minimize catastrophic failures within the petrochemical industry (e.g., Bhopal, India; Pasadena, Texas; BP Texas City, Texas) have been attributed to the inherent variability in people, leading to the development of internal control systems that document the tasks and processes associated with human work. These efforts manifest as written process information or "written procedures", designed for instilling consistency in tasks and operations, and to help workers at the "sharp-end" of the system cope with unexpected events.

Despite the suggested benefits, incident reports (Bullemer & Nimmo, 1994; Bullemer & Hajdukiewicz, 2004) continue to identify personnel non-conformance and deviation from written procedures as "root-causes" of incidents and near misses. While procedure deviations and safety violations in high-risk process industries have been studied (Alper & Karsh, 2009; Bullemer & Hajdukiewicz, 2004; Carim Jr. et al., 2016; Lawton, 1998; Mullen, 2004; Saurin & Gonzalez, 2013), few use a systems approach to investigate the factors that shape such operator behavior (Jamieson & Miller, 2000). Widespread investigation of systems factors that shape such behaviors at individual (e.g., cognitive), task, cultural, organizational, and environmental levels is necessary to unveil some of the systemic factors leading to issues related to procedure usage. To investigate this, a large-scale study involving nine oil & gas, petrochemical, and energy sites was conducted.

We previously documented industry-generic factors related to usage of procedures using the same interview dataset (Sasangohar et al., 2017). Procedures were reported to serve multiple purposes including training and general guidance for plant operations. Findings reaffirm previous research, suggesting the effectiveness of written procedures is limited by an abundance of outdated procedures and procedures plagued by information overload. Evidence suggests frustrations with handheld technology, reactive procedure change processes, users removed from the writing process, and a general lack of formal methods for updating the documents. Their perceived importance varied according to frequency of the task and the experience level of the participants. Other unintended consequences associated with written procedural systems ranged from complications in using the documents around personal protective equipment (PPE) requirements, harsh weather, and language barriers. These circumstances are only exacerbated as management imposes pressure to use procedures on personnel despite the issues encountered with the documents, severing communication between the emerging classes within their organizations.

Yet there is inherent variability in the way procedures are used that makes generalizable inference difficult. While the findings provide a basis for understanding the complexity in the overall industry, a multi-site systems-theoretic comparison and more detailed investigation of contextual factors was not reported. In this paper, we explore the effects of environmental, cultural, organizational, and task-related contextual factors that affect individual behavior in such industries using a systems-theoretic approach.

2.0 METHODS

Semi-structured interviews with operators were conducted at 9 different high-risk facilities, specifically refineries, up-stream drilling facilities (including an offshore drilling vessel), a power distribution plants, and chemical plants. A brief overview of characteristics including type, organizational units, units interviewed, information about site ownership, location and other significant characteristics are provided in Table 1 to provide context for the results. All facilities operate on a 24-hour cycle with staggered shifts, depending on roles, and are considered hazardous work environments requiring extensive safety procedures and appropriate PPE. Note that as a courtesy to the participating stakeholders, site names and locations will remain anonymous. Therefore, the sites will be referred to by site numbers. These interviews took place across 6 countries over 12 months to investigate the contextual variability between sites.

Table 1: Site Descriptions and Characteristics

Site	Type	Units	Ownership	Location	Other Characteristics
1	Refinery and chemical plant	Multiple units within both the refinery and the chemical plant. One of these units had 4 distinct posts (A, B, C, D). For all of the units, the control room was in communication with all posts	Large Oil and Gas Corporation (Company 1; same as Site 2)	United States	- Located in region with temperate climate-mild winters and hot, rainy summers
2	Refinery and Chemical plant	Multiple units within both the refinery and the chemical plant	Large Oil and Gas Corporation (Company 1; same as Site 1)	United Kingdom	- Facility over 50 years old - Located in a region with cold winters and mild summers
3	Refinery	Separated into North and South Zones, with different plants and units within each zone	Large energy corporation (Company 2; same as Sites 4,5 & 6)	South Africa	- Climate include mild winters and warm summers

4	Very large refinery	Multiple units in an older refining facility.	Large energy corporation (Company 2; same as Sites 3,5 & 6)	United States	- Located in region with temperate climate-mild winters and hot, rainy summers
5	Very large, onshore, drilling facility	Maintenance, pipelines, and residential furnace facility were focus of interviews. Large facility both in terms of geography and facilities	Large energy corporation (Company 2; same as Sites 3,4,&6)	Northwest Asia	- International site, with non-english as primary language, (interviews interpreted) - Extreme climate--very cold winters and very hot, dry summers
6	Onshore support for offshore drilling Elements	Maintenance, repair, and supply boat servicing	Large energy corporation (Company 2; same as Sites 3,4 & 5)	East Asia	- International site, with non-English as primary language, (interviews interpreted)
7	Chemical Plant	Multiple units within facility, operating as separate entities (2 polyethylene, 3 ethylene)	Moderate size chemical corporation (Company 3)	Canada	- Located in a region with very cold winters and mild summers
8	Electrical utility company and power distribution center	Includes substations and pump houses	Large energy company (Company 4)	United States	- Complete procedures are kept in common areas and control rooms - Climate can include cold winters and relatively hot summers
9	Offshore drilling vessel		Large transport and energy corporation (Company 5)	Gulf of Mexico	- Intense and fast-paced environment - Personnel spread between drilling floor and offices on the deck - Drilling continues despite effects of wind and rain

2.1 Data Collection

2.1.1 Participants

Seventy-two participants (Age M = 36.7, SD = 10.4) were recruited for on-site semi-structured interviews using a convenient sample facilitated by the site management. Average number of participants per facility was 8.1 (SD = 3.2). Participants' years of experience in the industry ranged from 1.5 to 40 with an average of 10.7 (SD = 9.3).

2.1.2 Instrument

A semi-structured interview guide was used that included questions to understand day-to-day procedures and workers' experiences with procedure usage; worker's perception of what procedures and other supplemental material meant in different contexts, general effectiveness and opportunities to improve procedures, as well as general challenges faced by workers with regards to procedures

2.1.3 Protocol

Five interviewer (faculty members and graduate students at a large research-intensive university) trained on qualitative data collection interviewed the participants at different sites. The interviewers started by asking the participants to sign an informed consent form. Participants were then observed while conducting a few daily tasks. Next, an interview was conducted in a private area using an interview guide and lasted about 1-2 hours. Interviews were recorded for further analysis.

2.2 Analysis Using Grounded Theory

The wealth of unstructured interview data provided an opportunity for analysis in grounded theory. Pioneers in qualitative research, namely Strauss and Corbin, have developed prominent methodologies that tackle the overwhelming complexity presented by such qualitative data sets (Corbin, & Strauss, 2014). These methodologies, which provided the basis of this research project's analysis technique, present analysis as a progression of coding stages. Our first inquiry (Sasangohar et al., 2017) mostly reported general findings from the first of three iterative phases: 1) Initial Coding 2) Focused Coding and 3) Theoretical Coding. This paper builds upon previous work by reporting a second cycle coding method combining the latter two stages into the so-called pattern coding (Miles & Huberman, 1994; Saldana, 2015), which groups codes from the initial cycle into more focused themes or constructs. This was enabled via a thorough note-taking function of a qualitative data analysis tool (MAX-QDA 12) and through the lens of systems framework consisting of five layers of systems considerations; personal, task, cultural, organizational, and environmental. This process is elaborated below.

2.2.1 Coding via MAX-QDA 12

Three transcripts from each interview site were initially read and coded. The term "coding" here refers to the process of categorizing and systematizing responses to interview questions as well as the surrounding tangential conversation. The qualitative data analysis software, MAX-QDA 12, was selected to facilitate this process. Its coding functions encouraged the identification of patterns and relationships among these categories. The initial coding phase emphasized the creation of many novel, descriptive impressions, therefore codes (Bryman, 2015).

Initial coding efforts also emphasized understanding the extent to which code categories could be generalized across sites. See Sasangohar et al. (2017) for a detailed report of the generalized findings of this stage.

2.2.2 Pattern Coding

The remaining interviews were read and coded site-by-site, emphasizing the emergence of sub-codes, or focused, context-specific topics (patterns) following the initial coding phase of grounded theory. The analysis of data and logging of observations proceeded with the implicit understanding of "human error", and more broadly, behavior in socio-technical systems as the result of interactions between people, their tools, tasks, and environment. The view is consistent with contemporary literature regarding the nature of "human error" in complex systems (Dekker, 2014; Vicente, 2010). Therefore, the data was recorded and framed using different layers of contextual considerations (Figure 1) which offers a model for representing the complexity surrounding the "effective use" of written process safety information. While traditionally the focus has been the technical consideration as comprising the entire system, the systems framework adopted from Vicente (2006) uses a broader lens by further exploring environmental, organizational, cultural, task-related and personal factors and interactions between them. These factors are often referred to as "constraints" that limit or influence human action in systems literature (Churchman, 1979; Johnson, 2003). Table 2 elaborates upon these systems layers that provides the framing for this study.

Figure 1: The "effective use" of written process safety information can be understood through the interactions amongst environmental, cultural, organizational, task, and personal considerations.

Table 2: Descriptions of System Layers

System Layer	Description	Contextual Variables
Personal Considerations	Considerations unique to each participant, capturing differences in attitudes reflective of demographic information such as participant roles / job responsibilities, and years of experience	• Roles and Job Titles • Experience Considerations • Mentorship
Task Considerations	Elements surrounding the specific tasks, operations or job described by the procedure; these include prerequisites for some tasks (such as hot work permits), tools necessary to perform tasks, and reflecting equipment updates with their associated procedures.	• Variety of Artifacts • Equipment Mismatch • Unit/Zone Rotations
Organizational Considerations	Behavior resulting from explicit and implicit relationships between personnel regarding tasks and work; For example, the relationship between upper management (including supervisors) and operators develops as an important pathway in for reporting errors, recommending improvements, and resolving uncertainties when deviating from procedures.	• Document Management Systems • Team Interactions • Sign-Off Process • Shipping and Vessel Considerations • Collaborative Tasks
Cultural Considerations	The multinational presence of most investigated companies presents additional layer of complexity pertaining to cultural variability. This includes issues such as language barriers, which were observed in sites outside of the US using English procedure and job safety analyses (JSAs), as two examples; Cultural considerations also extend to the effects of organizational cultures, such as punitive and fear cultures.	• Language Barriers • Culture of Blame
Environmental Considerations	Elements associated with the surroundings and infrastructure, which vary between chemical refineries, power distribution plants, onshore-offshore combinations, or offshore drilling vessels in international waters. While some of these considerations may be related to regulations, political climate, and economical challenges, this layer of the systems hierarchy usually describes the physical environment (e.g., climate, extreme weather, and Personal Protective Equipment (PPE) requirements).	• Effects of Weather

Pattern coding revealed a set of context-specific variables. These represent alternative interpretations of the interview responses in alignment with the systems framework (Fig 1). For example, using the personal attribute "Experience" as variable revealed differences in perceived importance of procedures between more and less experienced personnel within the same site (Sasangohar et al., 2017). Using this framework, the qualitative data can be cross-examined to reveal complex relationships between several variables and their outcomes, such as how these attitudes associated with experience level, coupled with a punitive work culture, mark an organizational division between management and workers, perpetuating a loss of valuable undocumented knowledge, should sites lack a formal procedure update process (Sasangohar et al., 2017).

3.0 RESULTS AND DISCUSSION

3.1 Personal Considerations

While it is impossible to capture all individual attributes, variability and its potential effects on behavior need to be explored to better understand and predict behavior with procedures. In this paper, we discuss three such variables:

participants' years of experience with the current employer, years of total industry experience, as well as the role of mentorship. These variables had independent effects on individual behavior and were interrelated as well. To discuss personal considerations, we will first refer to several main roles typically assumed in the industries under investigation as described below. Then we will describe the interrelation between the roles and other personal variables.

3.1.1 Overview of Roles

Console Operators: These participants communicate and receive the status of plant operations via interactions with field personnel, such as communicating with field operators during sample collection. These personnel are often more experienced than field operators and, while monitoring conditions at the control system (console), typically demonstrate greater situational awareness than other roles. They assist in startups and shutdowns, monitor operating conditions, stacks, and instrumentation (sometimes for multiple units) and relay this info to a shift supervisor. They serve as crucial communication pathways to accomplish work.

Field Operators: Outside operators, or field operators, are tasked with completing work in the plant environment, and are typically what one thinks of when considering the user of a process document (or procedure). These personnel are usually tasked with general tasks such as sample collection and preventative maintenance in their daily work. These personnel are often asked to help in the control room under the supervision of console operator.

Specialized Roles: Personnel in these roles have specific duties. These include trainers, blending/shipping operator, boiler house operator, engine room operator, etc.

Contractors: Personnel hired from contractor companies such as crane operators bring their own procedures/manuals for their specialized equipment and may have different understanding of roles.

3.1.2 Experience Considerations

The younger, less experienced generation of personnel have been observed to rely on procedures a great deal more than those participants with more experience. Less experienced participants reported relying on procedures as a source of training and guidance until a perceived competency is gained. They have expressed desire for more information in procedures and have been observed to ask more experienced personnel for guidance.

"*We have a lot of new people. We have a lot of people in that five to ten-year range who think probably like myself – we'll revert back to them when needed. You got some guys with 15 plus years that probably only have them on it as [insurance] in case something happens.*" -Site 1

"*Some of the older people have been around have done the "yeah you don't need that" while for some of the newer guys "it doesn't have enough detail, I need more detail." Everybody does take procedure with them. It's a guideline and the company does recommend you having it with you because it is to cover you if something happens.*" - Site 7

The older, more experienced generation of personnel has reported relying on procedures significantly less. They attribute safe, successful operations as a result of experience and training, emphasizing the importance of being knowledgeable and competent. Attitudes towards technology and management are somewhat negative, often a result of the division in organizational structure from the punitive systems in place. Thus, in addition to obstacles previously identified in Sasangohar et al. (2017) such as lacking formal update processes and users being removed from writing procedures, this can prevent a transfer of more experienced personnel's expansive, valuable knowledge base.

"***There is a lot of that culture in the generation that comes before me, that body of knowledge is what…****makes us* ***good at running the plant, and if we give that away, management can fulfill their dream of 'you're just a highly-paid monkey', that's actually been said in the control room "a trained monkey could do your job"****. So, when management has that attitude, you create this operator culture where you protect that knowledge as secret knowledge because no one else could do your job. It's going away, because management for now for the last 10 years has been a lot more open.* ***For my generation - I would rather have as much in procedures as possible*** *because I feel our generation, we've now been here long enough that we are taking over the reins of this plant and feeling the pressure and weight of that responsibility because things can go really bad and people can be killed if you don't respond properly****. So how do we take all this knowledge that we're learning from the older generation, that mystery body of knowledge and how do we keep it in our head in a short amount of time****. So I would say that we lean towards getting it documented. But the obstacle would be, that it's very cumbersome to get it documented and to make it accurate and up-to-date, so it's*

there but it's awkward to get in the system. So, there is that old culture, 'between me and you this is how it works', 'between you and me this is what you need to know' - because there is that attitude of job protection. I'm trying to just sap all that information out of them, and then keep it somewhere if it in my cheat sheet or somewhere, I just need to fit it in my head in four years of time." -Site 7

"*It really depends on if it was a procedure out of the [manufacturer's] manual or a procedure written on a rig by experienced personnel who actually changed that part.* ***You have more detail in like a manual from the actual manufacturer than you would from that experienced operator doing the job.*** *'Cause he's gonna give vague details. He's gonna tell you the suction cap. He's not gonna give you all this side looks like this looks like that. He's already gonna know where it is.* ***Like I said, we're experienced and trained and we know how to do the job. Checking the process checklist and whatever is not as important to us as it is to somebody that's never done it***." -Site 9

3.1.3 Mentorships

Majority of operators have insisted on experience and training as the greatest indicator of one's competency in completing safe work, in addition to relying on a procedure. Many of the participants have commented on an informal interaction with more experienced personnel as a means for learning and overcoming flaws in procedures (where experienced personnel have identified superior ways to complete tasks).

"*If you have an obstacle at a specific task,* ***I would first get someone to be on with you that job****, and then from there on, yeah. And then procedure-wise, you're gonna refer to your procedure,* ***but I will get a more experienced guy with them****. Just check with me. I will explain to you this is my understanding. You will say this is actually what you have to do, and then I can refer to your procedure, so that's gonna be a specific detail on the procedure.*" - Site 3

"Well-trained people and procedures go hand in hand with each other, you know what I'm saying? Because it teaches the upcoming younger guys how to learn and how to go about these guidelines and how to work safely. ***But if you have good teachers, good trained people to teach the newer guys, you're setting up success.*****"** - Site 9

"***Especially, being newer, these guys with experience, we do procedures reviews on crew,*** *so if any changes need to be made to the procedure, it helps me on the steps I'm not familiar with or* ***something that's not in the procedure that's a little bit different that over the years they've learned a different way to do it*** *and they've gotten really good at updating procedures.*" -Site 4

3.1.4 Summary of Personal Considerations

The variables identified for personnel considerations illustrate several things: Newer workers are relying on both procedures and mentorship to gain the knowledge necessary to do their jobs effectively and safely. More experienced workers see procedures as a tool for sharing their knowledge with future generations and an important augment for effective training--and should not be considered a substitute for training. Framing the data from this perspective captures differences in attitudes between generations of experienced and inexperienced participants and the effects on their use of (and need for) procedures.

3.2 Task Factors

To explore the effects of task factors on procedure use, variables were identified in the interviews that were associated with the actual tasks the workers were doing, the tools they used to perform the tasks, how frequently they performed the tasks and so on. Through understanding the workers' experience with the tasks, a more thorough understanding of variability in use and adherence with procedures may be clearer.

3.2.1 Variety of Documents/Artifacts

As has been mentioned previously, procedures have been implemented into operations in high-risk industries to promote safety through establishing procedural guidelines. Despite the wide range of tasks with varying risk levels, the term "procedures" is often used as a catch-all for many different types of process document. This investigation reveals attempts to conform to regulatory requirements (e.g., OSHA) results in the generation of a variety of types of documents, and those referred to as "procedures" can differ remarkably based on the company or industry. For instance, in one of the refineries, a procedure was a step by step document that required sign off on every step and was used for higher risk, complex tasks. In contrast, in the power distribution facility, a procedure referred to a document that was more of a work order and gave the worker his or her assigned task for the day. It is for this reason that a more accurate way to refer to these could be "artifacts", or written process information. Further, many of these documents play different roles in the day-to-day operations of the unit, e.g., JSAs are for reviewing the safety of the environment and are done with the work group at the beginning of every major task.

Written process information lacks standardization, demonstrated by the use of different terms to refer to documents with similar purposes (See "procedure" vs "JSA" in Table 3). It is difficult to know the level of standardization that would be good for written process information given the variability in task types, environments, and risk levels between sites and across industries. Indeed, the different types of documents used to support daily work could be an indicator of sites looking to adjust the type of support workers get based on attributes of the task. For instance, at Site 4, tasks done more frequently had a Job Aid that workers could refer to if they felt they needed the support but were not required to have in hand. At this same site, tasks that were more complex and done less frequently were associated with procedures that required initialing at each step and must be "in-hand" during the performance of the procedure.

As shown in Table 3, the number of documents workers have to complete to do their jobs can be onerous and sometimes the content of these redundant. This could lead to workers not attending to all of them with the needed level of attention merely due to the number of them. In addition, some artifacts are not reported at all sites even between sites owned by the same company (e.g., Sites 1 & 2 or 3, 4, 5 & 6). However, the interviews were focused on attributes of procedures and their use. Since we did not specifically ask about all of the artifacts workers used, it is likely that some artifacts used in each site were not reported. While the results of the qualitative data analysis has not provided a collectively exhaustive list of these artifacts, documents mentioned during the interviews are presented in Table 3 and are described below.

Table 3: Overview of Documents/Artifacts used by interviewees

Site 1	1. Job Loss Analysis (JLA) 2. "Regular" Procedures 3. Standards 4. Checklists 5. Safety critical or "In-hand" 6. On-Point Lesson Plan 7. Work Permit 8. Troubleshooting guides	Site 6	1. JSA 2. Hazard Wheel 3. Human Performance Checklist 4. Procedure Board 5. QAQC Documents 6. Permit Request 7. Pre-Use Checklist
Site 2	1. Operations Manual 2. Job Safety Analysis (JSA) 3. "Safety-Critical" Procedures 4. Logbook (Checklist for "structured rounds") 5. Safety Critical Task Analysis (SCTA)	Site 7	1. "Review" Procedures 2. "In- hand" Procedures 3. Joeffery Safe Work Practices (JSWP) 4. "Life-critical" procedures 5. Emergency Procedures 6. Work Permit 7. What - If Cards 8. Checklists
Site 3	1. JLA 2. Loss Prevention Self-Assessment (LPSA) 3. LPO (Loss Prevention Observation)	Site 8	1. Field Procedure 2. Job Briefing Sheet 3. Prints

	4. Handheld 5. Field Guides 6. Risk Matrix		4. Corporate Safety Instructions 5. Manufacturing Manuals 6. Checklists 7. Work Permits 8. Legal Documents
Site 4	1. JLA 2. Procedure 3. Job Aid 4. Handheld 4. Checklist 5. Safety Critical 6. Alarm Checklist 7. Layers of Protection Analysis (LOPAS)	Site 9	1. JSA 2. Safe Job Analysis 3. Process Instructions, PINS 4. Individual Risk Assessments 5. Checklists (operational checklists; process checklists) 6. Manuals (Dynamic Positioning; Mode of Operations; ~30 others) 7. Work Permits (e.g.,"Hot Work" Permit) 8. SIRIUS Work Instructions 9. Isolations Procedures 10. Bridging Documents
Site 5	1. JLA 2. Printed Procedures 3. Work Order 4. Work Permit 5. Manuals		

Job Safety Analysis (JSA)

JSAs are reported in sites 2, 6, and 9. Sites have reported that these documents are used in combination with some main operating procedure to evaluate safe work, with the shipping vessel (Site 9) adding that use surrounding them has moved out of the information management database and into handwritten format. Furthermore, Site 9 expressed frustrations at a lack of training around how these JSAs are written. Meanwhile, participants in Site 6 commented that JSAs are the primary document used, where supervisors lead team reviews of these documents to overcome language barriers. Overall, the reported role of JSAs illustrates the overlapping purposes of JSAs and procedures. For those sites expecting workers to use both, this duplication of effort may be counterproductive as it may result in the worker getting information from one instead of the other.

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*"**Well, I don't know if you actually call 'em procedures**, but they have. We used to have a database of what they call JSAs, which now we went with the handwritten JSAs. That's basically your job steps. With the addition of your job steps, they also have your hazards involved. **Yeah, there's different forms, but they all tell you relatively the same thing, you know?**"* -Site 9

"Yeah, I mean, you're already training for every freaking thing out here. Car, helicopters, what to wear, PPE, alarms, everything. Why not how to write a JSA, how to write a stop card. Why not incorporate that into the new guy training? I don't know if you want to call it new guy training or whatever, but orientation. That way, I just think it's a good idea. Something that they're eventually gonna see, you might as well train 'em on it, you know? Instead of just throwing them to the wolves." -Site 9

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Job Loss Analysis (JLA)

Job Loss Analyses (often considered synonymous with JSA) have been reported at sites 1, 3, 4, and 6. These are mentioned as means to understand risks and hazards, including information about past incidents related to the task at hand. They are sometimes discussed as alternatives to or used in combination with "procedures", and in some instances, these JLAs are *converted* into procedures.

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"What's different about the JLAs to a regular work procedure is that the information in there sometimes references things that did happen, like actual events that did occur that will kind of give you an idea of this is true fact, if you don't follow this, this could potentially happen. I like that information being in there because, like I said, it's "true fact" information. These are things that have happened because maybe someone didn't follow that step within that procedure." -Site 1

"So after the work has been dished out for the day, ***then after that meeting you have the opportunity to go in there and print out your procedure or combine the JLA. That's when you print or combine, after the work is dished out in the meeting."*** -Site 3

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Work Permit

Work permits are reported in Sites 5, 6, 7, 8, and 9. Work permits are authorizations from a supervisor for some work to be done, and in the case of hot work permits, they document OSHA fire protection and prevention requirements (OSHA, 2000).

Job Aid

Job Aids were reported at Sites 3 and 4. They are associated with routine, frequent tasks, and are reported to serve as a training tool for new people and refreshers for more experienced people. It seems that very similar types of information is present both on the procedure and job aid, one difference being that "procedures" are strictly enforced with signatures required while job aids allow for deviation and signatures are optional.

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"It's similar but different. Procedures tell you what you have to do. For a ***procedure****, you have to* ***jot down the date, the time you did it, put your code by it, and say "I did this".*** *Job aid, just telling you the steps* ***but you don't have to sign anything****."* -Site 4

*"****Job aids are more specific for routine tasks.*** *Not every time is that routine task going to be the same. Plant may be in a different posture. For ex, changing air filters- didn't follow all the way because there was still life left in that filter. Sometimes you can skip over some steps in the job aids."* - Site 4

Checklists

Checklists were reported at eight sites. Some sites use paper checklists while others have integrated task checklists into handheld devices (Sites 1, 3, and 4). Sentiments around these checklists vary--for some, the simplified document offers a superior alternative for verifying work accomplished, while others (i.e., those using checklists through the hand-held devices) have reported abuse of checklists, e.g., introducing a new checklist after an incident as a resolution of the incident, instead of identifying the root cause of the incident itself.

*"**We really don't use procedures as often as the checklists, and they start throwing the checklists at us as a way of mitigating a lot of things.** When something fails, then that is added to the checklist for every checklist in that unit (example of a pump failing- first time pump fails)."* -Site 4

"[It is important to know what you're doing and why] ...Especially like for the checklist. We'll have a meeting with everybody that's going to be involved with that procedure. We go over why it's a checklist procedure. Those are highlighted. And then we just go over the procedure – what we're doing, why we're doing it. Try to get everybody up to speed. Like I say, so far it's worked out pretty good since we've went over to that system." -Site 1

Overall, enforcing a variety of documents has resulted in confusion over what constitutes a "procedure" as well as their differing purposes and adoption in different situations for different types of tasks. In most cases these artifacts were perceived to be a type of procedure and there was no consensus among participants as to making clear distinctions between these documents.

"*Generally, people are very political about using procedures, **but the enforcement of procedures has just made people seem a bit confused and I think that has resulted into a bit of negativity.** You know? People do these procedures most of the time**, but when I mean, the guys who work on the field ask management, when is it necessary to use a procedure and when is it not necessary?** […] That doesn't cut into now and then every policy, there's no negative about the procedure usage, but everybody's out there that it does help because it does give a clear guide of how the job should be done.*" -Site 5

*"**This is the new nomenclature that is being pushed by OSHA.** I have no control about the JLAs. Probably need to talk about **operating procedures, and job aids.** The **job aids are designed as a training tool for new people**. The **procedures are more of a required document t**hat has to be signed and often turned in. They use procedures when they have a procedure for the task. I'm not gonna say they do it all the time*

because I've audited some of our startups and shutdowns and they may have used the procedures but they didn't turn it in, so I can't count it as they used one. But the procedures…they use them when they have a procedure. That's what they do. ***They don't use job aids every time they get a new job. They're just pretty much routine.*** *So if you look at* ***OSHA 1910.119 process safety management, procedures are required for startup, shutdowns, normal operation, emergency operations, abnormal situations; and job aids are considered part of volume four, which I still believe is training and they're managed differently than procedures****."* -Site 6

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3.2.2 Equipment Mismatch

The symptoms of outdated procedures manifest in a mismatch between the documents and the equipment for which they are designed. Over time, management replaces and updates equipment, and yet often little emphasis is placed on reevaluating the relevance of their respective documents. In fact, these older documents are observed in Site 8 to be used for new equipment. Operators also expressed frustration over inappropriate duplication of procedures for different tasks.

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"***We have some procedures that still relate that how the unit was set up in 1992. some of the equipment is not even there. Some of the stuff is not even there that is used [in the procedures] now****. Much work needs to be done.*" -Site 8

"***[Procedures] need to specify for each equipment****. Some of the procedures that they have sent out will be breaker and ground to test. I don't like that.* ***I think that's an accident waiting to happen. If they are going to give me a procedure, make sure that it's only for that equipment. Do not amend the procedure by saying also ground and test breaker. No. So now you get a procedure that's ground and test. I'm confused. I know it's a breaker. But why would you put that on there? Eliminate that. Make it but that piece of equipment is breaker only. The feeder breaker process, whatever you want to do. Do not amend and put two pieces of equipment on the same procedure****."* -Site 8

"*We're not really allowed to touch anything without a procedure. But often, procedure on the new equipment we'll try to find something similar from the older parts. And actually, carry over.* ***Like we have breakers that were from the 70's, and they were retro-fitted 15 years ago. So they have the spec and more reliable, but there's still some of the stuff from the old 1970's procedure that doesn't apply anymore because that equipment is gone.*** *So, you have to kind of pick and choose what you're actually going to do.*" -Site 8

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3.2.3 Unit/Zone Rotations

Process industry sites are often divided into many units or "zones" within the larger site. Rotations refers to the tendency of personnel in these locations to do work in different units and were reported in 8 sites. Procedures are

different depending on the surroundings in each unit, offering a means for combatting the complacency associated with repetitive use by providing new tasks and environments within the same site. This requires that operators re-train, and reinvigorates the importance of an operating procedure. However, such benefits are lost in environments where rotations are rare. On the other hand, the hectic nature of plant operations can confront operators with a rotation before reaching competency to work with the new post.

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"*[S1 with 4 zones] If you have some new hires out here and they're only trained on A and B post, or D post, however it shapes out, there may be times when you work C post three or four sets in a row, just for whatever reason. If you do that and if we're having an upset, then you're back watching one to two times a day, three or four weeks you get pretty proficient with the task. The same way, that's true of every post out here.* ***Stuff lines up where you don't always rotate posts like you're supposed to. People aren't qualified depending on the manpower.*** *You may be stuck on something, so you may have seen this three, four, five times in a row – it's the third time it's come up – I haven't seen it off because I haven't rotated.*" -Site 1

"*I think in rotation much more time to write a procedure for station-specific procedures would be smart, because they do change based on their surroundings in the station.*" -Site 8

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3.2.4 Summary of Task Considerations

In summary, procedures are used for a variety of plant operations, and not all of the procedures are perceived with equal importance. Participants prefer procedures for tasks associated with complex equipment (such as complex pumps at Site 5) and that occur infrequently while emphasizing their competency in handling routine tasks (e.g., introducing additives, draining pumps at Site 4) without dependence on procedures. The variability in attitudes toward the effectiveness of procedures seems to be a result of the myriad of tasks, reflected in a wide variety of "procedures" for different kinds of work, occasional outdated procedures (e.g. mismatch between procedures and equipment), and occasional role or zone rotations.

3.3 Organizational Factors

While a detailed discussion of organizational values, culture, and management styles is out of the scope of this paper, we reviewed the interviews to identify variables that highlight how organizational variabilities can impact process safety and procedure use. Given the complex, socio-technical nature of process industries, these variables

have a high level of impact that sometimes are not as obvious as personal or task related variables. Here we discuss variability in procedure storage and management systems, specific team interactions, the procedure sign-off and approval issues, and collaboration support.

3.3.1 Accessing Information / Document Management Systems

Companies vary in the amount and type of technological artifacts used to store, maintain, and access procedures such as information management databases and handheld devices. While management databases do offer means to handle the ever-changing updates to documents, their effective implementation demands that all personnel have access, and the degree of control over this access be well-defined and communicated. Indeed, complaints surfacing about handheld task overload and a lack of agency in accessing procedures without the supervisor sign-off reported in two distinct sites (Site 3 & Site 4), demonstrate the need to reconsider how people interact with technology when determining its effectiveness in mitigating risks and hazards. An overview of these systems is presented in the Table 4.

As Table 4 demonstrates, there is a high degree of variability in the technology implemented within each company and across all sites. Sentiments around the use of these systems is highly variable. Reports at one of the sites (S3) suggest success with CDMS which communicates procedure status as cancelled, under review, or active. However, the evidence regarding the perceived effectiveness of other systems was not clear. An immediate danger imposed by such variability is the possibility of negative transfer for personnel who switch companies. In fact, the volatile nature of jobs in this industry increases the chance of such company switches in which case the experience and familiarity with old systems may interfere with the training and adoption of new systems. Such negative transfer has been linked to degradation in performance in complex problem-solving tasks (Woltz, Gardner, & Bell, 2000).

Special note should also be paid to the high degree of variability in the method of access. Although the information databases, hosted online, serve as the central location for maintaining, documenting, and accessing procedures, there can be additional steps between these written procedures and access by their users (i.e., process operators). Such obstacles include supervisors that print the documents and pass them along to employees, procedure boards that host the documents during safety review meetings, or physical locations that operators must travel to for their paper counterparts. Physical copies can be favorable because they allow operators access to changes that have yet to be

reflected in the central databases (Site 1). From this holistic view, it becomes apparent how management databases can facilitate operations (Site 9) or hinder operations (Site 1), depending on the effort aimed at maintaining the documents after changes are reported. Furthermore, procedure binders have been observed to host personal notes for operators, or emergency procedures near the console as observed in Site 4, where the binder does not facilitate the quick-thinking needed to act in emergency situations.

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"... the computer might not be updated, which is a description. Our main copies are hard copies. ...So see there's a gap... It's really a final copy, but once it gets authorized for years, we put it – becomes a part of the procedure even though that would be take up to six months to make it finalized... So when I update that, then the computers update it. And so all the systems are gapped, the hard copy is the master copy... ***So you got to be real careful, because it makes more sense just to turn off the computer and everybody use the same copy****."* -Site 1

"...So after the work has been dished out for the day, then after that meeting you have the opportunity to go in there and print out your procedure or combine the JLA. That's when you print or combine, after the work is dished out in the meeting." -Site 3

"Yes, on the display, and you send somebody outside to make sure what's coming in on the console is a true reading or an actual problem. And a lot of times, we have our emergency procedures on the counter in a binder, but when these things happen so fast, you stay () the unit, click it again, and then you'll get the procedure, go through it again and make sure you didn't miss anything. Sometimes one of the outside guys says to print them a particular procedure, and HO will print it, but sometimes you have to get everything - ***Sometimes it all happens so fast you just get so focused on it. You get everything stabilized and then get the procedure and make sure you didn't miss anything****."* -Site 4

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Table 4: Overview Methods of Procedure Access

Site	Method of Access
Site 1	- Printing (prints often not updated) from online service - Paper copies stored at Console
Site 2	- Via Computer (previously paper manuals) - LAN System
Site 3	- Handheld - Printing from computer, hosted at online database - Stored at console
Site 4	- Handheld - Printing from computer, hosted at online database - Emergency procedures kept in binders near console
Site 5	- Print, but not typical - Foreman provides hard copy - PC laptop - Work request system (GDE-1)

Site 6	- Paper (provided by foreman) - Information pulled from procedure board
Site 7	- Console Access - Personal Binders / Notes - Computer, hard copies as backups (stored at location) - Some participants pull paper copies or keep personal binders
Site 8	- Printing from computer, hosted at online database - Sometimes obtained through supervisor
Site 9	- Printed from online resource (SIRIUS) - Obtained through supervisor (printed from SIRIUS) - Binders (for emergency responses,

3.3.2 Team Communications

Process industries are highly collaborative where operations rely on team interaction. Evidence from the interviews shows that in at least one site (Site 5) procedures are sometimes reviewed in a team setting to improve level-setting and shared awareness. The importance of teams is particularly evident for communications between onshore and offshore personnel (see the discussion of shipping and vessel considerations below) and field and control room personnel. It is important to understand organizational and cultural norms related to team interactions to uncover the negative effects on individual procedure usage.

Console and Field operators

Console and field operators are observed interacting via radio communications to carry out operations and communicate process information in a number of sites. Their relationship is noteworthy because it serves as an example of how team communication contributes to safe work. It also suggests an important information pathway for the status of the plant, as well as addressing uncertainty when personnel's judgement indicates a need to deviate. An example of this will be noted in environmental considerations in terms of overcoming the effects of rain and weather. Console operators at some sites claimed responsibility for communicating the need for emergency dumps, cessation of all fires, and the shutdowns of all pumps in the case of screen blackouts, where the console operator loses view on the console.

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"They might do four or five steps and sign them off for like the updates to the main procedure as the console, so they can check the instructions out there. ***So the main copy stays with the console. And they don't have it with them, but they are working together, you say I'm on step 3.7. That console follows along with them and checks it all.*** *It won't really do anything. You might put a dot or something. That's what I do is put*

a dot, build the next line and here is my procedure, I initial it, but the master copy stays in the console, so it don't get past the weather at all." - Site 1

"The least I'll do is communicate with the console. It's routine. [name of mentor] was my first trainer, and what he told us when we got here was, "Always communicate with the console. Pretty much, no matter what, let him know what you're doing." -Site 3

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Communication Across Shifts

The continuous nature of operations in process industries requires the exchange of information between incoming and outgoing personnel. While the interview questions did not include handover, evidence in at least one site reflects the perceived importance of synchronizing and communicating procedure updates across shifts.

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"*It's good cause here we work shifts, so if I pick up something important, it must be shared, like the communication to the other shifts because if they don't communicate maybe they can cause an incident about the thing that you could have written down but you don't tell them. So in order for us to avoid those things, we need to share.*" - Site 3

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3.3.3 Shipping and Vessel Considerations

Two of the nine sites that included offshore vessels exhibited issues related to shipping or vessel transactions between the onshore and offshore locations. Investigation of shipping and communication between onshore and offshore locations (one receiving and sending ships) highlights issues with written documents such as procedure outlines sometimes matching only the arriving vessel. In addition, while procedures have been reported to assist in this environment where roles may change frequently, operators described conflicting mandates from different entities such as the company, flag state requirements, and those from the American Bureau of Shipping (ABS).

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*"You have… bridging documents which is **[Company] and the client**. They talk and create their own hybridization. Then you have **flag state requirements**, which this vessel has a Singapore flag with Singapore rules. We're also classified by the **American Bureau of Shipping**, ABS, we have to follow their rules. It's a lot of things if you have to be up to date on. But usually, the rule of thumb is **three different organizations are getting their input on one rule…**"* -Site 9

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3.3.4 Sign-off Process

There are multiple types and levels of sign-off requirements associated with procedures. One is the conditional requirement for collecting signatures in order to begin, complete, or deviate from work, and this created an interesting relationship between supervisors and those completing tasks. Procedures with higher importance (such as "safety critical" procedures) are often required to have supervisor sign-off as a measure of preventing mistakes. When effectively implemented, the system has been seen to address changes to incorrect documents before work can continue, integrating a means of re-evaluating procedure correctness into regular work.

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"Whenever I would come across a procedure that maybe wasn't written as it should have been. Questioning it. That's when you stop and you get your supervisor on board – hey, this is what this is saying, this isn't quite how it's supposed to be, or that's not the best route. ***Then we stop, we make the changes. Then there're signatures that need to happen and people that need to know about that. Then you can continue on."*** -Site 1

"Every time they would take in so they've signed off in this notebook to confirm their acquaintance with the current actionable procedure. If any changes have been made to any of the procedures; so apparently, they are dated by someone; and they sign off to acknowledge that they're aware of the changes and the current updated list of the procedures." -Site 5

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Another type of sign-off occurs when workers are required to initial (and sometimes date) each step as they perform them. In some of these cases, requiring signatures frustrates workers, particularly if using procedure is deemed not helpful for some routine tasks. These frustrations also play into redundant signatures that are occasionally required of the operators themselves. Behavior around this process has evolved to cope with these frustrations.

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"I usually sign them off as I'm printing them, but I know that's not 100% correct, you're supposed to sign them off while performing the task. *But for routine tasks, I would usually just print and sign it there and then and put it in my pocket. If it's a new task which I'm unfamiliar with, obviously, the search you've done to use a procedure is the first thing."* -Site 3

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Indeed, when ineffectively implemented, this system of gathering signatures has inhibited work, demonstrated in the following quote regarding outdated equipment.

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*"Things will get added, but things will not be taken off that are no longer adequate. For example, we'll have checklists pop up for pieces of equipment that haven't been in service for 10 years. And trying to get things removed like that is very difficult**. It takes so much signatures to prove that this piece of equipment hasn't been used in 15 years, but they'll throw 13 other new checklists in before they find out there is nothing in place to help check that.**"* -Site 4

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3.3.5 Collaborative Tasks

Organizational and task considerations overlap when considering those tasks that require multiple people for work. The roles of procedures change in these more complex situations as they (ideally) synchronize the roles and responsibilities of each person, resulting in improved coordination. In such collaborative tasks, the procedures act as a pre-work safety meeting that facilitates planning.

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***"**Even before we do it we will sit down and have a thirty-minute conversation or this is your role, this is your role, this is your role. And then once everybody gets to their station and by-passes their valve, and I'm going to walk around and say, and I'm going to make sure he's standing by the right equipment according to the procedure. And it's very important to have that procedure, especially something that complex. You know?"* -Site 1

*"He said the JSA is like a routine for his team so no additional – but he repeats that sometimes – **especially for the non-routine risks it's a big deal for the team to prepare together and prepare the documents.**"* -Site 6

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Working with multiple people and communicating more openly among each other has instilled a sense of safer, smoother operations among some personnel. This however may result in a "group think" phenomena where potential unsafe acts may be perceived as normal and routine.

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"talking with my teammates and guys that have done that task before, that's what really makes me comfortable with [the task]" -Site 7

*"I work with the same two guys all the time. We got so used to each other. We know how everything goes and again, they're both aviation guys, too, s**o we all know how to check each other. Even though it's safe to check your work, if I go out and do a job, I'll go say hey, go look at my stuff real fast...little things like that. And they'll do the same thing, so we're always checking each other, which makes our job go pretty smooth.**"* -Site 9

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3.3.6 Summary of Organizational Considerations

This analysis of differences between sites based on company artifacts and team interactions captures the inter-variabilities that may affect the system and procedure use. The advantage of this perspective lies in understanding how such differences influence the behavior of the whole system in terms of process safety. In these interviews, it was clear that there was wide variability in how process documents were accessed, how they were used to support team performance, and requirements regarding accountability for using the procedure (i.e. sign off).

3.4 Cultural Factors

While culture is an inherent property of an organization, cultural factors need to be investigated in isolation due to their systemic contribution to latent human errors (Reason, 1990). International corporations studied may be composed of several (potentially conflicting) cultures. While a detailed discussion of such factors is beyond the scope of this paper evidence from interviews suggests issues with language barriers and culture of blame.

3.4.1 Language barriers

Two of the nine sites have operators that speak a language other than English as their primary language. Personnel from these sites reported issues with language mismatches on the documents they used. At one site, while the JSAs are written mostly in the native language, they contain occasional technical English terms. “Standards” and the procedure board, meanwhile, are written mostly in English. Personnel have adapted to this obstacle by using their smartphones applications (e.g., Google search) and asking supervisors for translation. At another site, procedures were in the native language but translation between several languages contributed to perceived difficulties in understanding and changed meaning especially among the crucial details. This motivates the need for a professional translator, as discussed by participants at site 5.

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“*Poor translation… From English to [Language 2], from English to [Language 3], from [Language 2] to [Language 3], from [Language 3] to [Language 2] and the way it was translated. A real mess! The professional should translate! The professional interpreter.*” -site 5

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3.4.2 Culture of Blame

Participants at five sites discussed perceived pressure to use procedures. These sentiments were divided into two themes: how pressure was perceived from the group and from the management. Responses leaned toward pressure from management to carry procedures, what is sometimes referred to as "in-hand" procedures, and revealed an incentive system (or more accurately put, a *deterrent),* that drives organizational behavior. In the case of incidents, personnel and their strict adherence to the procedure are often looked at first as causes. If determined to be at fault, or found without a procedure "in-hand", personnel suffer from various forms of punishments, such as 20 day suspensions without pay (referred to below at "the 20 day") to termination.

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"*... there are different levels of discipline. Let's say I messed up on my own fault, the first level, partially, and then probably I may get a talking to. Second time if it's really negligent, they put a letter in your file. Third time, that's when they pull this thing called [can't remember]. Positive, basically they give you three days off with pay and you got to write a letter to the plant manager saying this is why I like my job and I'd like it back.*" - Site 1

"*...I see guys, the guys that know their job or they play the game.* ***You know what it is, ever since the 20 day came in there's no deviation****. That's a big thing, that 20 days...The 20 days is a deterrent. Oh, the 20 days is a what do you call it, a load on your back. That's four weeks, no pay.*" - Site 8

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While the focus should be on how procedures help operators perform their tasks safely, some organizations have created cultures where the focus has been on enforcing procedure use which may develop into a culture of blame and fear in the long run. Generally, the effects of such cultures sever feedback--people are more careful of what they say and what they disclose to upper management as a division between these two classes emerges. This also limits personnel's ability to exercise good judgment should the need to deviate arise due to incorrect procedures.

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"*Now if you don't have it with you, you do an exercise of this, you suffer the consequences…* ***You have to look at the fear factor as well. Basically, cover yourself***." -Site 3

"*It becomes hard for us to be honest. So with me* ***by being honest we're taking a chance***." -Site 3

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3.4.3 Summary of Culture Considerations

The primary cultural influences on procedural processes were identified as language barriers and the punitive culture developed around having procedures in hand while performing tasks. Both of these influences create barriers to effective procedural systems for process safety as they engender divisions between the workers and those who manage procedures. These divisions are insidious in nature because the lack of communication regarding issues with procedural processes creates unknown risks in the working environment and unknown risks cannot be mitigated by any safety management system.

3.5 Environmental Factors

Most environmental considerations discovered are centered around the weather and some about the challenges imposed by the offshore environments. Here we briefly discuss the perceived weather effects on operator performance.

3.5.1 Effects of Weather

A previous topical analysis of this dataset revealed widespread overall reports (73% of all sites) of rain and wind affecting procedure use in the environment (Sasangohar et al., 2017). The specifics of these effects vary among sites. Site 8, for example, reported that operations will not continue in severe rain, while the offshore drilling vessel, Site 9, continues work despite any harsh conditions due to weather.

Rain has been observed to soak paper documents, forcing adaptations such as laminating or carrying additional copies tucked into clothing. Rain can also disrupt processes in some units (e.g. changing temperatures), and impede tasks depending on perceived task importance. Evidence from at least one site shows that the sign-off process may be interrupted by rain resulting in unsigned procedures which may lead to confusion and a culture of complacency. Naturally, operators wishing to avoid the rain may prefer alternatives to paper documents.

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"*You know there would be certain things and procedures…* ***that are weather-dependent****, like I can't do this [task] if it's raining****. They're telling me I have to do this today, but I can't****. If I do this, it's going to mess something else up.*" -Site 8

"*With rain, even if we're doing a procedure with a console, if we got our copy with rain, you can hardly read it. Rain messes with our unit so much, it changes your temperatures and everything. Normally he'll be having an alarm going off while he's trying to sign a procedure. And that's how you can get signatures missing.*" -Site 4

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Operators at a refinery (Site 4) commented that efficient communication with console operators may compensate for lost ability to use paper procedures in rainy conditions.

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"*Typically, if I'm working outside, I want to have the procedure with me. We can call and I'm at step 2.2, and talk about it. But if it's raining outside and I don't wanna get my procedure wet, then there is communication between yourself and console operator inside.*" – Site 4

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3.5.2 Summary of Environment Considerations

From the review of the interviews, the major concern with procedure use and the external environment was an intersection of the method of delivering the procedure (paper) and the impacts of weather (e.g., rain and wind). With paper procedures, in any kind of inclement weather, workers are not only burdened by one more thing in their hands but also must protect that item from being blown away and deteriorated (to a point of being useless) by rain. Although this challenge is long known in process industries and many work arounds have been developed (e.g., communication between console and field operator during rain), it is likely new technology that will truly mitigate the risks presented by environmental considerations.

4.0 CONCLUSION AND RECOMMENDATION

Interviews were conducted with personnel at 9 process industry sites to investigate issues related to the usage of written procedures. This paper builds on our previous work (Sasangohar et al., 2017) in which we documented several widespread, industry-generic factors related to procedure use from the same dataset. When these findings are viewed through a human factors lens, the effects of variety of factors from different system layers on workers' behavior pertaining to procedure usage becomes apparent. The types of facilities that are the topic of this report (like many complex socio-technical systems) are ideally managed with a "safety first" mindset. However, lack of effective consideration for the human element—which is perceived to be responsible for erratic, unpredictable

variation, and therefore the culprit behind many industrial incidents and disasters—has led to the implementation of systems using written information and procedures that do not consistently or reliably serve the purpose of reducing variability in human performance.

Our findings suggest large variations between the way procedures are operationalized and used within and between investigated organizations. At the personal level, personnel experience level was perceived to be a main indicator of procedure usage. While mentorship provided by the experienced operators was perceived to be an important part of novices' hands-on training, these more senior workers also seem to bypass procedures and rely mostly on experience making them possibly prone to the negative effects of cognitive biases and heuristics such as availability and recency (Reiman & Rollenhagen, 2011). For instance, the availability heuristics could occur if an experienced worker came across one or two procedures that were incorrect and had frustrating experiences trying to correct them, he or she will likely find this easy to remember and may experience that this happens more frequently than it really does and therefore not trust *all* procedures. At the task level, findings suggest inconsistencies between the way procedures are referred to and used between and within sites. Several terms were used interchangeably to refer to procedures including checklists and job aids. While the reported artifacts used are by no means collectively exhaustive, the interviews clearly point at lack of standardized way of operationalizing procedures in similar work settings across different sites.

The inconsistent methods of storage and access to procedures unveiled by the organizational level analysis is problematic as well. In addition, several operators mentioned outdated procedures that refer to legacy and non-existing equipment that may result in unnecessary interruptions to the process and may lead to lack of trust in and a resulting increased likelihood for deviation from procedures. At the cultural level, the impact of language barrier on understanding and interpreting procedures proves to be challenging. Evidence suggests a widespread culture of blame where operators follow procedures only to avoid harsh financial penalties. Such toxic climate may erode trust in the effectiveness of procedures and result in cultural disconnect between operators and management. Harsh weather conditions remain the main source of environmental complexity affecting perceived usability of written procedures. It seems that procedures in their current form have very limited usability in the existence of wind and rain specially when personal protective equipment such as gloves are used and as a result may be ignored.

While obvious changes such as regular updates to procedures, improving accessibility in extreme environments, and improved clarity are usual suspects, our analysis of systemic interactions between several layers of the socio-technical system under investigation may have uncovered an issue that has generated a true bottleneck for companies attempting to develop effective procedural management systems—specifically, conflicts between the multiple goals (stated and unstated) for these systems. The goals assumed in much of this paper (based on safety professionals interviewed) have been essentially: *safety*, *effective worker performance*, and *training*. An additional goal reflected in the interviews was that of *knowledge management*, i.e., insuring that the knowledge available from more experienced workers gets passed down to the newer workers—which is subtly different than training. However, companies have additional goals that must be considered—*regulatory compliance*, *documenting accountability of workers*, and *litigation considerations*. It is when these goals are considered in the context of the insight available from the analyses of these interviews that the dilemma of developing an effective procedural system becomes more apparent. We will first outline some general design guidelines for each of the different goals:

Safety: To support injury and death reduction, there needs to be clear and effective communication of risks, consequences, and mitigation methods at both the individual and team level (Rozenfeld, Sacks, Rosenfeld, & Baum, 2010). This should occur both before someone performs tasks so that effective preparations can be made and during the tasks so that the worker is reminded of necessary precautions.

Effective worker performance: To support all workers' performance of all types of tasks, a procedural system needs to be flexible, constantly (and reliably) updated, and based on principles of good Human Factors and User-Centered Design (Bullemer & Hajdukiewicz, 2004). A flexible procedural system is one that accounts for the fact that the needs of workers will differ based on workers' experience in the job and with the task. Further, more frequently done tasks likely need a different amount of documentation and support than those done less frequently (Sasangohar et al., 2017).

Training: Procedures that support training contains detailed content to support the work of the less experienced worker who is learning an abundance of procedures and the processes of the entire system. Based on the analysis of interviews, these procedures also need to be effectively coordinated with the mentoring efforts used for these workers.

Knowledge management: The idea of procedures being used to "take all this knowledge that we're learning from the older generation, that mystery body of knowledge and … getting it documented" is non-trivial because it is essentially the task of combining the knowledge of the process engineer and the mechanical engineer who built the system with the workers who have been running the system for many years. These bodies of knowledge are clearly related but are also disparate in subtle and important ways. To the authors' knowledge, there has not been specific work on design guidelines for these types of efforts but any effective effort will likely differ by system, company, and country.

External influences:

Regulatory compliance: A review of regulations associated with procedures for process industries internationally (Peres et al., 2016) generally requires that companies have written procedures that are up to date, accurate, and clearly written. Further, they often specify that hazard and risk mitigation methods must be communicated to the workers effectively. Most of these regulations however, do not specifically indicate how, where, or when this information should be communicated or even require workers to have procedures in hand while performing some specific tasks. It is apparent that there is a need for requirements that mandate processes to maintain up to date and accurate written procedures.

Accountability of workers and litigation considerations: Preparing or discussing the litigation processes that can occur when a worker is hurt or killed is never comfortable but it is a real consideration for any company. Often after an incident occurs where someone is hurt, the first question that is asked is "Were they following the procedure?" The assumption inherent in this question is that if the person was, then there was something else in the environment that was the root cause of the incident and if he or she was not following the procedure, then this procedural deviation is the root cause of the incident. This assumption requires a procedural system that documents workers' performance and adherence to standardized procedures and the ability to retrieve this documentation when necessary.

Some companies have as part of their system a requirement that employees sign off on every step of every procedure they do during their work shift and turn this in at the end of their shift. This policy is an example of one that is designed around the goals of worker accountability and can conflict with the goals of improving worker

performance and safety because the focus is exclusively on accountability. Workers at several sites indicated that they often signed off on the steps either well before or after they completed the task as part of their "paperwork" but did not use the procedure while performing the task itself, thus making the content of the document essentially worthless. At other facilities, many procedures were designed with enough information that a newer employee could get the information that he or she would need to perform the task, making the document cumbersome and frustrating for an experienced worker. This is particularly risky when considering low-frequency, high-risk tasks when even experienced workers prefer having a procedure with them but want only the information that is necessary.

Indeed, when considered with the differences in what is needed from procedures by workers at different stages of their careers, standardization of the artifacts may not support safe and effective work in these industries. We suggest that the lack of standardization is promising as it shows adaptation to the needs of the worker, but the fact that it is not done with sufficient guidance regarding the interplay of the layers between environmental, cultural, organizational, task, and personal considerations is likely a contributor to continued incidents associated with procedural failure and non-adherence. Further, the documents and processes that are currently used to support safe and effective work are often owned by different groups within the organization and thus not coordinated or integrated. For instance, safety department may "own" the Job Safety Analysis and Behavior-Based Safety programs while operations department owns the procedures and work permits, and the training department owns any documents associated with knowledge retention and training efforts.

These conflicting goals and lack of integrated efforts for safety and training are reflected in the interactions between the layers of the system evaluated as part of this study and may be as causal in the incidents associated with procedural errors as any of the more obvious elements such as procedures not being updated. Next, we offer several recommendations under two strategies to improve system safety pertaining the usage of procedures.

4.1 Recommendations

Strategy 1: Maximize the "Slack" between Interdependent Variables in the Current System

The evidence from the interviews suggests complex interrelations between the humans, other system elements, and contextual factors. Very little effort has been aimed at coordinating these, exemplified by findings such as

conflicting goals and *shipping and vessel considerations.* Safety conditions can be improved by maximizing the under-utilized "slack" between identified variables. This requires a seamless, horizontal coordination between people, management, and technologies as they currently exist. Put simply, each deficiency noted in this and the previous reports must be understood in relation to others. This process can initially involve identifying those variables that appear to have the *greatest* impact (e.g., outdated procedures). Some specific recommendations follow:

- *User-centered Design*: Operators should be involved in the writing process to ensure that 1) tacit knowledge (experience) is captured, 2) operators feel ownership boosting trust, and 3) collaborative environment will contribute to enhance safety culture.
- *Mentorship*: Procedural systems should be designed with the understanding that they are used in the context of the formal mentorship mechanism and that they are part of the transfer knowledge from experienced to novice operators. This, suggests that procedures used for training and less experienced workers will likely not be appropriate for more experienced workers.
- *Redundancy*: Operators should have access to alternative forms of procedures (perhaps via some technology) to deal with constraints imposed by environmental factors such as extreme weather.
- *Conciseness*: procedures should be well-written, streamlined documents that contain only the crucial task information for the experience level of person using them and the criticality of the task the person is performing.
- *Opacity*: reevaluation of safety artifacts and their purposes should be explicitly communicated to personnel
- *Maintenance*: strict processes (and resources to sustain these processes) should be in place for maintaining up-to-date written process information. This should include processes for reflecting equipment replacements, work created around reviewing and rewriting the wealth of currently outdated documents, improved methods of access, and integration into information management databases. Further, evidence from Sasangohar et al., (2017) indicates that this review process should be timely and transparent to the workers because when reviews and changes of procedures take too long, trust in the procedural system is lost.
- *Place-keeping*: Procedures should be designed to support workers' access to event history logs to facilitate rotations, handovers, and team synchronization.

However, coordinating all the myriad of layers of protection in various contexts has escalated into a level of complexity seemingly beyond control. Attempts to improve safety in these systems by focusing on a *particular* element risks sub-optimization, because this approach would ignore the interactions between many moving parts. If *Strategy 1* was successfully coordinated around the bureaucracy and socio-political barriers that manifest as cultures of blame, the available "slack" between these interdependent variables would be stretched to its limit. Meanwhile, the system will always suffer the uphill battle of *maintaining* its state through constant vigilance, or else risk drifting back into the state as it exists today, plagued by the plethora of issues that have been the primary concern of this series of reports. Indeed, this is an unreasonable expectation of the dynamic, changing environments in which the complex systems live. Therefore, process and petrochemical industries may benefit from a system redesign.

Strategy 2: System Redesign: Addressing System Needs from a 21st Century Perspective

To see a jump in magnitude of safety today will require a paradigm shift that could use technology as a vehicle to organize a new *modus operandi*. We need to think about how these systems operate *post* the Clean Air Act Amendments of 1990 which largely pushed written process information as the best means to promote process safety, resulting, over time, in the systemic issues which have been documented here and elsewhere (OSHA, 2000). Our understanding of human error and human-system interaction has developed since the written procedures first emerged, as has our options for technological interfaces to serve as mediums for system information and our mental models of how systems should operate. A revolutionary change could be ushered via bold problem solving approaches like "idealized design" (Ackoff, 1978), one that is driven by technological and operational viability. In Russell Ackoff's words, *"The design of a desirable future is best carried out when it is imbedded in an idealized redesign of whatever is being planned for. Such a redesign is an explicit statement of what the designers would have now if they could have whatever they wanted."* Recommendations under this strategy may include promoting use of operator expertise and training by increasing agency, and augmenting operator decision making via decision support or memory tools as well as implementation of social learning methods and technologies to facilitate mentorship and to ensure transfer of "undocumented body of knowledge."

In summary, while the safety focus has historically seen "effective" enforcement of procedures as equivalent to getting workers to adhere to written procedural protocols, the qualitative evidence supports a gap in focus on improving the "effectiveness" of written procedures as a support tool to help workers perform work safely. Such focus requires a holistic investigation of systemic variables that affect individual behavior. This paper documents an attempt in understanding personal behavior in the context of socio-technical factors and agrees with those who indicate that the common identification of "human error" in terms of deviation from procedures or non-conformance as the root cause for incidents is shortsighted. Human behavior is usually affected by the context in which work is conducted, which is driven by complex interactions between tools, tasks, organization, culture and the operating environments (Dekker, 2014). By using a system-layered analysis of factors, we have revealed some of the contextual variables that affect operators' behavior in relation to procedure usage while shedding light on some complex interactions between these layers.

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