Contents lists available at ScienceDirect

Process Safety and Environmental Protection

IChemE ADVANCING CHEMICAL ENGINEERING WORLDWIDE

ELSEVIER

journal homepage: www.elsevier.com/locate/psep

Investigating written procedures in process safety: Qualitative data analysis of interviews from high risk facilities

Farzan Sasangohar[a,*], *S. Camille Peres*[b], *Jason P. Williams*[a], *Alec Smith*[a], *M. Sam Mannan*[c]

[a] *Industrial and Systems Engineering, Texas A&M University, College Station, TX, 77843-3122, United States*
[b] *Environmental and Occupational Health, Texas A&M University, College Station, TX, 77843-3122, United States*
[c] *Chemical Engineering, Mary Kay O'Connor Process Safety Center, Texas A&M University, College Station, TX, 77843-3122, United States*

ARTICLE INFO

Article history:
Received 21 April 2017
Received in revised form 11 August 2017
Accepted 12 September 2017
Available online 20 September 2017

Keywords:
Operating procedure
Petrochemical
Process industries
Interview analysis
Process safety management
Grounded theory

ABSTRACT

Written procedures can play an integral role in mitigating risks and hazards in industries such as petrochemical, nuclear, and aviation. However, failure to adhere to procedures has resulted in major incidents. While there have been multiple studies investigating procedures in the aviation and nuclear industries, a comprehensive study of the high-risk industries' use of written procedures is largely absent. This paper documents one part of a large-scale project that addresses this gap by investigating the issues with procedure forms, usage, adoption, and challenges in a wide range of high-risk industries. A grounded theory approach in qualitative data analysis was used to examine 72 interviews with operators of varying roles and experiences across 6 countries and an offshore drilling vessel. Findings reaffirm previous research, suggesting an explanation for the lack of use of procedures due to the abundance of outdated procedures and procedures plagued by information overload. New findings suggest that frequency of the task and the experience level of the worker would impact workers' procedure use. Other unintended consequences associated with written procedural systems included reactive organizational behavior surrounding procedures and a general disconnect between the users and the writers of these documents.

1. Introduction

Disasters throughout the 1980s, such as Bhopal in India or the Phillips incident in Pasadena, Texas, demonstrate the need to establish effective methods to protect the facilities, environment, and humans from the damage caused by systemic failures in complex systems. Given the complexity of these socio-technical systems, process safety regulations and guidelines associated with the Clean Air Act Amendments (CAAA) of 1990 and the Occupational Safety and Health Administration (OSHA) require that employers in highly hazardous chemical industries implement written operating procedures and written safety information (OSHA, 2000). Ostensibly, the goal of these written procedures is to have them as an integral tool in mitigating risks and hazards in petrochemical industries by acting as guides for carrying out plant operations, address anomalies and emergencies, as well as training.

While the use of procedures is recognized as important for safety purposes, incidents have occurred due to procedural breakdown (Bullemer and Nimmo, 1994). Incidents such as the BP Texas City refinery report symptoms of problems with inconsistent, inappropriate, or voluminous procedures resulting in operator non-conformance and deviation from established procedures. Evidence suggests that procedures in complex environments are sometimes misunderstood, outdated, or simply not used (Bullemer and Hajdukiewicz, 2004).

* *Corresponding author at:* 3131 TAMU, College Station, TX 77843, United States.
E-mail address: sasangohar@tamu.edu (F. Sasangohar).
https://doi.org/10.1016/j.psep.2017.09.010
0957-5820/

To better understand the reasoning for such behavior, there have been multiple studies on procedural deviations and safety violations (e.g., Alper and Karsh, 2009; Bates and Holroyd, 2012; Bullemer and Hajdukiewicz, 2004; Carim et al., 2016; Dekker, 2003; Human Factors in Reliability Group and Violations Sub-group, 1995; Jamieson and Miller, 2000; Lawton, 1998; Mullen, 2004; Saurin and Gonzalez, 2013). Two studies in particular examined the cultural and organizational view and the safety—root cause—analysis perspective. The first of these studies (Jamieson and Miller, 2000) involved interviews and observations at four petrochemical refineries in the US and Canada. The study focused on how the cultural and organizational issues may impact the effectiveness of an organization's procedural system. They found that workers often did not trust their procedures because they were out of date or incorrect. Unfortunately, systematic barriers to maintaining procedures—such as the high cost of maintaining procedures, challenges associated with making procedures accessible given the large number of procedures needed, and infrequent use despite investment—perpetuated workers' distrust of procedural systems.

The second of these studies involved interviews and observations with key personnel at five different refining and chemical facilities, but instead focused on identifying the high frequency root causes of procedural breakdowns (Bullemer and Hajdukiewicz, 2004). Bullemer and Hajdukiewicz's findings support the findings of Jamieson and Miller regarding the extent of the problems associated with having correct and current procedures, but also identified other issues that may have more to do with the effectiveness of the written procedure themselves. Issues include flawed reasoning on the part of the worker; procedure used incorrectly; inadequate coordination of procedure activities; and incorrect data/facts for using the procedure. Although, these studies and others have provided guidance on how to mitigate both organizational and procedure design issues (e.g., Human Factors in Reliability Group and Violations Sub-group, 1995; Mullen, 2004), companies still report a high rate of procedural breakdowns as one of the root causes of their incidents (Bates and Holroyd, 2012). This warrants a more systematic examination of procedure use, in the field, by those who are using them. While procedures have been studied extensively in aviation (e.g., Carim et al., 2016; de Brito, 2002; Degani and Wiener, 1997) and nuclear operations (e.g., Dien, 1993; Park et al., 2013; Roth et al., 1994; Savioja et al., 2014), there has been little scientific effort to determine how these studies might apply to high-risk industrial settings such as petrochemical, oil and gas, and energy management. In addition, the two relevant studies discussed here are relatively old and may not reflect potential changes to procedure use and culture in the industry. A systematic analysis of different individual (e.g., cognitive), task, cultural, organizational, and political contributors is necessary to fully understand the issues. This paper documents a large-scale study that was developed to gain further insight into the current issues concerning the use of procedures in process industries and to make sense of attitudes and behaviors in sociotechnical systems such as this. The results of this study will be analyzed such that aspects of these complex socio-technical systems that are involved in successful procedural systems can be discovered, and potential extant barriers can be identified. This work will inform future work in creating and empirically testing mitigation methods to address these barriers.

2. Methods

Semi-structured interviews with operators were conducted at 9 different high-risk facilities, specifically refineries, upstream drilling facilities (including an offshore drilling vessel), an electrical management facility, and chemical plants. These interviews took place across 6 countries to investigate the procedure forms, usage, adoption, and challenges. The study was approved by Texas A&M University Institutional Review Board (IRB2015-0219D).

2.1. *Data collection*

2.1.1. *Participants*

Seventy-two participants (67 males and 5 females; $M(\text{age}) = 36.7$, $SD(\text{age}) = 10.4$) were interviewed. Average number of participants per facility was 8.1 ($SD = 3.2$). The participants were from chemical, drilling, or refining facilities of five different companies and their years of experience in the industry ranged from 1.5 to 40 with an average of 10.7 ($SD = 9.3$). The sites were in United States, Canada, and Offshore in the Gulf of Mexico, Thailand, South Africa, Kazakhstan, and England. Participants were recruited at each facility according to the methodology approved by the facility. Table 1 below provides details on each site and the roles of the participants.

Facilities would follow one of two protocols to recruit participants: (1) have the researchers present an overview to the workers (potential participants) at a shift meeting and then workers would approach researchers, indicating their desire to participate in the study; or (2) provide the researchers with a list of potential participant candidates and these participants would be approached by the researcher during the site visit at scheduled times. While this sampling method may lead to management-biased selection, barriers to accessibility presented by these fast-paced work environments and busy schedules sometimes require a convenient sample based on availability. To address this potential bias, anonymity was strictly maintained. Also, the presence of negative comments among interview responses toward procedures and management suggests participants were not necessarily selected according to their willingness to speak positively about the research topic.

2.1.2. *Instrument*

The interviewers used a list of questions to guide the interview. The list of questions was adjusted for each new site based on whether a topic had reached saturation or if the questions were relevant to that particular site. Further, the amount of time for the interview was sometimes limited and thus all the interviewers asked questions most relevant to procedure use during work and any problems or issues participants had while using procedures.

The questions on the interview guide changed subtly as the project progressed but generally covered the following topics: Understanding how workers use procedures; workers' experiences with their job and with procedure use; investigating workers' understanding of terms used in procedures (e.g., caution, warning); types of supplemental materials workers use with procedures and to complete work tasks; workers perceptions of procedure's general effectiveness; problems workers have with procedures and how they can be improved; how using procedures affects different aspects of a worker's experience on the job; what other factors affect how a worker uses a procedure; and likes/dislikes of procedures, checklists, job aids, and other supplemental materials. While the scope of the interview questions did not address all types of procedures (e.g. standard operating, emergency), one of the research objectives was to investigate what is generally perceived to be "written procedures." Our findings are discussed in Section 3.3.4.

2.1.3. *Protocol*

Five different interviewers conducted the interviews and used a semi-structured approach to gather information from the

Table 1 – Overview of sites and participant roles.

Site	Type of site	Ownership	Location	Number of interviewees	Job roles
1	Refinery and chemical plant	Large oil and gas corporation (Company 1; same as Site 2)	United States	9	Laboratory Technician; Instrument Technician; Maintenance Electrician; Process Technician (x2); Operations Day Superintendent; Console Operator; FAST Team Operator
2	Refinery and chemical plant	Large oil and gas corporation (Company 1; same as Site 1)	United Kingdom	2	Process Operator; Instrument Technician
3	Refinery	Large energy corporation (Company 2; same as Sites 4–6)	South Africa	9	Unit Operator; Process Operator (x3); Process Field Operator; Outside Operator; Trainer (x2); Blending/shipping operator
4	Very large refinery	Large energy corporation (Company 2; same as Sites 3,5,&6)	United States	9	Console Operator; Operator (x6); Outside Operator; Operations Training Analyst
5	Very large, onshore, drilling facility	Large energy corporation (Company 2; same as Sites 3,4,&6)	Northwest Asia	4	Oil and gas field production operator; Mechanical Fitter; Lead Instrument Engineer; Boiler House Operator
6	Onshore support for offshore drilling elements	Large energy corporation (Company 2; same as Sites 3–5)	East Asia	12	General Operator (x2); Craftsman; Senior Helper (x2); General Helper; PLE QA/QC; Crane Operator; Banksman and Rigger; Mooring Team Master; Forklift; Oversight Foreman
7	Chemical plant	Moderate size chemical corporation (Company 3)	Canada	8	Operator; PE2 Operator; Operations Tech Leader; Operator Technician; Senior Panel Operator; Day Trainer; Extrusion Panel Operator; Field Operator
8	Electrical utility company and power distribution center	Large energy company (Company 4)	United States	11	Senior Substation Operator (x3); Mechanic A (x4); Mechanic B
9	Offshore drilling vessel	Large transport and energy corporation (Company 5)	Gulf of Mexico	8	Crane Operator; Engine Room Responsible; Senior Dynamic Positioning Operator; Hydraulic Mechanic (x2); Assistant Fluid Drilling Operator; Floor hand; Able-bodied Seaman

participants about their experience with procedures and procedure use. Each interviewer followed the same procedures (within the constraints that existed at each facility) and were all trained on conducting interviews and collecting qualitative data. For each site, the researchers would first review the informed consent with the participants and obtain their agreement to be observed and interviewed. Next, the researcher would observe workers perform one or more of their work tasks assigned for that day or they would simulate a task they normally perform. If allowed by the facility, participants were recorded using a GoPro(R) video camera attached to one of interviewers to record worker(s) performing the task. During the tasks, workers would talk through their processes and explain what they were doing, why they were doing it, and the machine/paperwork they were using in their task. While unstructured observational notes were taken, no such data is reported in this paper.

After the observations, the researcher interviewed the worker in a private area and the interview usually lasted 1–2 h. These interviews were recorded and involved the researcher asking a list of questions designed to be prompts for discussions. During these interviews, interviewers occasionally asked clarifying questions or asked the worker to elaborate on a particular point.

2.2. *Analysis using a grounded theory approach*

A framework in grounded theory was selected for analyzing the wealth of data collected during the interviewing process. A critical component of this framework in qualitative analysis—coding—describes the process of systematically categorizing data using a Qualitative Data Analysis (QDA) tool. Approaches in grounded theory are often viewed as progression of coding stages, and two perspectives have developed these stages into formal approaches, namely, the Strauss and Corbin approach (1990) and the Charmaz approach (2006). While both schemes present the coding process as a progression of three coding phases (namely initial coding, focused coding, and theoretical coding), a variation of the Charmaz approach was selected for its tendency of delaying the point at which emerging concepts are set (Bryman, 2015). The analysis was conducted using the QDA software MaxQDA-12, which features a coding system for sorting segments of interview transcripts into user-defined categories, or codes, for further analysis. The researcher can then review coded segments and interpret relationships based on the information present in the category.

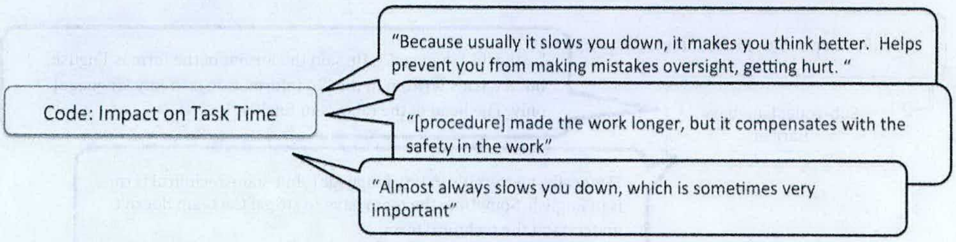

Fig. 1 – An example of interview responses assigned to a code regarding the impact of procedures on task time.

2.2.1. *Initial coding*

The first phase of analysis consisted of an initial reading and coding of three transcripts from each interview site. This process identified patterns among responses to interview questions and interesting tangential conversations, and marked them under a code category such as the code "Impact on Task Time" (Fig. 1). Emphasis in this phase was placed upon generating a wealth of descriptive, open-minded impressions or new ideas, and therefore codes (Bryman, 2015). Coding efforts here also emphasized understanding the extent to which code categories could be generalized across sites.

2.2.2. *Focused coding*

The remaining interviews were read and coded site-by-site exploring how personal, task, organizational, cultural, and environmental considerations impact participants' interactions with procedures. An emphasis in this phase was placed on the development of sub-codes, or more specific categories within the initial, high-level categories. Fig. 2 demonstrates this process, where sub-codes in a particular site reveal cultural influences on problems reported with procedures.

2.2.3. *Theoretical coding*

The third phase, theoretical coding, develops a framework from relationships between codes and concepts that explain why the observed phenomena exists (Corbin et al., 2014). The descriptive nature of the coded segments from the initial and focused coding provides details that motivate the formation of theoretical frameworks. In this paper we report some of the identified interrelations between concepts/codes (see Table 2, Column 3) as well as their theoretical implications.

2.2.4. *Inter-coder reliability*

The researchers performed intermittent inter-coder reliability checks to assess the extent to which coders reached similar interpretations of the interview data while coding. Two researchers, using the same code system (codebook), coded one site's interviews as a team to build a reliable coding process, discussing and resolving interpretations as themes emerged. An average pairwise comparison agreement method was used to calculate inter-coder reliability. While the threshold of 90% agreement is nearly always acceptable (Lombard et al., 2002), the co-coding continued until the coders reached consensus and the two sets of codes were similar (100% agreement).

2.2.5. *Iterative coding*

An implicit understanding in QDA approaches is the iterative nature of inquiry, that is, data interpretations evolve as more information is considered over the course of a project. MaxQDA-12's memo system for note-taking and logging observations was utilized throughout the study to facilitate this process. Memos describe the complex nature of the coding journey and the evolving thought on a project as initial observations, visions or ideas change over a period of time. To this point, codes were added as themes emerged during the initial and focused coding phases.

3. Results

The initial coding process resulted in formation of 16 generalized topics across all sites (Table 2, Column 2). During the focused coding phase, these codes were grouped into higher-level, abstract categories (Table 2, Column 1). These abstract categories represent the emerging themes from the qualitative data and are discussed below. An important strength of qualitative data analysis is the ability to identify and model the interactions between several constructs. These related topics generated from the interview data were documented for each high-level category to inform theoretical coding and future analysis (Table 2, column 3). The high-level categories and their associated concepts are discussed below.

3.1. *Purpose/use for procedure*

Procedures have multiple purposes, often dependent on task or equipment. Some examples include training, support or general guidance for plant operations, troubleshooting, mitigating risks, or handling emergencies.

3.1.1. *Training novices*

Many interviewees mentioned that procedures are used for training purposes, particularly for new employees. According to interviewees, procedure use and perceived importance decreases gradually as the effects of learning, repetition, and memorization set in. On this point, some highlighted the important role of experienced personnel in successful training on how to conduct tasks and use procedures.

> *"If it is a procedure that has not been changed in 10-15 years **once you are trained on it,** and you look at it and you are reading through it and you start doing the same things over and over and over again, **there is really no reason to go back and look at it**."*

> *"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.**"*

3.1.2. *Pressure from management*

A majority of participants described using procedures out of concern for job security, or fear from organizational punishment. This phenomenon explains the procedure use even when perceived importance significantly drops as a result of repetition. While many find such compliance-driven usage

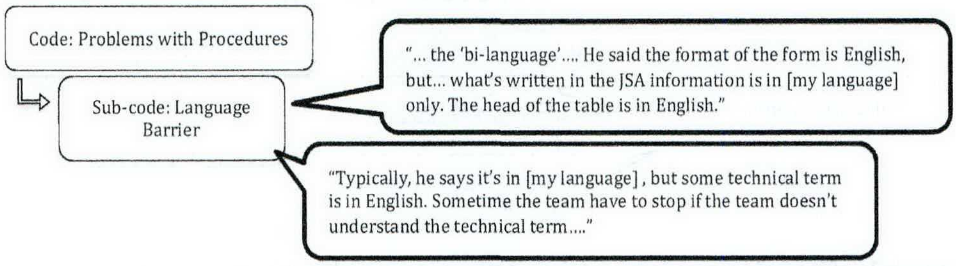

Fig. 2 – Sub-codes emerge regarding problems with a language mismatch between procedures and their users at a particular site.

Table 2 – Results of initial and focused coding and modeling relationships.

Higher-Level categories	Concepts/codes	Related topics
Purpose/use for procedure	- Training novices - Pressure from management	Alternative documents, effectiveness of frequent tasks, infrequent/critical tasks, emergency procedures, near misses/incidents
Procedure change/updates	- Reactive change process - Procedure endurance - Not changing procedure - User removed from writing/change process - Procedure change timing	Outdated, perceived importance, perceived reliability, near miss/incidents
Attitudes towards procedures	- Perceived importance for non-routine tasks - Perceived safety - Impact on task time - Alternative documents - Emergency procedures	Team interactions and deviation
Effect of environment	- Effect of weather - Personal protective equipment (PPE)	Technology, alternative access, digital mediums for procedure
Other reasons for deviating from procedures	- Outdated or excess information - Issues with digital access - Language barriers - Impact of format on usability	Change, impact of format, medium for procedure, digital access, mismatch between user and writer

necessary, for many it has resulted in frustration. The culture of blame may also mark a division in the organizational structure, which might obstruct communication pathways between users and supervisors, particularly involving the documentation of important information.

> *"Everything we think of out here is, "Am I going to get fired for this?" And **I know if I have that [procedure], I mean I don't have to worry about that part of it**... After I've done it five times the only thing I'm looking for specifically on it is just the tag numbers..."*

> *"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..."*

3.2. *Procedure change/updates*

Changes in tasks, equipment, teams, and operations over time demand procedure updates. Despite this, delivering and managing these needed changes may prove to be challenging in complex facilities.

3.2.1. *Reactive change process*

Many interviewees suggested procedure changes are made reactively after an observed error, near miss, or incident. This popular opinion has developed into a common saying in the industry (observed in two sites) that procedures are "written in blood", demonstrating a reactive organizational behavior for changing, as well as creating new procedures.

> *"We always said it's always procedures **written in blood,** so it's always been changed, or it's there because something bad happened."*

> *"We've gotten to this point because bad things happen, and we write one. Over the years, bad things happened and we make procedure."*

3.2.2. *Procedure endurance*

Coupled with this reactive behavior is a long evolution process for procedures, demonstrated over years of writing and adding information to older procedures. This may result in feelings of perceived safety and reliability toward procedures with a justification of procedures being tested over decades. However, the slow development offers another explanation for the reported problems of excess information, over-encumbrance of documents, and outdated procedures, as writing procedures then attends to newer updates rather than evaluating the relevance of past instruction.

> *"There are not a whole lot of new procedures here. **A lot of them have been around since the 1980s.** They have just continually evolved over time with slight changes here and there."*

> *"There are a couple that are still in circulation that need to be created, but quite simple, **a procedure has been written after years of getting things wrong.** I think I feel safer to have a procedure*

on it and following it. It allows you to predict who does wrong and what's not working."

3.2.3. *Not changing procedure*

About a third of interviewees mentioned a pattern of participants purposefully not changing procedures. Reasons for such behavior have been attributed to uncertainty regarding the change process and complacency with the current state of procedures, since practical knowledge develops as a result of training and experience and is viewed as more important than dependency on procedures.

> *"I mean **we have procedures out there right now that we know are wrong**... I know there's some that we try to get them changed and redline them, but until that gets changed, we know at that point, well, I can't do that or that isn't feasible to do."*

> *"... the biggest problem I could blame myself for is for looking at the procedures now and **knowing better than what the procedure says and not taking the time to update them** - and not taking the time to have the discussion with new hires. I know for myself that has caused problems and I can take the blame for that - you probably should have mentioned to a new operator."*

3.2.4. *User removed from writing/change*

Participants commented that after noticing procedural imperfections, the change process is often handed off to others in the organization. Just under half of participants identified an authority to whom they report directly regarding change processes. Many found the actual process of updating or writing new procedures to be non-transparent. After procedures were updated, about a third of participants expressed concern about an apparent gap in understanding between writers and users of procedures.

> *"I know that you should inform your supervisor. That's what you do, **but I'm not sure where it goes from there.**"*

> *"...**the coordinator is going to do it, the operator, the contract engineer, often they will go unrevised for a while until someone takes the initiative** - which is usually the operator. Usually somebody's got to get mad [before they will change it]"*

> ***"Okay, someone sitting in a cubicle who wrote this, but they have actually no idea what it looks like whenyou're putting your hands on the pieces of equipment.** And it makes it difficult sometimes."*

3.2.5. *Procedure change timing*

The timing for the response to a procedure change request varies widely depending on elements such as the perceived significance of the change, the facility (even unit within a facility), perceived task importance, and possible safety implications. The variability of the timings ranged from a few days to up to three years—with the efficiency of the change process being primarily dependent on the organization or the unit.

> "**I wrote four of them, and it took almost a year before they finally got processed.** Even then, by the time it got to the end of it, it's not what I wrote... And yet seven people approved of it."

> "...**I'd see it within a week or two, you know?** Now if it's some kind of big **emergency**... I'm sure they could get on the phones and talk to each other **and get that done fast.**"

3.3. *Attitudes towards procedures*

3.3.1. *Perceived importance for non-routine tasks*

While procedure usage decreases for frequent and routine tasks as discussed above, procedures for infrequent tasks are associated with high utilization. Participants completing an infrequent task benefit from a procedure review as a refresher of task requirements. Some participants associated the decline in usage of procedures for routine tasks with complacency.

> *"We do have some for routine tasks, also, but things like the non-routines, you really concentrate on those particular procedures more than routine, you do it over and over and over and pretty much know things don't change. **So, non-routine procedures usually, you kind of go over a lot more.**"*

> *"I like procedures related to things that require procedures, if that makes any sense. **If you start creating procedures for routine tasks that you do every single day...we'll become complacent with it...**"*

3.3.2. *Perceived safety*

Generally, those using procedures feel safer when using them than not using them. Due to long-term adoption of most procedures, users perceive procedures as safeguards against uncertain situations or potential dangers. Using the procedures as a refresher or guide also helps the user to feel safe when performing the tasks.

> *"Procedures here have been beaten and tried and tested for some of them decades, so **they've had a long time to figure out some of the kinks** in these procedures and they haven't changed them a lot."*

> *"...a procedure has been written **after years of getting things wrong. I think I feel safer** to have a procedure on it and following it. It allows you to predict who does wrong and what's not working."*

3.3.3. *Impact on task time*

Many participants mentioned that the task duration increases with procedure use. Some mentioned that this also prevents oversight. Task times are reported as generally longer for new employees but decrease as the procedure is learned. In addition, process sign-offs reported increasing task time significantly.

> *"A lot of times in this field... doing something quickly can lead you to a mistake, taking the time to talk to someone or looking at the procedure, **quite often slowing down is the answer to preventing incidents.**"*

> *"It could probably slow you down a little bit, but I don't think that that's necessarily a negative. **Because usually it slows you down, it makes you think better.** Helps prevent you from making mistakes in oversight, getting hurt."*

3.3.4. *Alternative documents*

A variety of documents have been developed to match the variety of tasks conducted in high-risk work environments, such as checklists, field guides, 'what if' cards, and Job Safety Assessments (JSAs) that are considered distinct from the "procedures." Alternative documents, while not framed as procedures, were perceived to serve the same goal of mitigating risks and hazards in operations. The abundance of different documents, serving similar purposes under different guises, may pose complications in procedure use.

"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?"*

"They invented this other idea that you should do these 'What If cards', which is kind of a procedure but not really, *there is too much emphasis on that"*

3.3.5. *Emergency procedures*

Many participants claimed they do not prefer a procedure in emergency situations. Participants believe training, experience, and review of procedures prior to work prepares participants for best reaction in a time-critical emergency situation. In addition, procedures may not exist for some emergency situations. Many mentioned using procedures retrospectively to validate decisions and in one facility they would review the emergency procedures for the task-at-hands that day to ensure they had memorized the first few steps.

"We don't really have a procedure for each individual emergency scenario. ***[As] part of your training, we already know what's going on with this. What we're responsible for, we're supposed to know.****"*

"...depends on the emergency, **usually you act first and do most of the stuff**, there could be smaller things that could be overlooked - so that's where the emergency procedure would be good to have printed off so you can check off and go through and make sure you've done everything"

3.4. *Effects of environment*

Environmental factors such as weather and protective equipment were reported to restrict procedure usage. This finding saturated at a very early stage in our interview process. As these findings emerged, emphasis shifted to other elements of the interview study surrounding contextual considerations.

3.4.1. *Effects of weather*

A majority of the participants who were asked about environmental factors reported on their negative effects on use of procedures. In particular, wind and rain complicate the use of paper procedures, motivating a closer look at alternative mediums and access, such as digital procedures.

"...especially 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."*

"...The rain if anything! Then **I have to carry around a wet piece of paper.**"

"Typically, if you want to take any paper to walk outside, ***you got terrible wind, it's difficult. Now you have to turn the page.*** *So, if you somehow grab onto your papers, because you get terrible wind..."*

3.4.2. *Personal protective equipment (PPE)*

These environments often demand PPE use, such as gloves or face shields, which were reported to impair operators' ability to handle procedures. Indeed, these PPE considerations, coupled with weather effects and requirement of in-hand paper procedures, create complications that lessen the intended effect of improving safety.

"...Rainy weather, PPE, yes. like you said they should have different types of gloves. You have ceramic gloves, you [have] PVC gloves, you have this type of glove, that type of gloves, so you find out ***that mostly when it rains, it's not comfortable to walk around with a certain pair of glove*** *or to hold on with a certain pair of glove because it might be slippery."*

"Even if you're wearing a pair of gloves and it says to wear your gloves, and you know, ***sometimes that little bulky and grim. So, 'all right, hold on. Let me take my glove off real quick.'*** *That happens...and you forget to put them back on, and still working without them."*

3.5. *Other reasons for deviating from procedures*

3.5.1. *Outdated or excess information*

Many problems were reported with procedure use, including issues with accessibility, format, and too little or too much information made available. The most apparent of these were *outdated procedures* and *information overload* (both mentioned by about half of the participants) as a contributor to abandonment of procedures. Indeed, the interaction between these symptoms as well as their mutual reinforcement may result in propagation of impacts. For example, sites with reactive procedure change cultures (discussed in Section 3.2.1) emphasized the addition of information regarding new changes over evaluating the validity of past instructions.

"The length and the actual critical steps are ***lost in the fluff that keeps getting put into them by people that don't understand.****"*

"I got a ***50-page procedure that could be 10 pages.*** *It doesn't have to be 50. It's like they try to make sure they cover everything precisely.* ***But I've been here so long that I know that I don't need them.*** *It doesn't need to be so long-winded or anything. It's like, talking to* ***somebody that doesn't understand it at all!****"*

3.5.2. *Issues with digital access*

Procedures are typically printed from a database that implements strategies to organize and manage procedures, and are physically distributed, or housed, at multiple points of access. Technology offers additional digital formats and access, such as the use of handhelds for checklists in some sites. Participants at sites without technological access suggest digital mediums may improve accessibility. Counter-intuitively, sites using handhelds have reported a misuse of the technology that perpetuates a burden of tasks.

Sites without handhelds:

"I don't know if it's an issue, but maybe easier accessibility – if I could ***pop it up on my phone quick.****"*

"... if there were ***something with a touch screen at the job site that you could just pop up,*** *you know, touch the screen, this is what I'm looking for, and it knows how to run through a quick little review for you and take it apart and think it up and shows it to you, that would be awesome."*

Site with handhelds:

*"Yes, I love the handheld, but **they use it to pile too much work on us**...Up to the operator to check every piece of equipment- some people can get caught up in the handheld. They need to make their rounds and check every piece of equipment instead of focus just on the handheld."*

*"[regarding handheld] **instead of really fixing the issue at hand, they just throw more checklists at us** to make sure we're checking it. Instead of fixing the main problem. This is what we've been seeing over last 2 years."*

3.5.3. *Language barriers*

A prevalent problem with procedures in some international sites is that English is not the primary native language. Procedures have been reported to include technical English terms that pose language barriers. Operators rely on team interactions and supervisors to translate the documents and procedure boards. Translations can be prone to misinterpretation and require extra time and resources (see Fig. 2).

3.5.4. *Impact of format on usability*

Different sites employ a variety of formats for written procedures. Responses have indicated that information such as key steps, risks, or cautions are perceived with greater importance, but may get lost in the symptoms of information overload. Making such information more salient was highly desired by participants. Additionally, labeling as well as pictorial realism (i.e., using pictures and diagrams to illustrate parts) were discussed as desirable methods to improve procedures' usability by some of the respondents.

*"...what I'd like to do in my time we used to make [cautions] bold. 'This is now critical'. And then I am involved in after them... **I would like them very bold or make them even in red color code.**"*

*"... I might read and then I **don't know what that part is, but if you show me the picture of it,** I can go to that part and be comfortable with it... Now, I'm not saying all of them are like that. Some of them do have the picture. But that... [picture] is like micro sized and it's in black and white."*

*"If it's something that's fairly routine, you can take it, label the valves, and **have a diagram** where the procedures/job aid says 'turn valve', 'open valve'..."*

4. Discussion

Some of the gaps identified in the analysis presented here are consistent with the findings by previous similar studies (e.g., Bullemer and Hajdukiewicz, 2004; Jamieson and Miller, 2000), specifically, the challenges regarding the change process and the resulting distrust of procedures by workers, the need for having updated and accurate procedures, and procedures not being presented in a clear manner that facilitated their use in the field.

However, this study also identified new concerning elements related to procedure deviation or disuse, namely: effects of the environment, unintended consequences of handhelds (digital access), changes to procedures often being reactive, emergency procedures not necessarily being used as intended, frequency of the task, and impacts of the workers' native language with understanding procedures. Handhelds and digital access are particularly interesting here in that they present a possible paradigm shift away from *paper* written documents, and possibly tackling the widespread symptoms of information overload and excess documentation while promoting use of the information databases already managing these procedures. These findings complement Hajdukiewicz and Reising (2004), who suggest limited integration of these mobile devices with procedures and databases. On the other hand, sites with handhelds reveal malfunctions in the organizational systems that mirror problems observed with written documents, namely, generating excessive information that can complicate, rather than streamline, plant operations. Future work should investigate proper integration and evaluation of implementing procedures via handheld technologies.

Further, the evidence suggests that procedures are sometimes used merely out of fear for job security which may hinder one's ability to identify or reflect on the accuracy or adequacy of procedures for certain context. Regardless, personnel sometimes deviate from procedures within the bounds of their comfort, experience, and training to accomplish work in a setting that discourages organizational flexibility or seek approval from management to deviate from procedures. Indeed, obstacles such as outdated procedures or even emergency situations could benefit from an organizational flexibility through enabling some autonomy on the part of an operator to respond to situations in line with previous trainings without fear of being punished.

Our findings are in line with the literature (e.g., Iannuzzi and Jamieson, 2015) in suggesting that operator experience level affects procedure usage. Attitudes towards procedures are not generally positive especially among experienced personnel given their extensive training, prior knowledge, as well as efficient teamwork and communication. While using learned responses and previous experiences may promote safety in some time-critical contexts (Park and Jung, 2003), experienced personnel may not find procedures necessary or efficient in all cases. The emerging relationships between frequency of tasks, expertise level, and perceived importance have been discussed in Vicente and Rasmussen's (1992) classification of complex human-machine systems where it is suggested that the current model of having all procedures presented in the same format may not be the best model. Specifically, Vicente and Rasumussen identified 3 types of events: (1) unfamiliar and unanticipated events, (2) familiar events, and (3) unfamiliar but anticipated events. Our findings suggest that some operators rarely rely on procedures during unfamiliar and unanticipated events, instead relying on training and experience to "just get the situation under control." Often, they mentioned that they may refer to the procedure after the system had been returned to a steady state but that using written procedures during an abnormal or emergency situation was often logistically impossible. This is in line with Bullemer et al.'s (2011) finding that suggest the majority of the procedure usage failures in this domain are associated with abnormal situations. Unfamiliar but anticipated tasks fall under the domain of safety critical tasks, and our findings suggest participants are most likely to use procedures for these operations and that current formats are best suited for these types of events. However, this does not seem to be the case for familiar tasks. With familiar tasks, training, automaticity, and complacency are key components regarding reported procedural deviation, slips, and lapses. Future research should focus on identifying how to best support workers' adherence to standardized procedures for tasks done frequently and as they progress from a novice to an expert with the tasks and environment.

While this paper documented the results of the initial and focused coding phases, and identified some interrelations between codes and categories that informed several theories, the detailed documentation of new theories and their impact on procedure usage in petrochemical and refinery plants is the subject of a future publication. Work is in progress to compare different sites in terms of specific contextual variables such as cultural and organizational factors, as well as expertise and task frequency to inform a set of context-specific recommendations regarding procedures' usage, adoption, and proper form. These contextual considerations will reveal the extent to which findings *cannot* be generalized across sites, such as those immediate opportunities for improvement in tackling translation issues in international sites.

5. Conclusion

A large-scale study was conducted to investigate the issues pertaining the use of procedures in petrochemical and refinery industries. A large sample of 72 operators from 5 companies were interviewed across 9 international sites. A rigorous coding mechanism was used to understand the main constructs and their interrelations. This paper provides an overview of some of the important topics discovered. The findings of this study indicate that while the perception of procedures among operators is generally positive, there are several issues that contribute to deviation, disuse, or frustration. In line with previous findings, outdated procedures plagued by information overload contribute to deviation and abundance. Further, current trends show a reactive organizational behavior surrounding procedures, a general disconnect between users of these documents and those who write them, and, some sites using a punitive culture around procedural adherence. Interviews suggest that experience level of the worker and the frequency of the task—NOT the criticality of the task—has reliable influence on workers' use of and perceived importance of the use of written procedures in their current format. Work is in progress to identify complex relationships between the identified constructs. In future reports, we will present the findings as well as several context-dependent variables that effect procedure use in petrochemical and refinery industries.

Acknowledgements

This work was supported by a joint effort funded and supported by ATR®, Chevron, ExxonMobil, Nova, NASA, Maersk, and ConEdison. We thank Paul Ritchey, W. Sloane Hoyle, Kathryn Tharpe, Pranav Kannan, and Abbe Barr for their help in data collection and analysis. We thank the members of the Applied Cognitive Ergonomics Lab (ACE Lab) at Texas A&M University for their insightful review and feedback.

References

Alper, S.J., Karsh, B.-T., 2009. A systematic review of safety violations in industry. Accid. Anal. Prev. 41 (4), 739–754, http://dx.doi.org/10.1016/j.aap.2009.03.013.

Bates, S., Holroyd, J., 2012. Human Factors that Lead to Non-Compliance with Standard Operating Procedures. Health and Safety Executive Laboratory Research Report RR919, Retrieved from http://www.hse.gov.uk/research/rrpdf/rr919.pdf.

Bryman, A., 2015. Social Research Methods. University Press, Oxford.

Bullemer, P.T., Hajdukiewicz, J.R., 2004. A study of effective procedural practices in refining and chemical operations. Proc. Hum. Factors Ergon. Soc. Ann. Meet. 48 (20), 2401–2405, http://dx.doi.org/10.1177/154193120404802006.

Bullemer, P.T., Kiff, L., Tharanathan, A., 2011. Common procedural execution failure modes during abnormal situations. J. Loss Prev. Process Ind. 24 (6), 814–818, http://dx.doi.org/10.1016/j.jlp.2011.06.007.

Bullemer, P.T., Nimmo, I., 1994. Understanding and supporting abnormal situation management in industrial process control environments: a new approach to training. Proceedings of IEEE International Conference on Systems, Man and Cybernetics vol. 1, 391–396, http://dx.doi.org/10.1109/ICSMC.1994.399870.

Carim Jr., G.C., Saurin, T.A., Havinga, J., Rae, A., Dekker, S.W.A., Henriqson, É., 2016. Using a procedure doesn't mean following it: a cognitive systems approach to how a cockpit manages emergencies. Saf. Sci. 89, 147–157, http://dx.doi.org/10.1016/j.ssci.2016.06.008.

Corbin, J., Strauss, A., Strauss, A.L., 2014. Basics of Qualitative Research. SAGE.

de Brito, G., 2002. Towards a model for the study of written procedure following in dynamic environments. Reliab. Eng. Syst. Saf. 75 (2), 233–244, http://dx.doi.org/10.1016/s0951-8320(01)00097-7.

Degani, A., Wiener, E.L., 1997. Procedures in complex systems: the airline cockpit. IEEE Trans. Syst. Man Cybern. A: Syst. Hum. 27 (3), 302–312, http://dx.doi.org/10.1109/3468.568739.

Dekker, S., 2003. Failure to adapt or adaptations that fail: contrasting models on procedures and safety. Appl. Ergon. 34 (3), 233–238, http://dx.doi.org/10.1016/s0003-6870(03)00031-0.

Dien, Y., 1993. Safety and application of procedures or: how do they have to use operating procedures in nuclear power plants (No. EDF-93-NB-00143). Electricite de France (EDF), Retrieved from http://inis.iaea.org/Search/search.aspx?orig_q=RN:26037810.

Hajdukiewicz, J., Reising, D.V., 2004. Effective Practices in Deploying Mobile Computing Devices for Field Operations in Process Industries. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting. September. SAGE Publications, Sage CA, Los Angeles, CA, vol. 48, no. 10, pp. 1155–1159.

Human Factors in Reliability Group, Violations Sub-group, 1995. Improving Compliance with Safety Procedures: Reducing Industrial Violations. HSE Books, London.

Iannuzzi, M., Jamieson, G.A., 2015. Usability of paper-based industrial operating procedures. Proceedings of the 9th International Topical Meeting on Nuclear Plant Instrumentation, Control & Human-Machine Interface Technologies, 229–240, La Grange Park, IL: American Nuclear Society.

Jamieson, G.A., Miller, C.A., 2000. Exploring the "culture of procedures". Proceedings of the 5th International Conference on Human Interaction with Complex Systems, 141–145, Retrieved from http://cel.mie.utoronto.ca/wp-content/uploads/HICS00_JamiesonMiller.pdf.

Lawton, R., 1998. Not working to rule: understanding procedural violations at work. Saf. Sci. 28 (2), 77–95, http://dx.doi.org/10.1016/S0925-7535(97)00073-8.

Lombard, M., Snyder-Duch, J., Bracken, C.C., 2002. Content analysis in mass communication: assessment and reporting of intercoder reliability. Hum. Commun. Res. 28 (4), 587–604.

Mullen, J., 2004. Investigating factors that influence individual safety behavior at work. J. Saf. Res. 35 (3), 275–285, http://dx.doi.org/10.1016/j.jsr.2004.03.011.

Park, J., Jung, W., 2003. The operators' non-compliance behavior to conduct emergency operating procedures—comparing with the work experience and the complexity of procedural steps. Reliab. Eng. Syst. Saf. 82 (2), 115–131, http://dx.doi.org/10.1016/S0951-8320(03)00123-6.

Park, J., Jung, W., Yang, J.-E., 2013. Investigating the appropriateness of a decision chart to characterize the level of task descriptions in nuclear power plants. Prog. Nucl. Energy 66, 41–51, http://dx.doi.org/10.1016/j.pnucene.2013.03.004.

Occupational Safety and Health Administration, 2000. Process safety management, https://www.osha.gov/Publications/osha3132.html. (Retrieved 24 March 2017).

Roth, E.M., Mumaw, R.J., Lewis, P.M., 1994. An Empirical Investigation of Operator Performance in Cognitively Demanding Simulated Emergencies (No. NUREG/CR-6208). Nuclear Regulatory Commission, Washington, DC (United States). Div. of Systems Research; Westinghouse Electric Corp., Pittsburgh, PA (United States). Science and Technology Center. Retrieved from https://www.osti.gov/scitech/biblio/10168347.

Saurin, T.A., Gonzalez, S.S., 2013. Assessing the compatibility of the management of standardized procedures with the complexity of a sociotechnical system: case study of a control room in an oil refinery. Appl. Ergon. 44 (5), 811–823, http://dx.doi.org/10.1016/j.apergo.2013.02.003.

Savioja, P., Norros, L., Salo, L., Aaltonen, I., 2014. Identifying resilience in proceduralised accident management activity of NPP operating crews. Saf. Sci. 68, 258–274, http://dx.doi.org/10.1016/j.ssci.2014.04.008.

Vicente, K.J., Rasmussen, J., 1992. Ecological interface design: theoretical foundations. IEEE Trans. Syst. Man Cybern. 22 (4), 589–606, http://dx.doi.org/10.1109/21.156574.