Human Factors and their Optimization

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Prepared for Presentation at
8th Global Congress on Process Safety
Houston, TX
April 1-4, 2012

Keywords: human factors, human error, process safety, preventing errors

ABSTRACT

Weak control of human factors leads directly to error. An error can result in an initiating event of an accident sequence (directly by the mistake made or indirectly, such as by a process control loop failing prematurely). Human error is also the cause of failure of each layer of protection. This paper discusses each of the 10 primary human factors and describes what we know about their relative importance in accident causation. The data presented is from basic research by the authors on the root causes of more than 2000 accidents and near misses; and also based on the review on the review of hundreds of accidents analyzed by others and on summary data from many companies. This paper lists where focus should be placed (i.e., which human factors tend to be key) and provides proven ways to optimize these human factors so that the base human error rate at a site is

as low as possible. Tie in to other applications, such as determining the probability of human error for risk analysis is also presented. Case studies and examples are used to illustrate key points. This paper is a follow-on to *Human Factors Elements Missing from Process Safety Management (PSM)*, presented in 2010 at the 6th Global Congress on Process Safety, AICHE.

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INTRODUCTION

All accidents (or nearly all, if you consider that there are some natural phenomena that we either cannot guard against or choose not to guard against) result from human error. This is because humans govern and accomplish all of the activities necessary to control the risk of accidents. Humans influence other humans in the process – not only do humans cause accidents (unintentionally) by making errors directly related to the process itself, but they also cause errors by creating deficiencies in the design and the implementation of management systems (i.e., we make errors in authorities, accountabilities, procedures, feedback, proof documents and continual improvement provisions). Ultimately, these management systems govern the human error rate directly contacting or directly influencing the process. The process-related activities where errors have the most influence include:

- Designing a process
- Engineering a process
- Specifying components
- Receiving and installing equipment
- Commissioning
- Operating a process
- Maintaining, inspecting and repairing a process
- Troubleshooting and shutting down the process
- Managing process, procedure, materials, facility and personnel changes

ALL accidental losses (except for natural disasters) begin with a human error *(supported by data from more than 1500 investigations catalogued by PII; plus hundreds of thousands by others)*

Root causes of accidents are management system weaknesses
(Center for Chemical Process Safety, American Institute for Chemical Engineers, "Guidelines for Investigating Chemical Process Incidents", 2003) – OSHA agrees

Weak Management Systems → Human Error → **Accidents**

Recent major accidents have highlighted the need for increased focus on human factors. The U.S. Chemical Safety Board (CSB) cited (US CSB Video, 2006) human factor deficiencies as one of the main contributors of the catastrophic accident at the BP Texas City Refinery in March 2005. The human factor deficiencies included lack of control of worker fatigue, poor human-system-interface design, poor communication by radio/phone, out-of-date and inaccurate operating procedures, and poor (no) communication between workers at shift handover. The CSB cited similar issues from many other accidents and has urged industry and the U.S. OSHA (the regulator) to pay much more attention to human factors. As a result, the recent U.S. OSHA National Emphasis Program for Refineries included human factors as one of the 12 core elements.

Implementing human factor engineering and policies to prevent accidents is not a new concept. Nearly all (or all, from a more complete perspective) of the causes and root causes of major accidents in the past 30 years have been the result of poor control of human factors. This has been cited in many root causes analysis reports and papers concerning these major accidents.

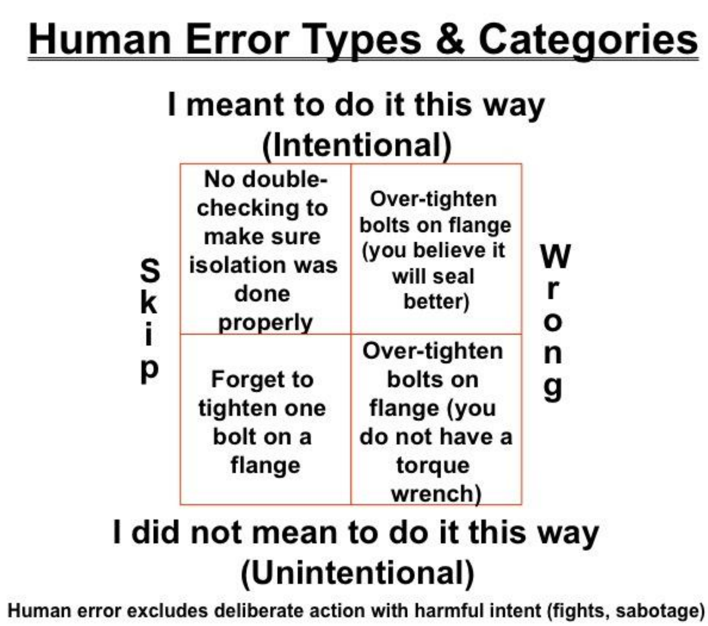
Process Safety Management (PSM) systems based on OSHA's PSM standard are likely lacking the fundamental human factor elements and implementation guides that, if applied across the applicable PSM elements, would work together to reduce human error. The newly developed *Risk Based Process Safety* industry guideline from the CCPS/AIChE (2007) does contain these human factor requirements.

Definitions for Use in This Paper:

- This paper will use the term **Human Error** to mean the errors that are made during direct interface or direct influence of the process.
- **Human Factors** are those aspects of the process and related systems that make it more likely for the human to make a mistake that in turn causes or could cause a deviation in the process or could in some indirect way lead to the increased probability of an accidental loss.
- **Management systems are** the administrative controls an organization puts in place to manage the people and workflow related to the process under consideration, and so these inherently attempt to control human factors.

Note that there is confusion in terms across the industry. In occupational safety, the terms unsafe act and unsafe condition are commonly used; these terms have been in use for more than 80 years. It is best to drop these terms in favor of the terms human error and component failures and natural phenomena; doing so will allow all problems within an organization to be grouped together. For instance, if a mechanic made a mistake that led to a process component failing prematurely and causing a loss of production, this is not necessarily unsafe. But, very similar errors on a different process or different component in the same process could result in harm to people along with loss of production. An organization needs to learn from all mistakes.

Types of Human Error: In simplest terms, there are only two types of human error: *Errors of Omission* (someone skips a required or necessary step) and *Errors of Commission* (someone performs the step incorrectly). In addition, these errors occur either inadvertently (unintentional error) or they occur because the worker believes his or her way is a better way (intentional error but not intentional harm). Intentional errors can usually be thought of as errors in



judgment. Some believe a "lack of awareness of the risk" causes these errors, but in actual practice, the worker who commits an intentional error is well aware of the risk. They instead believe they know a better way to accomplish a task, or they believe there are already too many layers of protection (so bypassing one layer will not cause any harm).

Regardless of type or category of human error, the organization can and should exert considerable control of the errors.

STATISTICAL LIMITS OF CONTROL OF HUMAN ERROR RATES

Not all errors can be prevented. Since the beginning of time, humans have tried to control error rate with more or less success. Human errors have been measured for hundreds of years. Psychologists have studied why humans make mistakes and have gradually put a science around human error probability. Today, the best models for control of human error in the workplace are generally agreed to be related to control of human factors; in turn, these have grown out of what was previously denoted performance shaping factors. Human factors, and the relative importance of each, are discussed in greater detail in the next section.

It is important to understand that with excellent control of all of the human factors, which will be discussed next (requiring excellent design and implementation of management systems for each human factor), a company can begin to approach the lower limits that have been observed for human error. The first, best detailing of the lower limits was by Alan Swain and H Guttmann (NUREG-1278, 1983) and by others. However, many times, the limits they referenced get used out of context. The lower limits in the NUREG-1278 assume excellent human factors, but such excellent control is rarely, if error achieved. Additionally, some human errors listed by Swain or others were for a single error under highly controlled conditions or on a "best day" instead of average error probability or rate over an average year of tasks. In general, we have found it best to use the following average error probabilities:

Error Probability for Initiating Actions: This is for actions that do not have to become accomplished in a specific time frame to be effective (so these do not include response to alarms, or similar actions with time limits). Of course, there is always pressure from the organization (business goals) to accomplish tasks in a timely, efficient manner. The values below are the lower limits for human error rates which we use, assuming excellent control of human factors, these are expressed as the probability of making a mistake on any step:

- 1/100 - process industry; routine tasks performed 1/week to 1/day. *This rate assumes excellent control of all human factors. Most places we visit, the workers and managers and engineers believe this is achievable, but not yet achieved.*
- 1/200 - pilots in the airline industry; routine tasks performed multiple times a day with excellent control of human factors. *This average has been measured by a few clients in the airline industry, but for obvious reasons they do not like to report this statistic.*
- 1/1000 - for a reflex (hard-wired) action, such as either proactive or minor corrective actions while driving a car, or very selective actions each day (on a couple) where your job depends on getting it right each time and where there are error recovery paths to correct the mistake. *This is about the rate of running a stop sign or stop light, given no one is in front of you at*

the intersection; the trouble is measuring this error rate, since you would have to recognize (after the fact) that you made the mistake.

Example: One of the authors has been working at client sites (not in a home office) for 100 days a year for 20 years; most of this teaching courses to engineers at plant sites. This requires use of laptop each of those days. The laptop is also used in a hotel each evening after work; this is normally with the power cord attached. So, there have been 2000 opportunities to mistakenly leave the power cord in the hotel room. This would be very bad for business. Overall, the power cord has been left in the hotel room three times. That error rate, which includes some error detection and recovery, is about 1/700. So far, the related error of leaving the power cord at the client site has not occurred, but there have been about three near misses and then error recovery worked.

Coupled Error Rates: This is the probability of repeating an error, i.e., performing a second task wrong after the first task (the same task or one with the same goal) was done wrong:

- 1/20 to1/90 - if the same tasks are separated in time and if visual cues are not present to re-enforce the mistake path. *This error rate assumes a baseline error rate of 1/100 with excellent human factors. If the baseline error is higher, then this rate will increase as well.*
- 1/2 - if same tasks performed back-to-back and strong visual cue is present. *This error rate assumes a baseline error of 1/100 with excellent human factors. If there the baseline error is higher, then this rate will increase as well.*
- Two or more people become the same as one person (with respect to counting of errors from the group), if people are working together for more than three days; this is due to the trust that can rapidly build.

Response actions (time driven): This is the probability that the correct action will be completed within the time necessary, but after that time, the action will not help (so would be the same result as not doing the task).

- 1 to 1/10 - if practiced/drilled once per year and there is not sufficient time to accomplish the response task. *It may get done in time on selected occasions, but you cannot count on there always being sufficient time available.*
- 1/10 - if practiced/drilled once per year and if there is always sufficient time, theoretically, to accomplish the response task. *This error rate assumes excellent human factors related to response actions.*
- 1/100 - if practiced/drilled once per week and there is sufficient time to accomplish response task. *This error rate assumes excellent human factors related to response actions.*

Adjusting the lower limit rates to estimate a baseline rate at a site

As mentioned earlier, the lower limit rates assume excellent (but not perfect) control of human factors in the industry mentioned. Note that airline pilots have a lower error rate than what we have measured in the process industry. This is due, in part, to the much tighter control by the airlines and regulators on factors such as fitness-for-duty (control of fatigue, control of substance abuse, etc.). Due to sheer numbers of operators and maintenance staff, we doubt the process industries will ever go to the extremes necessary to match the level of error rate control practiced by the airline industry.

Excellent control of human factors is not achieved in many organizations. In those cases, the human error rates will be higher than the lower limit, perhaps much as much as 20 times higher. The table on the next page provides adjustment factors for each human factor. These factors can be used to adjust the lower limit of error rate upward, but the factors should not be applied independently. For instance, even in the worst situations, we have not seen an error rate for an initiating event higher than 1/5:

- 1/5 - highest error rates with poor control of human factors; this high rate is typically due to high fatigue or some other physiological or psychological stress (or combination). This is the upper limit of error rates observed with poor human factors and within the process industry. *The error rates in the Isomerization Unit the day of the accident at BP Texas City Refinery were about this rate. The operators, maintenance staff and supervisors had been working about 30 days straight (no day off) of 12 hour shifts.*

Table 1. SUMMARY TABLE of 10 HUMAN FACTOR CATEGORIES

Based in part on: Gertman, D.; Blackman, H.; Marble, J.; Byers, J. and Smith, C., The SPAR-H Human Reliability Analysis Method, NUREG/CR-6883, U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington, DC, August 2005. Another US NRC initiative, NUREG/CR-6903, Human Event Repository and Analysis (HERA), 2007 (prepared by B. Hallbert, A. Whaley, R. Boring, P. McCabe, and Y. Chang), builds on the human factors categories described in SPAR-H in order to develop a taxonomy for collection of human error data from events at nuclear power plants. PII has modified the list slightly to account for general industry data and terminology and to incorporate PII internal data.

Human Factor Category	Human Factor Issue/Level	Multiplier for Cognitive & Diagnosis Errors
1. Available Time	Inadequate time	P(failure)=100%
	Barely adequate time (≈2/3 x nominal)	10
(includes staffing Issues) – for responses only	Nominal time 1	1
	Extra time (between 1 and 2x nominal and >than 20 min)	0.1
	Expansive time (> 2 x nominal and > 20 min)	0.01
2. Stress/Stressors	Extreme	5
	High	2
(includes staffing issues)	Nominal	1
3. Complexity & Task Design	Highly complex	5
	Moderately complex	2
	Nominal	1
	Obvious diagnosis	0.1
4. Experience/Training	Low	10
	Nominal	1
	High	0.5
5. Procedures	Not available	20
	Incomplete	10
	Available, but poor	5
	Nominal	0.5
	Diagnostic/symptom oriented	1
6. Human-Machine Interface (includes tools)	Missing/Misleading	20
	Poor	10
	Nominal	1
	Good	0.5
7. Fitness for Duty	Unfit (high fatigue level, illness, etc.)	20
	Degraded Fitness	5
	Nominal	1
8. Work Processes & Supervision	Poor	2
	Nominal	1
	Good	0.8
9. Work Environment	Extreme	5
	Good	1
10. Communication	No communication or system interference/damage	10
	No standard for verbal communication rules	5
	Well implemented and practiced standard	1

OPTIMIZING HUMAN FACTORS

Many site and company staff do not know there are standards for the control of human factors. However, at last count there were more than 300 non-governmental standards (such as from ANSI, ISO, IEEE, etc.) for the control of human factors, and there are more than 100 government regulations and standards and guidelines. Some of the better government regulations cover aviation, marine operations (shipping) and aerospace. An organization should devote resources to finding and implementing such best practices.

The following is a description of each of the human factors mentioned above and specific ways to control each. Our data from review of more than 2000 incidents reveal that:

- 90% of accidents had at least one root cause related to deficiencies in written work instructions.
- 70% of accidents had at least one root cause related to miscommunication between workers or between workers and supervisors.
- 40% of accidents had at least one root cause related to excessive fatigue of the worker.

Therefore, we will devote more relative space to discussion of these three human factor categories.

1. AVAILABLE TIME FOR THE TASK:

The available time for the task refers to the time the task is expected to be completed. In many cases the time determined for particular processes are determined using the theoretical times where the conditions are the "ideal" and not necessarily realistic. When task and process duration are not realistic people tend to "find the best and easy way" to get it done, ultimately creating latent conditions for error occurrence. This applies for mistakes that can be initiating events. For mistakes related to responses to alarm, the time is the most critical parameter, since failure to complete the response in time can lead to some consequence, such as a process shutdown or worse.

Why is it important?

The worst enemy for quality of performance is hurry. Operating under tight deadlines and trying to achieve unrealistic metrics increases the *level of pressure to complete work.* These increases reach a point where the emphasis may shift to "just get it done" and "check the box" wherein appropriate controls are bypassed in favor of achieving the goal. As a result, mistakes are made and not caught. Standards are not followed and variation increases. Fatigue and stress levels increase and ultimately accidents happen.

What to do?

Task design is directly linked with this category. Process design, procedure development and worker scheduling need to take into consideration not only the time it takes to complete each task but also the time it takes to manage usual as well as potentially unusual or unexpected situations.

True; we do not create norms for exceptions, but exceptions sometimes are more usual than realized.

Specific Example: For tasks related to response to alarms, make sure you have time to detect the alarm, diagnose the problem, and complete the full response. If the process excursion or similar problem does not allow enough time for these actions, then consider automating the response. As a general rule, a human needs 10 minutes or more to accomplish a response correctly and within time, about 90% of the time.

2. STRESS/STRESSORS

Work Stress refers to the emotional response that arises when work demands exceed the person's capacity and capability to cope. Stress has been associated with absenteeism, is a significant cause of illness and disease, and is known to be linked with high levels of staff turnover and other indicators of organizational performance issues, including human error. Some processes have been designed paying little attention to job design, work organization and management systems. Lacking to fulfill this requirement eventually results in work stress.

Staffing levels directly impact this human factor. An adequately staffed organization ensures that personnel are available with the proper qualifications for both planned and foreseeable unplanned activities. Issues with staffing include selection of right staff for a job and avoiding staff overload (but also avoid having too many staff during lulls, when lack of stress will lead to boredom or distracting activities, which in turn lead to more errors).

Why is it important?

Stress decreases working memory capacity, resulting in distraction. Attention is critical for identifying the onset of problems. Also long term memory is affected, causing delays in action and increasing task difficulty (attention effect). Another effect of stress is its impact on the quality of decision making and rule based actions.

What to do?

A well-designed, organized and managed work process helps maintain and promote individual health and well-being, but stresses will arise through no fault of the organization. Supervisors should be trained to recognize stress in workers and, in severe cases, reassign them and help them get assistance to deal with the stress and in other cases, reduce their job pressures for a day by shifting assignments. A wellness program may also be necessary to help cope with stress. Simple approaches, such as training workers to recognize and deal with stress, can help most individuals. Approaches to deal with stress include positive self-talk and practicing relaxation techniques (i.e., breathing control).

3. COMPLEXITY & TASK DESIGN

The risk of errors due to poor task design relates to the definition of tasks and the interactions among multiple work members, and between the work members and equipment and systems, and between different work groups.

As the volume of systems, variety, integration and coupling increases, so does the inherent complexity of the environment and tasks. Tasks should be designed considering human limits, since it is more likely to be accomplished that way than if one assumes humans can and will "always" do what is supposed to be done correctly. For instance, a worker cannot be expected to do a boring task more than 30-45 minutes at a time; after that, statistics (Swain, 1983) show that worker error rates increase rapidly due to day dreaming.

Why is it important?

Humans do not operate in a vacuum; experience and other elements effect how we think, remember, and in how we factor prior data and prior knowledge and compare it to today's task. Included in the analysis is the multitasking myth. A person split between a given numbers of tasks is likely to make mistakes due to shifts in concentration and delays between actions. As the number of tasks increases, and more attention is compromised, the likelihood of error increases.

What to do?

If roles and responsibilities for accomplishing tasks are not clearly defined, then there will be a risk of serious errors. It is also important that employees and engineers/designers understand the characteristics of the work elements involved, how each element passes information to the other, how each person involved communicates, and that each person has guidelines to adhere to during task design and procedure development.

For optimal performance, task designers often must integrate human and automated equipment in their task analysis.

Specific example*:* If the task is response to an alarm and if the time available is not practical for the human to take action the vast majority of the time, then the designers should make sure this task is assigned to a computer (the automated operator) instead. Similarly, if the valve is too large for an operator to turn quickly, but it must be, then a remote valve actuator is needed.

It is crucial for task designers also to have an understanding of the appropriate allocation of roles and responsibilities to the various participants in a task. Understanding the characteristics and limitations of all of the humans and automated systems involved in the task (particularly critical tasks) will allow for establishing additional controls where needed.

The task analysis process includes *Task definition* which is the initial operational description of the operator tasks required for execution of a given system function; *Performance analysis* of all tasks with respect to human performance requirements; *Error and workload analysis* to be included in the design process, particularly when the likelihood of unacceptably operator error is high; and *Evaluation* since evaluating the design of a new or complex task is important to ensure that the task can be effectively performed as designed. For very high consequence scenarios involved complex human interaction, it is likely prudent to invest in a human reliability analysis (HRA).

4. EXPERIENCE/TRAINING

Training refers to the process of workers developing an accurate mental model of the process system so they can perform the assigned tasks correctly, diagnose process upsets properly and quickly, and understand the consequences of their actions. The only way such mental models can be built is for operators to be thoroughly trained not only in *what/how* to do something but also in *why* to do it. Also, workers should be required to demonstrate their proficiency (via tests, talk-troughs, etc.) before being allowed to work independently. Training must be reinforced with periodic drills so workers can practice and perfect their skills.

Why is it important?

Full Knowledge and (mastery of) Skills and Abilities (KSAs) are predictors of success. They are basically the vaccine for errors. Lack of KSAs causes failure in judgment when making decisions. Also a lack of knowledge about the science of the different processes and the consequences of deviating from written instructions and policies can result in poor decisions of action when managing unexpected situations.

What to do?

Training to master the KSAs required for a job may be obtained from a variety of sources. Companies provide the training or it is obtained from other sources (e.g., trade schools, universities, contractor organizations, etc.) to reach the skills and knowledge established in job descriptions. There are several factors that may result in personnel not mastering the required KSAs for a job. These include course design and delivery methods, course completion, practical skills demonstrations or simulation, and training frequency. Course design begins when the learning objectives have been identified. The design process consists of determining the delivery methods (simulator, on-the-job training, etc.), number of hours required to cover the materials, instructor qualifications, etc. Although some methods, materials and instructors may be more effective or efficient than others, the important issue is that the course content is complete and addresses all of the relevant KSAs, so that the learning objectives are met and the KSAs mastered.

Another determinant of KSA mastery is course completion. Although this factor appears obvious, there are often competing demands on personnel that may pull them out of training at times. As a result, they may miss the instruction related to specific KSAs. Testing may not identify the KSA deficiency because it is impossible to test mastery of all KSAs. Sampling techniques are used to generate examinations. If attendance and participation are not controlled, some personnel may miss training on specific KSAs and testing may not identify the deficiencies before an error is committed.

Another factor affecting KSA mastery is forgetting. An individual's ability to perform a task will degrade over time unless the relevant KSAs are refreshed. Proficiency training (i.e., refresher) will be required for some tasks to maintain the level of mastery that was demonstrated following initial training. One function of training programs is to identify those tasks that require proficiency training.

If certain tasks are performed frequently, proficiency training may be unnecessary. By performing a task, personnel practice the task and obtain feedback on where they have weaknesses. Task performance refreshes the KSAs and successful task performance verifies that proficiency has been maintained. Furthermore, since humans learn by comparison to similar activities, as a worker practices one task, they are learning about similar tasks. Care must be taken here to avoid the practice drifting away from what the procedure requires. Also, if new operators are trained by experienced operators, you must ensure that the new employee is trained according to the procedure, not whatever practice is actually being used. (Of course, ideally, the practice and procedure will be identical.)

Example: For this reason, the U.S. NRC and various chemical companies, such as Dow Chemical, Nova Chemical and Petronas, are learning that when a worker practices response to one high level alarm as part of ensuring a human IPL (independent protection layer) will be perform as intended, the worker is also practicing all similar responses. In this way, a worker may only need to drill on 10% or 5% of alarm responses to attain a 90% proficiency (in response actions and speed) for all similar alarm responses (Bridges 2011).

5. OPERATING AND MAINTENANCE PROCEDURES

Procedures are instructions for performing a task. The instructions may be provided in formal written procedures or as hand-written information included in a work package. Procedure-related errors are errors that occur because some characteristic of the procedure caused task performance to fail. ***This is currently the most critical human factor at most sites since 90% of accidents have at least one root cause related to mistakes within procedures.*** Reducing these procedure deficiencies can reduce human error rates by a factor of 2 to 5, normally.

The primary purpose of procedures is to ensure that tasks are performed correctly. Procedures also can document the best way to perform a task, so work is performed more efficiently. Procedures are used by trainers for initial instruction of newly assigned workers and procedures serve as quick reference guides to experienced workers. Procedures may also serve a record-keeping function to document when and how a task was performed.

Written procedures should embody everything that we know about how to correctly and safely operate a system. Procedures should explicitly state the proper actions a worker should take during start-up, shutdown, normal operation, and upset/emergency conditions and explain the reasons for those actions. Task instructions should be written in simple, understandable language in a format (including appropriate pictures and diagrams) that the workers will use. To help ensure that procedures are accurate and useful, managers should have the workers author and validate the procedures.

Why is it important?

Procedures reduce the likelihood of human errors under several conditions. When a task is complex or performed infrequently, even the most experienced workers may forget the steps required or the order in which certain steps must be performed. Procedures can also fill gaps in a worker's knowledge about a task, component or system. For both of these cases, a procedure will serve as a field reference for experienced workers. Procedures are particularly helpful when plant systems are in an unusual configuration and routine actions, that may normally be performed without a procedure, can result in adverse consequences.

For procedures to be effective in ensuring that tasks are performed correctly, they must be used. There are a number of reasons that workers may not use procedures: a procedure is inaccurate, out of date, there is no procedure or is not available, among others. Data from more than 50 sites has shown that when the procedures are written in the wrong language (engineering language instead of operator language) or when the written steps are less than 80% accurate, the operators stop referring to the written procedures. This is a critical parameter, since across the same 50 sites, procedure accuracy ranged from 30% to 95% accuracy.

What to do?

Many procedures do not follow best practices for controlling human error, and so the written procedure actually "contributes" to increased error rates. Additionally, many organizations do not have guides on how to troubleshoot (what to do when process deviations occur). The best practice rules for writing and validating procedures have been published for many years *(see Bridges, 1997, 2010).* Table 2 is a checklist (in auditing format) based on the current set of best practice rules for developing, operating, maintenance, and other work-instructions (procedures):

Procedures have not traditionally been developed from the perspective of optimizing human factors; instead, procedures have been traditionally developed to meet a compliance requirement to have written procedures. Examples of procedure deficiencies (inaccuracies) include:

- Incorrect/incomplete/nonexistent (most procedures we have audited have been only 70-85% accurate – the inaccuracies include missing critical steps, steps as written are not what needs to be done, or the steps are out of sequence)
- No/misplaced warnings or misuse of warnings (for example, a warning should never **state** the action to take; it should instead **emphasize** the action to take an the statement of the action should be in a numbered step)
- Poor format and presentation rules

Other reasons workers may not use procedures include:

- Procedures are out of date.
- No procedure has been written for the task.
- Users cannot find the procedure they want to use.
- Users do not need a procedure because the task is simple.
- Users need more information than the procedures contain.
- Users see procedures as an affront to their skill.
- Procedures are difficult to use in the work environment.

- Procedures are difficult to understand.

So, in addition to the rules for writing procedures that are shown in Table 2, the organization must also address the reasons that cause the worker not to use the written procedure.

Table 2. PROCEDURE QUALITY CHECKLIST ***(copyright PII, 2003-2012)***

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

3	On average, is there only one implied action per instruction? Best practice is to average 1.2.	
4	Does the procedure indicate when sequence is important? • If sequence matters, each step should be numbered (with an integer or letter) • If sequence does not matter, bullet lists should be used	
5	Are only common words used? Apply "education" level test (5 grade reading level is best)	
6	Do all acronyms, abbreviations, and jargon aid understanding? • Develop a list of such terms for use in procedures *and* communication. • Use terms that users use (within reason)	
7	Is each step specific enough? No room left to guess/interpret: • The meaning of a word or phrase (Check vs. Make sure) • The intent of a step or series of steps • A desired quantity or value • To what equipment the step applies	
8	Is the procedure free of steps that require in-your-head calculations? • Values expressed as ranges rather than targets with error bands • Conversion tables, worksheets, or graphs provided where needed	
9	Are graphics to the user's advantage? • No explanatory paragraphs or lengthy instructions that could be replaced by a picture • No impressive graphics that provide no real advantage	
10	Are references to the user's advantage? • No lengthy explanations or instructions that could be replaced by branching to a reference • No references to a procedure that references still another • No gaps or overlaps between this procedure and a referenced document • If branching, must branch to a procedure, not to a specific step in a procedure	
11	Are rules followed for writing warnings, cautions, and conditional steps? • No more than 2 per page • No actions within a warning or caution (actions must always be numbered steps) • Warnings and Cautions contain descriptions of potential consequences	

To develop accurate and useful procedures:

- **Have the worker write the procedure (with consultation with technical staff as necessary).** Development of technically accurate and usable procedures is enhanced by the authorship of the user. They will inherently write in the language used by the other users of the procedure. However, they will need help in the form of training on how to write procedures and they will need access to computers.
- **Have a writer's guide** with the rules that will provide information to procedure writers regarding techniques for formatting procedures, presenting different types of content (e.g., action and decision steps), and for developing usable graphics. If a writer's guide is not followed or it is incomplete, the resulting procedures may be difficult to comprehend and follow.
- **Have other users validate the procedures.** This must be accomplished by a walk down during mock use; simply reading at a desk will not find the errors left by the author.
- **Have the procedure reviewed by technical staff.** Procedure verification is a process that provides a final check on the technical accuracy of the procedure steps and on the procedure's compliance with writers' guide requirements. This likely happened during the procedure writing process.
- **Risk review.** This is performed by a guideword or what-if analysis to ensure that there are enough layers of protection in place in the process when an operator makes a mistake.
- **External review and final approval**. The procedure review and approval process ensures that personnel in all other departments whose work may be affected by the procedure have

the opportunity to review it to assure that activities in their departments are not adversely affected.

- **Revise.** The procedure program should include a process for reviewing and revising procedures when changes occur at the plant that may affect the technical accuracy or usability of the procedures.

6. HUMAN-MACHINE INTERFACE

Human-machine interface errors are one of the biggest sources of errors in any complex system. Many operator errors are attributed to a poorly designed human-computer interface. The *human-system interface* (HSI) is defined as the technology through which personnel interact with plant systems to perform their functions and tasks. The major types of HSIs include alarms, information systems and control systems. But it also alarm management, and device labeling and color coding and error proofing. Many types of HSIs are made up of hardware and software components that provide information displays, which are the means for user-system interaction, and controls for executing these interactions.

Why is it important?

Computer-based control systems can dramatically improve the quality, productivity and safety of chemical processes. However, they are not immune to human errors. Programming errors and erroneous operator inputs account for about 40% of the observed failures of computer-based control systems. To reduce the likelihood of such failures, managers must ensure that workers are properly trained, that software is thoroughly tested, and that programming changes are strictly controlled.

When computer-based control systems are retrofitted to existing processes, managers sometimes try to preserve the old instrumentation as an emergency backup in case the computer fails. (New control rooms usually have multiple computers/terminals that can back each other up.) Even if the old hardware is maintained, the operators' abilities to use the old equipment will quickly deteriorate. As new workers are hired and experienced ones are reassigned, the likelihood of errors will further increase.

Other HSIs, such a labeling and color coding will directly help to reduce human error by allowing the worker to more quickly find the device they are looking for. Alarms are critical interface signals that alert the worker to an upset or other condition they may otherwise fall to detect. Alarms need to be designed to be noticed but not overload the worker with too much simultaneous information.

What to do?

Design for operability refers to designing the HSI to be consistent with the abilities and limitations of the personnel who will be operating it. Weaknesses in the design processes can result in an HSI that is not well suited to the tasks that personnel must perform to ensure plant safety, resulting in increased workload, decreased performance by personnel, and an increased likelihood of errors.

__Example:__ The relief valve on a low pressure separator was actuated during apparently normal operations. Operators verified that the separator pressure was normal, and in their haste to stop the release, they blocked-in the "bad" relief valve before unblocking the parallel relief valve. The separator immediately ruptured and killed two operators. The pressure transmitter on the separator had failed, closing the normal discharge valve and sending a false signal to the control room.

Table 3 lists the typical response times a worker expects from a control system. If these are exceeded, the worker will normally assume they need to re-send the command to the control system. This, of course, can result in many types of process upsets.

System Interpretation	Response Time Definition	Time (Secs)
Key Response	Key depression until positive response, e.g., "click"	0.1
Key Print	Key depression until appearance of character	0.2
Page Turn	End of request until first few lines are visible	1.0
Page Scan	End of request until text begins to scroll	0.5
XY Entry	From selection of field until visual verification	0.2
Function	From selection of command until response	2.0
Pointing	From input of point to display point	0.2
Sketching	From input of point to display of line	0.2
Local Update	Change to image using local data base, e.g., new menu list from display buffer	0.5
Host Update	Change where data is at host in readily accessible form, e.g., a scale change of existing image	2.0
File Update	Image update requires an access to a host file	10.0
Inquiry (Simple)	From command until display of a commonly used message	2.0
Inquiry (Complex)	Response message requires seldom used calculations in graphic form	10.0
Error Feedback	From entry of input until error message appears	2.0

Table 3. MAXIMUM ACCEPTABLE SYSTEM RESPONSE TIMES ***(from the US DOD, 2000)***

Design for maintainability refers to designing the HSI and associated plant equipment to ensure that personnel are able to perform necessary maintenance activities efficiently. Weaknesses in the design process can result in systems that impose excessive demands on personnel for maintenance and, therefore, are prone to maintenance errors or problems with reliability and availability. *If it is hard to reach, workers will make more errors, including the error of deciding it is not worth it.*

Design for flexibility refers to the way that changes, such as upgrades to the HSI, are planned and put into use. A new HSI component may require the user to perform functions and tasks in new ways. Skills that the user developed for managing workload when using the former design, such as ways for scanning information or executing control actions may no longer be compatible with the new design. The new HSIs must also be compatible with the remaining HSIs so that operators can use them together with limited possibilities for human error. Also, HSI modifications may not be installed or put into service all at one time, causing the user to adapt to temporary configurations that are different from both the original and final configurations. Weaknesses in HSI implementation can increase operator workload and the likelihood of errors.

Sources of HSI: The U.S. Nuclear Regulatory Commission (NRC) has promulgated a number standards and guides related to human system interface and other human factor engineering aspects; these apply to plants and control rooms. NUREG-0800 describes the staff's review activities to verify that accepted human factors engineering principles are incorporated during the design process and that they reflect a state-of-the-art of human factors in design. NUREG-0800 provides a reference to NUREG-0711 (Human-System Interface Design Review Model for detailed review. Various organizations, including militaries, have standards for HSIs. One good starting place is the Human Factors and Ergonomics Society (HFES.org); a few example references are:

- BSR/HFES100**,** *Human Factors Engineering of Computer Workstations, 2002.*

- IEEE Std. 1023-2004: *IEEE Recommended Practice for the Application of Human Factors Engineering to Systems, Equipment, and Facilities of Nuclear Power Generating Stations and Other Nuclear Facilities* (Institute of Electrical and Electronics Engineers, issued 2005).

- ISO 11064-1: *Ergonomic Design of Control Centres -- Part 1: Principles for the Design of Control Centres* (International Standards Organization, 2000). Part 2 and 3 of the same standard describe arrangements of control suites and control rooms.

- ISO 9241 -2010: *Ergonomics of human-system interaction (this has many parts related to the design of any system that humans use to interface with equipment and information).*

- *Effective Operator Display Design*, 2008 and also *Effective Alarm Management Practices*, 2009, both by ASM Joint R&D Consortium.

As mentioned at the start of this section, there are ***hundreds of non-governmental standards*** on human factors and about a hundred U.S. (only) government standards on human factors; many of these focus on human system interface issues.

7. FITNESS FOR DUTY

Successful task performance requires that the capabilities workers bring to the task fall within an expected range. Impairment or a reduction in an individual’s mental or physical capabilities due to substance abuse, fatigue, illness, stress or physical limitation (such as weakness following an injury or color blindness) increases the likelihood of errors.

Why is it important?

Barriers to fitness-for-duty-related errors include company programs for the detection and prevention of potential or actual impairment, as well as the individual responsibility of workers to decline assignments if they are impaired for any reason. The latter barrier is a weak one, however, because humans are generally over-confident of their capabilities when under the influence of drugs or alcohol, or are stressed, fatigued or ill. Other factors that may discourage self-reporting include the fear of poor performance reports from bosses or having to pay extra overtime.

Many companies have a program to guard against fitness-for-duty issues related to substance abuse, shift rotation and illness; but some do not. Most companies do not have programs in place to train supervisors how to identify and correct fitness-for-duty issues.

The aspect most commonly lacking is control of fatigue (or normally, lack of enforcement of the company standards for control of fatigue). Fatigue can greatly increase error rates. One study (UniSA, 2006) shows that 17 hours of work (or driving a vehicle) without a break produces the same human error rate as someone who has a blood alcohol content of 0.05 g/100ml and drivers who have been awake for 24 hours have an equivalent driving performance to a person who has a blood alcohol content of 0.1 g/100ml, and is seven times more likely to have an accident. *But note that the effect on the baseline human error rates is even more severe than the overall likelihood of causing a traffic accident; there can be up to 20 times more errors in judgment or errors in decision making, as measured from actual accidents in the workplace*.

According to the aviation and marine industries that have studied fatigue intensively, the overall relationship for fatigue can be expressed as:

Fatigue = function of [(cumulative fatigue) + (shift work fatigue – breaks) - naps]

Most chemical process operations do not allow naps (and have likely never thought of the use of naps) to limit the effect of fatigue. Instead, the hours worked are consecutive and sometimes quite long. In a study by the U.S. DoT (Della Rocco, 2000), the percent of risk of errors increases with the number of consecutive days of work. Even for an 8 hour shift, the error rate doubles by day 5, compared to day 1. Other data has shown that for 10 days straight of 12 hour work-days, the error rates for non-routine tasks such as startup of a continuous unit can increase to 1 mistake in 5 to 10 steps (as opposed to the target of 1 mistake in 100 steps for optimized human factors). *This was similar to the error rate observed during the Isomerization unit disaster mentioned earlier in this paper*.

What to do?

Implement a company fitness-for-duty program with a primary responsibility for detecting and preventing impaired personnel from performing tasks that may affect productivity and safety.

Medical evaluations of personnel, behavioral observation programs, employee assistance programs, and drug and alcohol testing are used to detect impairment. Weaknesses in this program may allow impaired personnel to have access to vital areas in a plant where they could commit errors.

Overtime Policies and Practices – Most companies establish limits for work hours to reduce on-the-job fatigue and the potential consequences for poor task performance. Routine authorization for work hours in excess of those recommended may result in fatigued workers. Furthermore, a practice of excluding training or meetings that occur outside of an individual's normal work schedule from work-hour limitations will also contribute to fatigue. But in many cases these have weak enforcement, especially during shutdowns when the company is under stress to re-start soonest.

In US NRC 10 CFR 26 (2005), the guidance given for control of overtime hours is:

- A maximum of 72 hours of work per six day period.
- A maximum of 16 hours of work in one day (and no more than one 16 hour day within that period).
- A minimum of 24 contiguous hours away from work within a seven day period.

The U.S. NRC guidance also provides helpful guidance on the entire fitness-for-duty program and implementation, covering not just fatigue, but also how to prevent and detect and cope with substance abuse, extreme stress (such as from some issue in home-life), illness, etc.

The U.S. DOT has even more stringent rules on limiting work hours and establishing required hours for recovery from fatigue. The maritime regulators (in the EU, USA, Canada, Australia, etc.) use limits similar to those mentioned above for U.S. NRC. One such standard states:

> ***Article 5***
> *1. The limits on hours of work or rest shall be as follows:*
> *(a) maximum hours of work shall not exceed:*
> *(i) 14 hours in any 24-hour period; and*
> *(ii) 72 hours in any seven-day period;*
> *or*
> *(b) minimum hours of rest shall not be less than:*
> *(i) 10 hours in any 24-hour period; and*
> *(ii) 77 hours in any seven-day period.*

Similar requirements are listed in API RP 755, but unfortunately there is an exception in the standard that allows 15 days straight of work for remote and offshore locations and the same exception applies to maintenance turnarounds/outages. There should be no exceptions if you want to control human error rates. These exceptions substantially limit the effectiveness of API recommended practice since this *will not prevent high fatigue during restart of the process, which is when controls of fatigue are most necessary*.

Shift Scheduling – Shift scheduling may also affect the likelihood that personnel will show performance decrements due to fatigue. A change in the assigned shift or a rotating shift schedule will disrupt circadian rhythms and may increase the likelihood of errors. So, a company must choose the proper shift rotation to allow adjustments to sleep patterns.

8. WORK PROCESSES & SUPERVISION

Supervision is the process by which work is directed and overseen by first-line management. Successful supervision requires a combination of leadership skills and technical competence. Supervision differs from peer checking or quality control because a supervisor has line management responsibility for the worker(s) as well as responsibility for the work activity.

Supervision is more than the moment-to-moment direction of a work activity. Successful supervision requires the assessment and shaping of worker attitudes and motivation, communication and implementation of management expectations for performing work, the assignment of the best-qualified workers to various tasks, as well as the technical competence to identify incorrect actions and stop improper activities before an error is committed. Effective supervision involves directing the work, overseeing how it is performed, and leadership.

Why is it important?

The role of supervision during work preparation is to assure that the personnel who will be performing the task have the information and resources required to perform effectively. These resources include knowledge of the goal(s) of the work activity, as well as management expectations for how the work is to be performed. Goals and expectations are often communicated during pre-job walkthroughs of the task environment and in pre-job briefings. Supervisors may also be required to ensure that the personnel assigned to perform the task are qualified, that the necessary tools and equipment are available, and that procedures and other instructions for performing the task, such as those included in a work package, are complete and understood by the workers. Supervisors may be responsible for verifying that the prerequisite conditions for tagging equipment out-of-service are met before the work begins and for obtaining authorization to start the task. Supervision may play a role in errors through weaknesses in direction, oversight or leadership.

What to do?

Written plant policies and procedures are meaningful only when they are enforced; otherwise, worker practices are the policy. Once discrepancies are tolerated, individual workers have to use their own judgment to decide what tasks are necessary and/or acceptable. Supervisors and managers should vigorously enforce plant policies/procedures and ensure that plant policies/procedures and practices are revised as necessary to be consistent. To enforce well, a supervisor must (1) lead by example, (2) watch workers often to ensure they are following company policies and procedures, and (3) determine the correct course of action (including recommending changes to policy and procedures) when workers are found deviating from procedures.

9. WORK ENVIRONMENT

The task environment refers to the physical conditions in which work is performed. Environmental conditions that can affect performance include excessive vibration and noise, temperature extremes, and insufficient lighting.

Why is it important?

These adverse environmental conditions can stress personnel, interfere with performance, and increase the likelihood that they will commit errors while performing a task. Work conditions that require protective gear, such as high radiation or some confined space environments, or that requires unusual physical postures, also can interfere with task performance, as may poor housekeeping.

What to do?

Programmatic causes of task environment errors are typically found in the company's processes for designing human-system interfaces or in managing maintenance activities. Other programs may also be implicated. Common programmatic causes of task environment errors include:

Industrial Hygiene and Radiation Protection – These programs are responsible for ensuring that task environments have been evaluated to identify hazards and that needed controls are implemented to minimize exposures. Weaknesses in these programs may result in personnel working in task environments that are conducive to errors.

Work Planning and Control - Weaknesses in the work planning and control system may allow work to be planned without consideration of adverse environmental conditions and performed without the necessary compensatory measures. For example, communication devices may not be provided in noisy environments to support task performance. For tasks that involve unusual physical positions or cramped workspace, additional time to complete the task may not be scheduled. Rest breaks for hot and cold environments may not be planned into the work, or additional temporary lighting may not be provided if the work site is not adequately lighted.

Procedures - Weaknesses in the company's procedure development process may result in the design of procedures that are inappropriate for the conditions in which they will be used. For example, procedures that may be used at night, outside and in the rain should be laminated and the type size should be larger to ensure the procedure can be read. Procedures that will be used in vibration conditions may also require larger type size than procedures read in the stationary environment of the control room.

Human Factors Engineering - Weaknesses in the human factors engineering program may result in the installation of new equipment or systems without consideration of task environment characteristics. For example, the impact of control room lighting on the visibility of digital displays or effects of vibration on the legibility of dials or gauges at local control stations should be considered before installation.

Example: Table 4 lists the typical minimum acceptable lighting requirements for a workspace in order to control human error rates.

Operating Experience - Reviews of relevant operating experiences of the plant and other facilities with similar environmental conditions should be conducted to identify and analyze task environment problems and successful mitigation efforts. Personnel may have reported task environment conditions that interfered with performance that are recorded in the company's corrective action database, and corrective actions should have been implemented. Weaknesses in this program will result in repeated errors.

Labeling - Weaknesses in this program may result in tags and plaques that are illegible in the task environment, if low lighting levels or vibration are present.

Work area of type of task	Illumination Levels lux (foot-candles)[1] Recommended	Minimum
Assembly, missile component	1075 (100)	540 (50)
Assembly, general		
Coarse	540 (50)	325 (30)
Medium	810 (75)	540 (50)
Fine	1075 (100)	810 (75)
Precise	3230 (300)	2155 (200)
Bench work		
Rough	540 (50	325 (30)
Medium	810 (75)	540 (50)
Fine	1615 (150)	1075 (100)
extra fine	3230 (300)	2155 (200)
Bomb shelters and mobile shelters, when used for rest and relief	20 (2)	10 (1)
Business machine operation (calculator, digital input, etc.)	1075 (100)	540 (50)
Console surface	540 (50)	325 (30)
Corridors	215 (20)	110 (10)
Circuit diagram	1075 (100)	540 (50)
Dials	540 (50)	325 (30)
Electrical equipment testing	540 (50)	325 (30)
Emergency lighting	NA	30 (3)
Gages	540 (50)	325 (30)
Hallways	215 (20)	110 (10)
Inspection tasks, general		
Rough	540 (50)	325 (30)
Medium	1075 (100)	540 (50)
Fine	2155 (200)	1075 (100)
extra fine	3230 (300)	2155 (200)
Machine operation, automatic	540 (50	325 (30)
Meters	540 (50)	325 (30)
Missiles:		
repair and servicing	1075 (100)	540 (50)
storage areas	215 (20)	110 (10)
general inspection	540 (50)	325 (30)

Table 4. SPECIFIC TASK ILLUMINATION REQUIREMENTS ***(from the US DOD, 2000)***

10. COMMUNICATION

Communication is the exchange of information while preparing for or performing work. Verbal communication occurs face-to-face, by telephone, sound-powered phones or walkie-talkies, as well as over public address systems. Written communication occurs, for example, through policies, standards, work packages, training materials and e-mail.

Communication involves two sets of activities: (1) creating and sending messages and (2) receiving and interpreting them. Communication always involves at least two individuals, the sender and the receiver, and occurs between individuals, within and among work groups, in meetings, in pre-job or pre-evolution briefings, and during shift turnover.

Why is it important?

Most work activities in organizations require coordination within and among work groups. Coordination requires effective verbal and written communication. Communication is necessary to define the work to be done and how to do it, so communication errors are frequently found to be causal factors in events. However, because so many work activities depend on effective communication, a wider variety of programmatic causes are associated with communication errors than with other types of human errors.

Programmatic causes have been shown to cause or contribute to communication errors. Weaknesses in other programs at a plant may also cause communication errors, like *Information management* - Flaws in programs for developing and managing technical documentation, *Work Planning and Control* - Planning and scheduling maintenance activities is a complex task. Weaknesses in work planning and control programs may result in written and verbal communication errors associated with, for example, inadequate work orders, inadequate pre-job briefings, or communication failures during job performance. *Also, shift staffing* - Insufficient staffing can increase the workload for those performing a job, and so interfere with required communications. Increased workload during plant outages and the increased numbers of workers on-site, or increased workload during off-normal events, can tax the supervisory abilities of those responsible for coordinating the work, resulting in incomplete or too few communications.

What to do?

Successful communication requires several steps. The sender first develops the intention to communicate either verbally or in writing. The sender then composes a message that presents the meaning as clearly as possible. The receiver must pay attention to the message and then interpret its meaning. If the communication is successful, the receiver interprets the message consistently with the sender's intended meaning. Table 5 summarizes the rules for successful verbal communication

Table 5. Rules for Effective Verbal (face-to-face, radio, phone) Communication ***(copyright PII, 2012)***

#	Communication Rules
1	Senders MUST require repeat back by the receiver; ask questions to make sure of understanding.
2	Receivers of messages MUST repeat a message they receive.
3	Communicate one task at a time.
4	Sender & receiver must use the standard name and component number (and building name and number) and/or for related reference material (drawing, procedure name/number) in each message.
5	Sender must require receiver to give feedback of foreseeable conflicts. Sender (if message is to subordinate) should follow-up in the field if possible, to make sure message was understood.
6	Receiver must request clarification anytime they believe the message is confusing.
7	Do NOT give verbal instructions to workers who do not have the demonstrated skills to correctly understand and perform the task assignment (unless you plan to supervise/coach the task yourself).
8	Communicate to the most senior member on the work crew.
9	Know your audience & change message accordingly to compensate for lack of knowledge (when appropriate; see other related rules).
10	Use units (and use approved units, such as SI) for process parameters.
11	Always count from left to right when giving instructions related to multiple choices of equipment.
12	Use approved jargon only.
13	Use the words **check**, **make sure**, and **actions** consistently (see procedure writing rules).
14	When possible, write out the task (use a special procedure or work order) rather than communicating verbally. Use formalized templates for consistency and make sure the receiver is provided all information (such as work orders and drawings) necessary for the task.
15	Perform pre-job meeting with work crew (including with contractors or construction company).
16	Perform walkthrough at the location where the work will be completed.
17	Have a backup communication method. Don't rely on one mode of communication. In emergency situations have hand signals as backup to loss of verbal communication.
18	Talk to the operator or technician who is doing the work (no delegation of work); but see Rule 8.
19	Receiver (worker or group) must report back when work is complete.
20	If confusion exists in implementing a task, the shift supervisor (and higher, if supervisor is unavailable) must be contacted to make sure he/she understands the problem.
21	Do NOT use a PA (public address system) for process instructions, since this method of communication does not allow repeat-back.
22	Use Open questions and non-confrontational questioning methods when requesting clarification.
23	When communicating remotely (by phone or radio), if the message is not understood on the second attempt at clarification the Sender must find the Receiver and communicate face-to-face.
24	For large or complicated jobs, in addition to repeat back, the sender must ask the receiver for an assessment of the pre-job briefing to ensure the workers are not confused.
25	Workers and supervisors must keep a shift log to aid in turnover between shifts. Workers and supervisors and support staff (if necessary) must have a minimum or 15 minutes overlap with a relieving shift. *See shift turnover standard for more details.*

The similarity of the meanings given to the message by the sender and receiver can be verified through feedback. An example of feedback verification in verbal communication is when the receiver "repeats back" the message and the sender either agrees with the receiver's repeat back or corrects it. Verification feedback serves an important error-checking function in the communication process. It also allows supervisory oversight of communications to catch errors before they have consequences.

A sender and receiver must both be active for communication to be effective. The sender and receiver share responsibility for ensuring successful communication. However, when companies analyze the causes of events, errors in sending messages are more often identified than errors in receiving. The reasons for the difference are unclear. A company's investigation should consider sending and receiving errors and corrective actions should address both to be effective.

Shift handover is another critical aspect of communication. The status of equipment, repairs that occurred, problems faced, upcoming chores, etc., are all key information the oncoming worker will need to know. One good guide on shift turnover is U.S. DOE 1038-93.

CONTROLLING HABITS

The previous section described direct control of human factors. However, it appears that 10-20% of human errors occur due to bad habits formed over time or instilled by the trainer. Supervisors help to correct most of these habits with frequent observations of workers, but there are not enough supervisors to correct all bad habits. Furthermore, research begun in universities indicated that peers influence habits (behaviors) more than bosses or trainers.

The most effective approach to overcome these types of errors is to have a program of Peer-Peer Observations (PPO) which is termed behavior-based safety observations by many companies. Such programs can eliminate about 70% of bad habits. The contents of such programs include:

1. Developing an inventory of habits you want to correct (collected from worker comments and from incident investigations).
2. Developing a form for recording PPOs, using the positive (reverse) of the bad habits as some of the things to observe; but also include normal, generic aspects of any task, such as preparation steps, tool selection, PPE (if required), etc.
3. Train peers how to do the PPO (this could take 3 hours of training).
4. Train supervisors and managers what to do and what not do (for instance, management and supervision should not interfere with the system or PPOs and should not ask a worker who they observed).
5. Perform PPOs and make sure not to list the name of the peer observed (or the date/time) on the PPO form.
6. The peer should give feedback to the peer on what they did right and what they did wrong.
7. The peer should not focus on the mistakes.
8. The peer should ask the observed what they will do differently next time.
9. The observer gives the checked-off form to their immediate supervisor for credit.
10. All workers should be required to do about four PPOs per month.
11. Update the inventory of habits every six months or so and update the PPO forms.
12. Do not tally the number of unsafe (erroneous) acts; instead just keep score of the PPOs being completed or not.

Table 6 is a typical PPO form. This one is called ***STAR (Safety Task Action Reporting)*** because the client wanted a catchy name to roll out the program.

Table 6: Example of a Peer-Peer Observation Form *(copyright, PII 2005)*

STAR Observation Checklist	Dept:		
	Month/Yr:		
Observer/coach:		Day of Week/Shift:	
Desired Behavior	**Safe** (correct)	**Unsafe** (incorrect)	**NA** or Not Obs
Task Set-up			
SWP and Master Card filled in correctly and completely			
Task set up correctly and clearly by supervisor or others			
Qualified worker is assigned to the task, and the worker knows which task to do and where it needs done and how to do it			
Special equipment set-up/rig complete (includes setting up scaffold, barricades, fork truck, crane, etc., if required)			
JSA is developed/followed for this task (if required)			
Other:			
Task Performance			
The correct tools and specialized equipment are present at the work-site for the task (including bolt tensioner, if required)			
The correct materials and parts are present at the work site for the task			
Workers are doing the job correctly (in general)			
Body positioning is correct to prevent injury/strain			
Other:			
Personal Protective Equipment (PPE)			
Right gloves are present and worn			
Right breathing protection is present and worn			
Right eye protection is present and worn			
Right fall protection is present and worn			
Right hearing protection is present and worn			
Other:			
Work Environment			
Working space is big enough to allow safe movement			
There is a clear way to get out of the immediate area if a problem occurs			
Workers are cleaning up area			
Other Critical Issues (either positive or negative)			

Step 1: Observe a task and score each category above as safe (correct) or unsafe (incorrect) or NA
Step2: Give the co-workers you observed feedback on what they did right and what they did wrong. Do not use "but" to move from positive to negative. Do not emphasize the negatives.
Step 3: Ask (do not tell) the co-workers what they will do next time to avoid the incorrect acts.

CONCEPT FOR SUSTAINABLE CONTROL OF HUMAN ERROR

The first step is always to assess the risk and understand what layers of protection a system needs. This is done with methods such as HAZOP, What-If, job safety analysis (JSA), and reliability center maintenance (RCM) analysis. From this information, the process design and task designs are influenced.

Next, the human factors described in this paper must be optimized to control human error rates so that the initiating events and layers of protection perform as needed (give the hoped for reliability). It will likely take much iteration to optimize each human factor. This paper gave some advice, but you may want to get a much deeper background on human factors to reduce your trial and error. This can be done by reading on the subject, attending courses by experts, and by networking with peers. It may not be obvious, but all elements of process safety are implemented to either control or compensate for human error. Therefore, be sure to read the other papers (Bridges & Tew, 2010) and the CCPS/AICHE Risk-Based Process Safety which illustrate how to integrate all human factors into process safety.

In addition to optimizing human factors, you will likely need to implement a PPO program, similar to the approach described here. This takes effort, but is not complicated. It can be done with the help of one person who has made it work somewhere else.

Of course, to ensure success, you must have strong tracking and enforcement of implementation of controls (performance measures, incentives, discipline day-to-day, leadership, etc.). This applies to implementation of human factors and implementation of a PPO approach.

Although not the focus of this paper, you will also need to get very high reporting rates for near misses to learn quickly (and for low expense) where your systems are weak in controlling human error. This system cannot allow blaming of individuals; instead, it should find and correct management system weaknesses. The investigation results can also help an organization see where it may need additional layers of protection to guard against the consequences of a scenario, especially for the scenarios where human error cannot be further reduced by enhancing human factors or by PPOs. See Bridges, 2012 for the most recent paper on getting near misses reported and investigated.

Of course all of this will take a great deal of work, but the alternative is to allow human error rates to continue at the present level. Implementing the solutions mentioned in this paper can reduce losses by >95% and greatly reduce the number and severity of accidents (perhaps by >90%).

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