Human Factors Elements Missing from Process Safety Management (PSM)

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Abstract

Process safety is about controlling risk of failures and errors; controlling risk is primarily about reducing the risk of human error. All elements of Risk-Based Process Safety (RBPS) and alternative standards for process safety (such as US OSHA's standard for Process Safety Management [PSM] or ACC's Process Safety Code™ [PSC]) have many elements, and each of these in turn helps to reduce the chance of human error or else helps to limit the impact of human error. But each process safety standard has some weakness in the control of human error.

This paper presents an overview of human factor fundamentals, discusses why many PSM systems are weak on human factors and outlines a comprehensive process safety element on Human Factors. It describes what belongs in each category within the Human Factors element and explains the intent, content, and the benefit of each category. The paper also presents examples of Human Factors' deficiencies and selected examples of industry practices for human factors control are provided.

Introduction

All accidents (or nearly all, if you consider that there are some natural phenomena that we either cannot guard against of 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, 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 of a process
- Engineering of a process
- Specifying the process components
- Receiving and installing equipment
- Commissioning
- Operating the process
- Predicting safeguards necessary to control the risk at an acceptable level and sustaining these safeguards for the life of the process
- Maintaining, inspecting and repairing the process
- Troubleshooting and shutting down the process
- Managing Process Changes

99% of accidental losses (except for natural disasters) begin with a human error ***(supported by data from more than 1500 investigations)***

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 US Chemical Safety Board (CSB) cited 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 US OSHA (the regulator) to pay much more attention to human factors. As a result, the recent US OSHA National Emphasis Program for Refineries included human factors as one of the 12 core elements it reviewed in detail across many of the 148 oil refineries in the USA.

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.

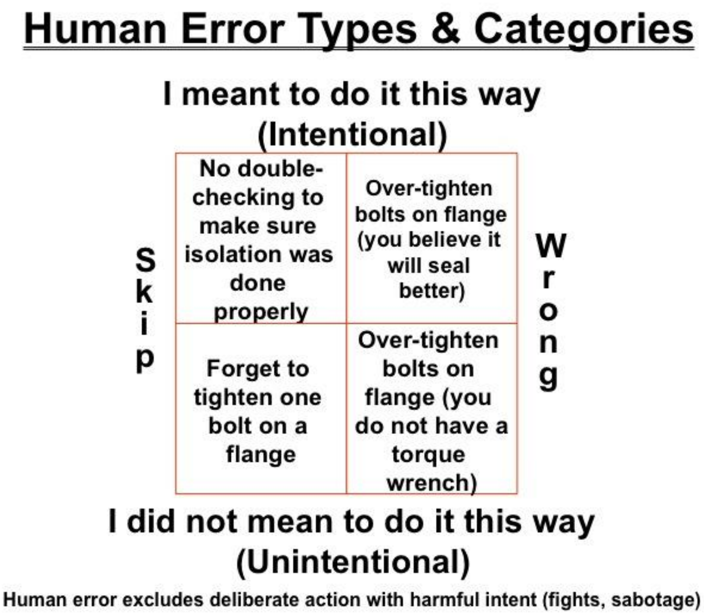
Process Safety Management (PSM) systems based on OSHA's PSM standard are likely lacking the fundamental human factor standards that if applied across the applicable PSM elements, would work together to reduce human error. The newly developed *Risk Based Process Safety* industry standard from the CCPS/AIChE does contain the human factor standards, but these are presented under several PSM elements instead of under a stand-alone human factor element. This guideline does not provide a needed road map to help companies transition to RBPS from the minimum PSM systems defined in OSHA's PSM standard. A starting point for this transition should be implementing a human factor element comprised of the human factor categories missing from most PSM systems (especially from those based on the OSHA PSM standard).

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

Human Error Fundamentals

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 wrong). But 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.

Relationship of Control of Human Error to Control of Risk from an Activity or Process

A process is a combination of the utilities, raw materials, and human actions (direct actions and those actions involving programming the process to accomplish automatic functions). If anything goes wrong with these Inputs, or if there are basic design flaws or basic fabrication flaws in the process, then the Outputs will not be desired. The desired output is acceptable (or high) production rates at acceptable or higher quality factors with no harm to the humans (long term or short term), no harm to the environment, and with acceptable (or higher) life of the process components. The negative outcomes resulting from humans failing to control the raw material quality, failing to control the utility levels consistently, making errors directly related to the operation of the process, or making errors in the care of the process (such as maintenance) will result in lower production, lower quality, higher number and severity of safety-related accidents, and more negative impact on the environment. The potential (probability) of the negative outcomes is collectively referred to as ***business risk*** – more precisely, the risk is a product of the likelihood of one or more of these negative outcomes and the severity of each outcome.

A critical concept is therefore:

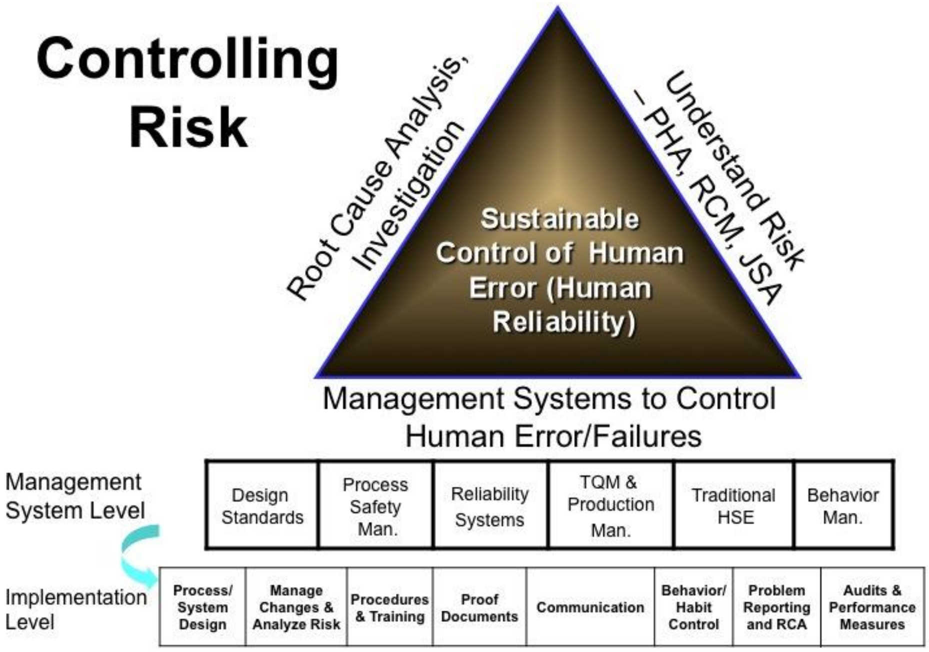
> ***If an organization does not directly control risk, the organization cannot directly control quality, safety, environmental impact, or production to acceptable levels. An organization must sustainably control human error to manage the risk of accidental losses that impact quality, safety, the environment, production, or assets.***

In order to sustainably control the risk of a complex process (such as an oil/gas operation, refinery, chemical plant, steel plant, automobile manufacturing, aircraft manufacturing, etc.), the organization must design and implement management systems to:

- **Understand the Risk** – This involves predicting problems; which in turn includes predicting the risk of possible accident/loss scenarios, establishing the appropriate design and the right layers of protection to control risk to a tolerable level

- **Control Risk Factors Day-to-Day** – This involves controlling the original design by maintaining the established layers of protection and managing changes to the design using integrated management systems

- **Analyze Actual Problems and Determine Weaknesses in the System –** This involves identifying weaknesses in designs and management systems and weaknesses in risk understanding through root cause analysis of actual problems (losses and near-losses)



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Management systems control the interaction of people with each other and with processes. They are the high level procedures we use to control major activities like conducting PHAs, management of change, writing operating procedures, training employees, evaluating fitness for duty, conducting incident investigations, etc. If management systems are weak, then layers of protection will fail and accidents will happen.

To reiterate, accidents are caused by human error. In general, Process Safety Management (PSM) is focused on maintaining these human errors at a tolerable level because:

- All accidents happen due to errors made by humans; including premature failure of equipment. There are a myriad of management systems to control these human errors and to limit their impact on safety, environment, and quality/production
- When these management systems have weaknesses, near misses occur
- When enough near misses occur, accidents/losses occur

Human Factor Categories and Typical Impact of Each

To minimize human error, process safety systems should address the **Human Factors Categories** (see various US NRC and US DOE standards from 1980s and 1990s). The table on the next page lists the key human factor categories along with multiplication factors that poor human factors can have on the base human error rates. If all of these human error rates are controlled very well, then the optimized human error rates listed in the next section are achievable.

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
Available Time (includes staffing Issues)	Inadequate time Barely adequate time (≈2/3 x nominal) Nominal time 1 Extra time (between 1 and 2 x nominal and >than 20 min) Expansive time (> 2 x nominal and > 20 min	P(failure)=100% 10 1 0.1 0.01
Stress/ Stressors (includes staffing issues)	Extreme High Nominal	5 2 1
Complexity & Task Design	Highly complex Moderately complex Nominal Obvious diagnosis	5 2 1 0.1
Experience/ Training	Low Nominal High	10 1 0.5
Procedures	Not available Incomplete Available, but poor Nominal Diagnostic/symptom oriented	50 20 5 0.5 1
Human-Machine Interface (includes tools)	Missing/Misleading Poor Nominal Good	50 10 1 0.5
Fitness for Duty	Unfit (high fatigue level, illness, strong medication, not physically capable of job today) Degraded Fitness Nominal	P(failure)=100% 5 1
Work Processes & Supervision	Poor Nominal Good	2 1 0.8
Work Environment	Extreme Good	5 1
Communication	No communication or system interference/damage No standard for verbal communication rules Well implemented and practiced standard	10 5 1

Observed Lower Limits of Human Errors

With excellent control of all of the human factors just listed (requiring excellent design and implementation of management systems), a company can begin to approach the lower limits that have been observed for human error. These lower limits are about:

- **1 mistake in 100 steps for most procedures-based tasks** (such as starting up a process unit), a little less for a routine (daily) task that becomes almost a reflex

- **1 in 10 chance or a little better for diagnosis and response to a critical alarm**

Overview of Addressing Human Factors in Process Safety Management Systems

Process safety management (PSM) is a collection of management systems and their implementation with the purpose of controlling the risk of major accidents; PSM focuses on preventing the accidents that originate from process hazards (such as release and explosion of flammable gases or liquids, release of toxic, etc.). This differs significantly from **occupational safety**, which is focused instead on preventing personal injury to workers from activities related to a task (such as getting particulate in eyes, injury from a falling object, falling from heights, etc.).

Human Factors Addressed in Industry Standards and Regulations

PSM systems have been in place for about 30 years, with the first formal industry-wide standard being issued by the Center for Chemical Process Safety (CCPS, 1985), which is a division of the American Institute of Chemical Engineers (AIChE). From the start, there was strong emphasis on human factors, since Human Factors was one of the original 12 elements of the PSM standard. The CCPS revised their PSM standard in 2007, renaming it Risk-Based Process Safety (RBPS), and now instead of one global element on human factors, the direct control of human factors is spread throughout 6 elements. Additionally, not having a specific element titled "Human Factors," diminishes the importance of human factors. For example, if there were an element specifically focused on human factors, then industry would like invest more in research of how to optimize human factors, how to avoid miscommunication, how to optimize displays, researching the best rules for designing human system interfaces, and researching the best rules for writing work instructions. Private industry is conducting some ad hoc research on some of these human factors, but most of the current data has come from the nuclear power industry, US Department of Energy, and various militaries around the world.

The RBPS standard addresses human factors under the RBPS Management System Accident Prevention Pillars "Commitment to Process Safety" and "Manage Risk." To some extent the 10 human factor categories introduced earlier addressed within 6 of the RBPS elements. The RBPS elements that address human factors are:

- Process Safety Culture
- Workforce Involvement
- Operating Procedures
- Training and Performance
- Operating Readiness
- Conduct of Operations

In comparison, the PSM standard that was issued by US OSHA (29 CFR 1910.119) in 1992 (and has been essentially unchanged since) is devoid of human factor controls with a few exceptions. The only direct reference to the term “human factors” is mentioned in paragraph (e), Process Hazard Analysis (PHA), which states that the PHA team must consider human factors (presumably in the review of the causes and the quality of the safeguards). The other mention that alludes to human factors, is in Operating Procedures (see paragraph (f)) which states procedures “must be written clearly and understandably.” This is accomplished by following best practices for human factors as they relate to procedures discussed later in this paper. Paragraph (g) defines standards for Training but does not directly address how to design training programs to address controlling human errors. In summary PSM systems based on compliance with OSHA’s PSM standard are likely addressing human factors only through the standard’s SOP, training and PHA element requirements. These OSHA based PSM systems likely lack the fundamental human factor standards that when applied across the applicable PSM elements, work together to reduce human error.

Clearly more guidance is needed to fully implement human factors in PSM systems. While the newly developed Risk Based Process Safety industry standard from the CCPS does contain the human factor standards, they are not presented under a stand-alone human factor element. This organization does not provide a needed road map to help companies wanting to transition to RBPS from the minimum PSM systems defined in OSHA’s PSM standard. A starting point for this transition is implementing a human factor element comprised of the human factor categories missing from most OSHA based PSM systems, that when combined with the RBPS standards, provides the roadmap.

The Figure below compares various standards/systems for PSM.

Comparison of PSM Systems

US OSHA 29 CFR 1910.119 and EPA 40 CFR 68

- Management System
- Employee Participation
- Process Safety Information
- Process Hazard Analysis*
- Operating Procedures*
- Training*
- Contractors
- Pre-Startup Safety Review
- Mechanical Integrity
- Hot Work Permit
- Management of Change
- Incident Investigation
- Emergency Planning and Response
- Compliance Audits
- Trade Secrets

AIChE/CCPS Risk-Based Process Safety (RBPS) Standard

Commitment to Process Safety
- Process Safety Culture*
- Compliance with Standards
- Process Safety Competency
- Workforce Involvement*
- Stakeholder Outreach

Understand Hazards and Evaluate Risk
- Process Knowledge Management
- Hazard Identification and Risk Analysis

Manage Risk
- Operating Procedures*
- Training and Performance*
- Safe Work Practices
- Asset Integrity and Reliability
- Contractor Management
- Management of Change
- Operational Readiness*
- Conduct of Operations*
- Emergency Management

Learn from Experience
- Incident Investigation
- Measures and Metrics
- Auditing
- Management Review & Continuous Improvement

***Addresses some of the 10 Human Factors Categories**

Responsible Care® Process Safety Code

Management Leadership
- Commitment*
- Accountability*
- Performance Measurement
- Incident Investigation
- Information Sharing
- CAER Integration

Technology
- Design Documentation
- Process Hazard Information
- Process Hazard Analysis
- Management of Change

Facilities
- Siting
- Codes and Standards
- Safety Reviews
- Maintenance and Inspection
- Multiple Safeguards*
- Emergency Management

Personnel
- Job Skills*
- Safe Work Practices
- Initial Training*
- Employee Proficiency
- Fitness for Duty*
- Contractors

Human Factors Within Existing PSM Systems

Many of the basic Human Factor Categories are already part of most companies PSM systems and include: procedures and reference documents, training knowledge and skills, tools and equipment, supervision, communication, and coordination and control. Here are the descriptions:

- **Training, Knowledge, and Skills** – This is of course necessary for general functioning of management systems and also for task-specific skills such as how to start up a compressor, how to repair pump P113A, how to lead root cause analysis, how to perform a proper Lock-Out/Tag-Out, etc. Organizations normally do a good job on training, including hands-on training. Training systems can be weak (inadequate) because the system does not adequately address:
    - How to troubleshoot the process (handle process deviations or upsets). On the other hand, training is many times listed as the "cause" or "root cause" of an accident, when in fact the training is adequate and some other human factor is the major cause.
    - Provide workers to have a mental model(s) of the process
    - Provide workers with enough practice of critical tasks

- **Procedures and Reference Documents** – for all aspects on the process/organization, including operations, maintenance, safe work practices (Lock-Out/Tag-Out, etc.), lab support, security, engineering support, etc. Many of these procedures do not follow best practices for controlling human error, and so the written procedure actually "contributes" to increased error rates. Further, many organizations are missing guides on how to troubleshoot (what to do when process deviations occur). The best practices rules for writing and validating procedures have been published for many years ***(see Bridges, 1997-2000).*** Below is a checklist based on the current set of best practice rules for developing operating, maintenance, and other work-instructions (procedures):

PROCEDURE QUALITY CHECKLIST (courtesy PII, 2008)

#	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 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	

- 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 ***Deficient Procedures are*** the most prevalent problem in process industries since procedures have not traditionally been developed from the perspective of optimizing human factors; instead, procedures have been traditionally developed to meet a compliance requirement to have written procedures. Examples of procedure deficiencies (inaccuracies) include:
    - Incorrect/incomplete/nonexistent (most procedures we have audited have been only 70-85% 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 (for a example, a warning should Never **contain** the action to take; it should instead **emphasize** the action to take)
    - Poor format and presentation rules

  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 don't 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 the table above, the organization must also address the reasons that cause the worker not to use the written procedure.

- **Tools/Equipment** – this typically refers to hand tools or devices, which as general designed with the user in mind. A big part of human factor consideration is how to make the equipment and process operation mistake-proof (to prevent errors as much as possible). Below are some examples of error proof in designs and in process/operations:

    - **Design for unambiguous assembly.** Design the product or device such that the assembly process is unambiguous (by designing components so that they can only be assembled one way); i.e., design matching parts that are easy to insert and align. For example, use notches, asymmetrical holes, and stops to mistake-proof the assembly process. Products that go together in only one way require less worker training, perform more reliably, and can be repaired more quickly.

        - Computer cables are good examples
        - Gas supply lines in medical facilities with error-proofing (to ensure the proper gas is used)

        - **Consult workers.** Operators, technicians, and maintenance personnel can pinpoint the most troublesome areas.
        - **Avoid symmetry.** When a particular orientation is critical to the design, avoid symmetry. For example, use nonsymmetrical hole patterns.

        - **Use labels sparingly.** Labels tend to come off equipment too easily and often are wordy.
        - **Review the environment.** Environmental problems that encourage mistakes include poor lighting; high/low heat; excess humidity, dust, and noise — anything that distracts workers.

    - **Error-proof Operation Design Considerations**
        - **Error-proof mechanisms.** Error-proof mechanisms are very powerful in improving system reliability when incorporated into the design. These mechanisms, by design, will not allow a user to perform an illegal operation. For example, if a user enters a value that is outside the accepted range of operation, the control logic will not accept the value.
        - **Automatic alerts.** Automatic alerts immediately inform the user of an illegal operation to prompt corrective action. These alerts are particularly useful in critical operations that allow time for corrective action before some adverse consequence occurs. For example, a piping manifold may be designed such that a warning alarm sounds if valves are not opened/closed in the proper, critical sequence, or if a critical valve is left opened/closed.
        - **Automatic system shutdown.** Automatic system shutdown should be incorporated into the design when an illegal action is performed during a critical operation and no time is available for corrective action. For example, if an operator uses the wrong sequence in charging a reactor, the reactor will shut down before other materials are charged that may lead to critical temperatures and pressures.

- **Supervision** – Organizations are typically structured to have sufficient supervision of the job, but many times the definition between the trainer and the supervisor roles is blurred. Supervision can and normally does play a key role in selecting of the right worker for the job, scheduling of workers to match the required tasks for the day/week, and generally overseeing the task execution to ensure policies and procedures are followed. Supervisors are not always trained on all of their key roles in support of control of human factors, such as detecting issues in workers related to fitness for duty or fatigue.

- **Behavior Control (not normally considered a human factor, but is related to motivation and demonstrated leadership by upper management)** – About 15% of human error is due to acquired habits. Some call these Behaviors, but that normally carries negative connotations. Many (most) companies have effective systems for combating bad habits; these systems normally involve peer-to-peer observations and feedback (coaching), and these are many times labeled behavior-based safety management (which is a trademark phrase belonging to BST), or behavior-based reliability, or simply job-observations. A peer-observing-peer system, such as these, can reduce habit-based errors by about 70%.

- **Coordination and Control** – This is a collection of activities and management systems that control the coordination of human activities related to the process. These can include management of change (MOC) systems, document control systems (if not within the MOC system), work order control systems, issuing of operating orders for the day/week, project management procedures, performance measurement, auditing, continual improvement, etc. The categories of Risk Reviews and II/RCA can fit under this general category as well. These activities are normally controlled directly by management or by a technical department (such as engineering) or by a safety or loss prevention department.

- **Miscommunication between workers** – How much attention has your company given to ensuring that appropriate shift overlap occurs? Do you ensure that verbal instructions are clearly understood? Do you provide means to compensate for noise interference of communication? Do you ensure that commands/instructions are always repeated back? Do you require the workers to use the same jargon and is the jargon written down?

Developing a Human Factors PSM Element to Address the Human Factor Categories Missing from OSHA's PSM Standard

Some organizations strive to control all human factors to reduce human error rates as far as possible, such as the US DOE and US NRC initiatives mentioned earlier.

As mentioned earlier, the OSHA standard addresses human factors only in the training (g) and operating procedures (f) elements and it mentions that PHAs (e) must identify human factors as part of hazard identification process. Therefore to close the human factor gap and begin to correct deficiencies, implementing a Human Factor element which addresses the human factors categories not covered in OSHA's PSM standard and that are not cohesively defined in the RBPS standard is necessary. By slight rewording of the human factor categories introduced earlier in this paper, the **6 key human factors categories that are missing from an OSHA-based PSM system can be defined as:**

- **Fitness for duty**
- **Attention and motivation**
- **Staffing issues**
- **Human system interface design**
- **Task design**
- **Communication between workers**

A new PSM element which covers all six of these categories (perhaps as 6 sub-elements) is needed. The details of what each sub-element should contain is described on the next ten pages:

- **Fitness for Duty –** Successful task performance requires that the capabilities that workers bring to the task fall within an expected range. Fitness for Duty issues include reduction in an individual's mental or physical capabilities due to substance abuse, fatigue, illness or stress, increases the likelihood of errors. Types of possible impairments are:
    - Physical attributes – strength, reach, eye-sight and color acuity, hearing,
    - Mental attributes **–** drug and alcohol (abuse), mental stress (on and off the job); fatigue – issues from on the job and off the job (especially control of hours per work-day and per work-week)

  Safeguards to prevent 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 safeguard 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. Company programs that may be implicated in errors caused by personnel impairment include:

    - ***Fitness-for-Duty Program*** – Company fitness-for-duty programs are primarily responsible for detecting and preventing impaired personnel from performing tasks that may affect public health 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. One excellent starting point for a Fitness for Duty sub-element is the guidance provided in ***US NRC's 10 CFR 26 (2005).***

- ***Overtime Policies and Practices*** **–** Most companies establish limits for work hours to reduce on-the-job fatigue. It has been shown that 17 hours of work without a break is the same as being legally drunk. And, at 10 days straight of 12 hours 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). Routine authorization for work hours in excess of those recommended may result in fatigued workers. Further, 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. In ***US NRC's 10 CFR 26*** (***2005)***, the guidance given for control of overtime hours is no more 72 hours of work per 6 day period, no more than 16 hours of work in one day within that period, and a minimum of 24 hours contiguous hours away from work within a 7 day period. The US DOT has even more stringent rules on limiting work hours and establishing required hours for recovery from fatigue.

- ***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.

- ***Safety Culture*** **–** The effectiveness of self-reporting and behavioral observation programs depends greatly upon the safety culture at a site.
  - *Example:* If self-reporting of impairment or reporting an impairment concern about another staff member even occasionally results in disciplinary action, then supervisors and workers will naturally be reluctant to report other staff members who appear to be impaired. On the other hand, if individuals who have come to work under some form of stress are treated fairly and with concern, personnel will report more frequently. If the company's culture emphasizes safety over other goals, personnel may be willing to turn down overtime and monitor their own fatigue levels, even if turning down the opportunity results in a loss of income

- **Attention and Motivation --** Attention and motivation are often identified as causes for error. "Inattention to detail," "Attitude less than adequate," and "complacency," as examples, are frequently cited as causal factors in company problem reports. The evidence supporting these conclusions is often weak, however. Issues to consider in controlling attention and motivation include:
  - Demonstrated commitment of leadership to long-term values (trust in leadership)
  - Work culture – How is behavior rewarded? Is near miss reporting rewarded? Are short-cuts rewarded? Are workers involved in peer-to-peer job observations?
  - Leadership - Do workers perceive conflicting interests from management? For instance, do workers walk on pipe-racks when management is not around (rather than go down the ladder, move the ladder, go back up the ladder)?

Determining the role of attention or motivation in a human error is difficult outside of a laboratory or simulator setting. Attention and motivation are internal states that cannot be measured directly. In the laboratory, the experimenter can use sensitive instruments to track eye movements and record focus times as measures of attention, for example, or can establish control over the incentives presented to subjects to manipulate motivation levels. Recordings of workers "thinking aloud" as they perform tasks also provide insights into attention and motivation. However, in the example of an investigation, real-time, objective measures of attention or motivation cannot be obtained because the investigation necessarily occurs after the fact. As a result, the investigator must rely on self-reports and inference, which are subject to biases and inaccuracies.

Attributing accident causes to workers' attention, attitudes, motivations, or traits may be common because it is consistent with the "fundamental attribution error." As mentioned in other documents, this "error" is a natural human tendency in how we explain another's behavior and appears to be "hard-wired" into the human perceptual system. In the absence of compelling evidence that some characteristic of the work environment affected the workers' actions, investigators may resort to this "default" explanation and conclude that the workers were not paying attention or lacked the motivation to perform their work correctly. **After reviewing more than 1000 accident investigation, we have not found any cases where the error was attributable to "inattention" or "lack of internal motivation."**

Prevention of errors related to motivation and attention – Many company programs, policies, and practices are intended to reduce errors associated with attention and motivation. Some programs directly focus on these potential causes and contributors to error, such as the human factors engineering program at a site or a behavior-based safety program. Others may indirectly affect attention and motivation during task performance. Company programs that may be implicated in errors caused by attention or motivation include:

- *Human Factors Engineering* – Weaknesses in the design of human-system interfaces, for example, may make it difficult for personnel to detect changes in important parameters or to interpret the information displayed correctly. Difficult-to-use human-system interfaces may also frustrate personnel and inadvertently communicate a management message that accurate, timely human performance is not important.
- *Procedures* – Accurate, accessible and usable procedures also play an important role in directing attention, and lack of accurate and easily accessible procedures can frustrate the worker and degrade their motivation.
- *Human Resources* –Weaknesses in the personnel job performance evaluation and reward systems also may fail to communicate management expectations or may reward behavior that does not meet those expectations. If disciplinary actions are not perceived as being administered fairly, employee motivation to work productively and safely will be reduced.
- *Supervision* – Supervision communicates and reinforces management expectations and establishes goals and requirements for task performance. Supervisory oversight may increase motivation to perform in accordance with expectations as well as detect and correct any errors that occur. Weaknesses in supervision, for example, may cause staff to choose production over safety goals in their work or to tolerate workarounds that may lead to errors.
- *Problem Identification/Resolution* – Company programs for reporting, documenting and resolving barriers to effective performance maintain staff motivation levels when problem reports result in elimination or mitigation of the barriers. Weaknesses in these programs may not only frustrate personnel, but also encourage the development of workarounds that may lead to errors.
- *Employee Concerns* – Employee concerns programs provide another avenue for personnel to raise safety issues. Weaknesses in the employee concerns program will discourage personnel from raising problems when they fear adverse consequences and will call stated management expectations into question, resulting in lower compliance.
- *Behavioral Safety* – Behavioral safety programs focus on identifying and correcting work behaviors that may result in adverse consequences through behavioral observation and feedback from supervisors and peers. Some programs also emphasize self-checking, such DuPont's STOP program, FMC's START program, the Institute for Nuclear Power

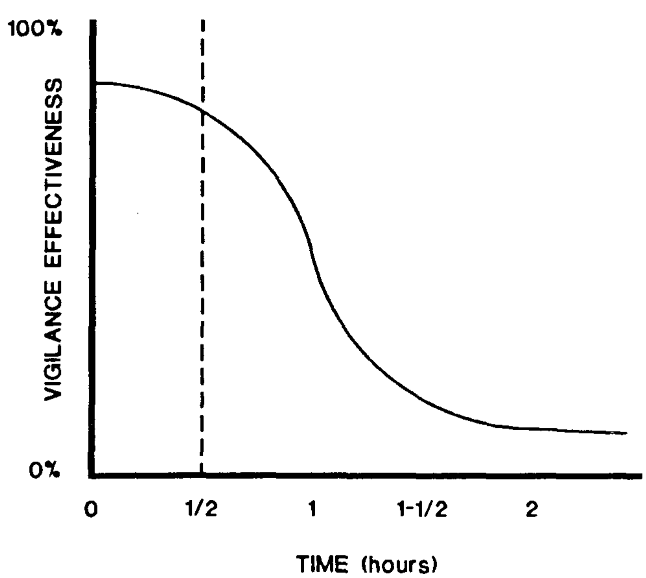
Operations' STAR program (stop-think-act-review), and PII's STAR Program (Safety Task Action Reporting). Focusing on potentially unsafe acts appears to improve human performance at some sites.

- **Staffing** – is the process of accessing, maintaining and scheduling personnel resources to accomplish work. An adequately staffed organization ensures that personnel are available with the proper qualifications for both planned and foreseeable unplanned activities. Staffing is a dynamic process in which plant management monitors personnel performance to ensure that overall organizational performance goals are met or exceeded. The result of an effective staffing process is a balance between personnel costs and the achievement of broader organizational goals. Issues with staffing include:
  - Selection of right staff for a job
  - Avoiding staff overload (but also avoid too many staff during lulls, when lack of stress will lead to more errors)
  - Rotating staff every 1 hour or less for tasks that require high vigilance

  Each organization requires the proper amount and type of expertise to safely and competently operate the plant under a variety of conditions. The term "expertise" includes the attributes of talent, effectiveness, knowledge, skills, abilities, and experience necessary to operate and maintain plant systems, structures and components.

  Surges in workload, such as during outages, typically require staff augmentation as well as longer work hours for permanent staff. The introduction of contractor personnel or company personnel from other sites may increase the likelihood of errors due to unfamiliarity with the plant, its procedures and hardware, for example. Longer work hours have the potential to increase fatigue, which also contributes to the likelihood of error.

  Humans are inherently unable to remain alert for signals that seldom, if ever, occur. Even a sailor whose life is at stake cannot maintain an effective watch (look-out) for hostile submarines for more than 30 minutes or so. (The figure below illustrates the rapid decrease of vigilance with time). It is important that control systems be designed to require regular operator interaction so that the operator will remain attentive. Placing a worker in situations requiring extended, uneventful vigilance may lead to accidents like the ones described below:



- **Human-System 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. Each type of HSI is 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. Personnel use of HSIs is influenced directly by (1) the organization of HSIs into workstations (e.g., consoles and panels); (2) the arrangement of workstations and supporting equipment into facilities, such as a main control room, remote shutdown station, local control station, technical support center, and emergency operations facility; and (3) the environmental conditions in which the HSIs are used, including temperature, humidity, ventilation, illumination, and noise. There are three important goals to be achieved in the design and implementation of an HSI. These are:

    - **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.

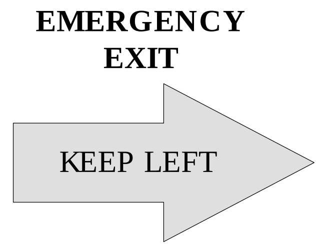
        Example: The relief valve on a low-pressure separator actuated during apparently normal operations. Operators verified that the separator pressure was normal, and in their haste to stop the release, they blocked-in the "bad" relief valve before unblocking the parallel relief valve. The separator immediately 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.

    - **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.

    - **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.

- ***Improving Human-machine interface*** **-** Have you performed a human factor engineering or hardware interface evaluation of your processes and control rooms? Are components clearly labeled? Is it easy to select the right device or component? Do the components or displays violate norms? Are feedbacks clear and timely? Do workers need to jumper/bypass interlocks often? Equipment, routes, etc., are inadequately labeled (includes color coding, tags, numbers, numbering system, etc.).

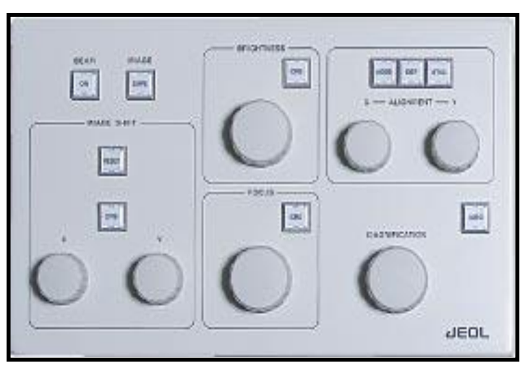
- What would you do if you saw this sign at the "T" in a hallway and if your life depends on taking the right action immediately?



- What would you do if you saw this sign at the door of a building and if your life depends on taking the right action immediately?

- Equipment is poorly designed for human use – If it is difficult for the mechanic to get to the last grease port under a gearbox, will they go to the trouble (knowing that no-one will notice if they just skip that port)? Other examples of poor equipment interface designs:

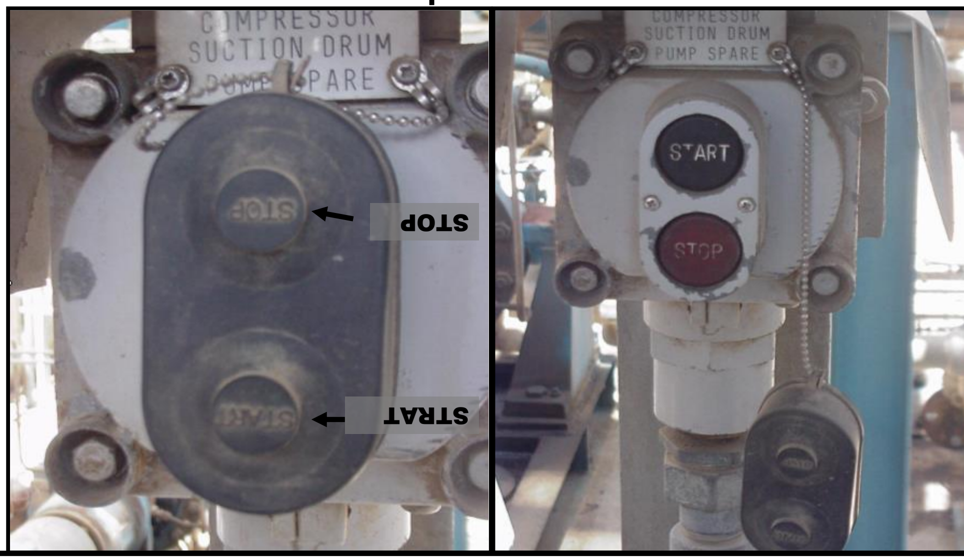
<u>Example</u> – Good Human Factor Engineering can be as simple as "grouping" control elements by function:



Management should ensure they have a minimum specification for human factor engineering – from control panel layout to control room layout

- Labeling is confusing. Which button should you push? Or, it better with to leave the dust boot off?

<u>Example</u> – *Poor* Human Factors can be as simple as not properly designing/specifying a dust cover or lack of enforcement to keep a dust cover on a switch



- **Task Design** – A task that is designed with the human limits in mind is much more likely to work effectively than one that assumes humans can and will "always" do what is written. The task must consider that humans think and remember and factor in prior data and prior experiences.

  - **C**omplexity of task (procedure-based or a call for action) – If the task is too complex, then humans can forget their place in the task, fail to understand the goal of each step or sub-step, or fail to notice when something isn't going right. Task complexity is a function of:
    - number of choices available for making a wrong selection of similar items (such as number of similar switches, number of similar valves, number of similar size and shaped cans)
    - number of parallel tasks that may distract the worker from the task at hand (leading to either an initiating event or failure of a protection layer)
    - number of staff involved (more staff = more complex)
    - number of adjustments necessary to achieve the goal
    - amount of mental math required (as a rule, NO math should be required in anyone's head when accomplishing a standardized task)
    - how much judgment is required to know when you have accomplished each goal within the task

    For most chemical process environments the complexity of the task is relatively low (one action per step), but for response actions (human IPLs) there is almost always other tasks underway when the out-of-bounds reading or the alarm is activated. Complexity is difficult to predict (since it is not known when a human intervention will be needed), but higher complexity can increase error rates by 2 to 10 times.

- Error detection and error recovery – Is there enough feedback in the process to allow the worker to realize (in time) that they made a mistake? Have they been trained on how to reason through how to recover from mistakes they or others make? (Sometimes, doing a step too late is far worse than NOT doing the step at all.) Is there enough time available for the type of intervention necessary.

- Environment where the task is to be performed (too noisy, too cold, to hot, too distracting):
    - There are two types of vibration that may cause errors. The first is **whole-body vibration**, in which vibration is transferred to the worker from standing or sitting on a vibrating surface. The second is **object vibration**, in which a stationary worker interacts with a vibrating object in some fashion. The effects of vibration depend upon its frequency and acceleration. **Frequency** is the number of oscillations (cycles) that occur in one second. **Acceleration** is the force, or intensity, of the vibration.
    - Noise is unwanted sound. Noise can cause errors in several ways. It may disrupt communications, affect the ability to perform tasks and annoy personnel. The effects of noise on communications are complex. Even relatively low levels of noise can mask speech, but only under some circumstances. For example, speakers naturally raise their voices when there is background noise and may be able to overcome some of its effects on communication. Being able to see the speaker's face or using standardized phrases also improves communication in a noisy environment. The type of background noise also affects communication. It is easier to communicate over noise that is steady and uniform than noise that includes sharp tonal peaks, such as background speech.
    - Heat exposure is a common problem in many areas of a plant, such as the turbine building when the plant is operating. The extent to which workers will be affected by heat depends on many factors. These include physical characteristics, such as age, weight, acclimation to heat, physical fitness and dehydration. Other factors that determine the effects of heat on performance include airflow, humidity, clothing and level of physical activity.
    - Exposure to cold affects the performance of manual tasks. Decreases in the ability to control hand movements begin at an air temperature of approximately 54° F. The fingers may become numb to pain at this temperature and touch sensitivity is reduced. Performance of gross manual tasks, such as those involving the arms and legs is also degraded at 54° F. The speed at which manual tasks can be performed is affected by the rate of cooling. Slow temperature drops have a greater negative impact on manual dexterity than rapid temperature decreases, during the initial exposure period.
    - Adequate lighting is required for accurate performance of nearly every task in a unit operation.

- The organization must have engineering controls to help control each factor; but sometimes there is no other choice but to rely upon administrative controls.

- **Communication between workers – *verbal and signal 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 behaviors: (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
- During shift turnover

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.

- **Sending Errors**
  - *Content wrong*
  - *Content inconsistent*
  - *Content inappropriate for the job*
  - *Content inappropriate for the receiver*
  - *Standard terminology not used*
  - *Familiar terminology not used*

    Example: In preparation for construction work, the plant staff marked the location of an underground electrical bus with flags on the surface. The backhoe operator, believing the flags indicated where he was supposed to dig, cut through the electrical bus and blacked out half the facility.

  - *Message production inadequate or interfered with*

    Example: Unit operators had practiced responding to an acid vapor leak and devised a system of hand signals to communicate with personnel responding to the release in fully encapsulated suits. Unfortunately, when an actual leak occurred on a calm morning, visibility was restricted throughout the unit by the acid-induced fog. Emergency response personnel could not coordinate their actions with the unit operators, and attempts to isolate the leak were initially unsuccessful, resulting in a much larger release.

  - *Necessary information not sent*
  - *Wrong place or person*
  - *Wrong time*
  - *Sending verification failure*

- **Receiving Errors**
  - *Information not sought*
  - *Information not found*
  - *Information not used*
  - *Receiving verification failure*
  - *Message misunderstood.*

Example: Each shift normally made an entire batch of resin, but equipment failures had interrupted the usual schedule. The arriving shift misunderstood the batch status and mixed in a second bag of additives. They realized their error when the agitator motor overloaded. The entire process had to be disassembled so the solidified resin could be removed.

Identifying Human Factors – prediction as Causes and Safeguards and determining Weak Human Factor Practices via root cause analysis

It is important to note that while not directly controlling human factors, the PHA/HAZOP (hazard identification and risk assessment) and the Incident Investigation management systems help to identify where and how human factor practices are necessary to control certain risks, and help to identify weaknesses in human factor practices and implementations.

- **Risk Reviews (PHA/HAZOP, HIRA, JSA, etc.)** – Addressing Human Factors during risk reviews can help identify gaps in all human factor categories since human factor categories are types of safeguards. This is fundamental for predicting where and why humans might make mistakes and for determining (qualitatively, at first) if the protection layers are sufficient if such errors occur and if not, what else is needed. Unfortunately, many organizations do not full analyze for errors during all modes of operation, and so many (in some cases, most) of the accidents that start with a human error are not predicted, as they should be **(*See Chapter 9.1 of CCPS/AIChE, Guidelines for Hazard Evaluation Procedures, 3rd Edition, 2008; and paper by Bridges, LPS/AIChE, April 2009, Optimizing Hazard Evaluations. This practice ultimately strengthens SOPs and human system interface human factors).***

- **Incident Investigation/Root Cause Analysis (II/RCA)** – II/RCA is necessary to learn from mistakes. Although all companies have an II/RCA system, many companies are lacking in the awareness of where human factors fit into an accident sequence. This leads to the II/RCA missing the human factor weaknesses that led to the human error and so the II/RCA may stop at the cause (and even root cause) being "operator error." Many companies also do not get nearly enough near misses reported (the ratio should be about 20 to 100 near misses reported per actual loss/accident ***(See CCPS/AIChE, Guidelines for Investigating Chemical Process Incidents, 2nd Edition, 2000; and paper by Bridges, 8th conference, ASSE-MEC, 2007, Getting Near Misses Reported).***

Closing

An organization involved in implementing PSM (or similar, SMS or OSHAS 18001 for occupational safety) must develop management systems for optimizing human factors to control human error rates. This is not as much work as it sounds, except that most international standards and government regulations fail to adequately address human factors, leading some organization leaders to ask "Why do we have to control all human factors if the XYZ standard does not require this?" The exceptions to these rules are the nuclear power industry, aviation, and certain military organizations (typically navies and air forces); most of these organizations have excellent systems for optimizing human factors.

For organizations that must implement process safety (e.g., PSM), there are two main approaches for closing the gap on control of human errors. These are:

1. Follow some relative weak government PSM regulation, such as US OSHA PSM or EU and UK COMAH regulations, and then develop the additional requirements for strengthening each existing element's control of human factors and also add a specific global element on human factors to address:
    a. Fitness for duty
    b. Attention and motivation
    c. Staffing issues
    d. Human system interface design
    e. Task design
    f. Communication between workers

2. Follow the newly released (2007) standard from AIChE, *Risk-Based Process Safety*, and make sure the elements that control human factors are fully implemented (including all advice on human factors given in this paper), especially for the elements of:
    a. Process safety culture
    b. Workforce involvement
    c. Training and performance
    d. Operational readiness
    e. Conduct of operations

In addition, companies will want to supplement these approaches by implementing a PHA/HAZOP management system that defines how PHA teams are to address human factors and how teams are to analyze specifically for human errors of not following operating procedures. Companies should also ensure that incident investigation teams are trained on human factors to help them correctly identify the human factor weaknesses that led to human error or component failures.

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