Human Factors Implementation – for Plant Workers

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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. Often it is believed that human errors committed by plant workers are the cause of most process safety accidents. However, the entire organization contributes to these human errors. Therefore, actions are needed by the organization to reduce plant worker human errors by improving Human Factors that contribute to the plant worker human errors, and to build an organizational culture that seeks to learn from plant worker human errors, rather than to assign blame.

This paper introduces the multiple types and categories of human error and the Human Factors that influence the rate at which human errors are made. It establishes the need for creating management systems for these Human Factors, and how to implement them in a manner to reduce plant worker human errors. Finally, it describes a Safety-Principled Organizational Culture that allows an organization to create the proper environment to enable these critical improvements to reduce plant worker human error. This paper builds on earlier papers, starting from 2010, on the same topic.

The data presented is from basic research by the authors on the root causes of more than 3000 accidents and near misses; and also based on the review of hundreds of accidents analyzed by others and summary data from many companies. This Video Presentation and the related slides are even more keenly focused on the selected human factors for which the frontline workers should take the lead so that the base human error rate at a site is as low as possible. Case studies and examples are used to illustrate key points.

1. 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. Quite often, the erroneous conclusion is drawn that the error was "caused" by the actions of the individual directly involved in the incident. However, this view not only does a disservice to the affected individual, but it prevents proper corrective actions because **humans govern and accomplish all of the activities necessary to control the risk** of accidents. In other words, 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. Specifically, we make errors in authorities, accountabilities, procedures, feedback, proof documents, continual improvement provisions, etc. Ultimately, these management systems govern the human error rate of those directly contacting or influencing the process. Thus, the entire organization (plant workers, technical staff and management) contribute to the human errors resulting from the actions of the plant worker.

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

Figure 1: Relationship between Accidents and Management

The optimum approach to reduce plant worker human errors therefore is not to "fix" the plant worker but rather to strengthen management systems so that it is less likely that the human errors will occur (and that when they inevitably do, their consequence is controlled to the greatest extent possible).

This paper outlines this approach by first providing context to the term "human error" so that the means to reduce and mitigate it can be better understood. It then establishes that the most practical and efficient means to minimize plant worker human errors is through properly designed and implemented management systems. Next, it establishes the key Human Factors that contribute to human errors. Conceptually, plant worker human errors are controlled by understanding the Human Factors related to them and their work to the degree that effective management systems for each of them can be developed. Therefore, the paper then details how these Human Factors can be improved for plant workers. Finally, it explains that this entire process is only possible with the right type of organizational culture.

This paper introduces the concept of a Safety-Principled Organizational Culture as one that enables the proper application of Human Factors to plant workers to reduce their human errors. Further, with this culture, when human errors are made, the appropriate lessons are learned so that those errors, and even seemingly unrelated errors, are not repeated. In this way, a plant's overall safety performance will improve.

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.

2. Types and Categories of Human Error

Quite often people will analyze a plant incident and draw the (typically correct) conclusion that it was due in large part to a plant worker human error. However, they end their analysis at that point, and are therefore unable to draw conclusions as to what could or should be done to prevent its recurrence. To fully protect against future harm, however, plant worker human errors must be fully analyzed, and the first step in this analysis is to understand the types and categories 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 plant 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 plant worker who commits an intentional error may well be 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).

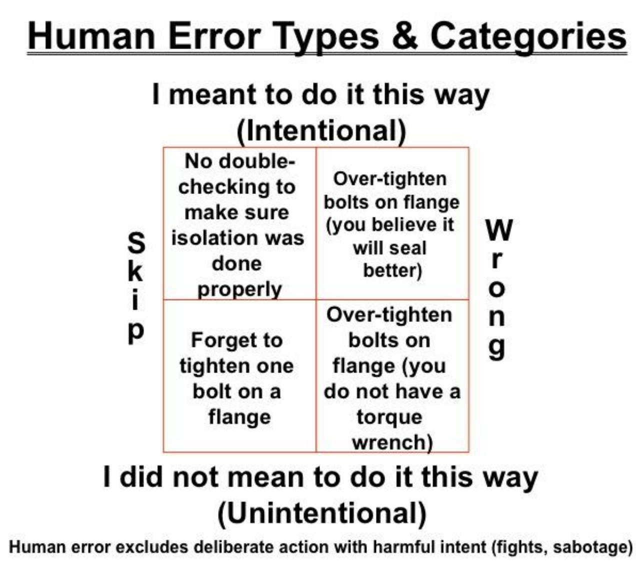

Figure 2: Types and Categories of Human Error

Regardless of type or category of human error, the organization can and should exert considerable control of the errors through properly implemented management systems.

3. Controlling Human Error through Management Systems

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 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 plant workers 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 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)

These three elements are illustrated in the following figure:

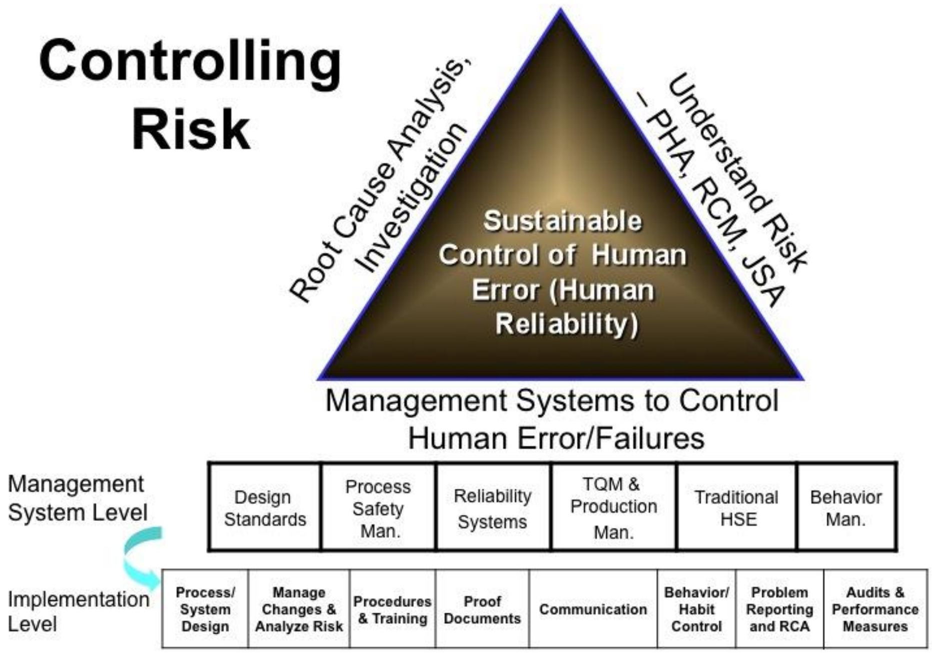

Figure 3: Controlling Risk through Human Reliability

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 is 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

4. Human Factors that Contribute to Human Errors

To minimize plant worker human error, process safety systems should address the **Human Factors Categories** (see various US NRC and US DOE standards from 1980s and 1990s)[1,2]. Table 1 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.

TABLE 1: SUMMARY of 10 HUMAN FACTOR CATEGORIES

Based in part on: Gertman, D.; et. al., *The SPAR-H Human Reliability Analysis Method*, NUREG/CR-6883, U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington, DC, August 2005. 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) – ***for responses only***	Inadequate time	P(failure)=100%
	Barely adequate time (≈2/3 x nominal)	10
	Nominal time (1x what is expected)	1
	Extra time (at least 2x nominal and >20 min)	0.1
	Expansive time (> 4 x nominal and > 20 min)	0.01
Stress/Stressors (includes staffing issues)	Extreme (threat stress)	5
	High (time pressures such as during a maintenance outage; issues at home, etc.)	2
	Nominal	1
Complexity & Task Design	Highly complex	5
	Moderately complex (requires more than one staff)	2
	Nominal	1
	Obvious diagnosis	0.2
Experience/Training	Low	10
	Nominal	1
	High	0.5
Procedures	Not available in the field as a reference, but should be	20
	Incomplete; missing this task or these steps	8
	Available and >90% accurate, but does not follow format rules ***(normal value for process industry)***	3
	Good, 95% accurate, follows >90% of format rules	1
	Diagnostic/symptom oriented	1
Human-Machine Interface (includes tools)	Missing/Misleading (violates populational stereotype; including round valve handle is facing away from worker)	20
	Poor or hard to find the right device; in the head calc	10
	Some unclear labels or displays	2
	Good	1
Fitness for Duty	Unfit (high fatigue level (>80 hrs/wk or >20 hr/day, no day off in 7-day period; or illness, etc.)	20
	Highly degraded fitness (high fatigue such as >15 hr/day, illness, injury, etc.)	10
	Degraded Fitness (>12 hr day and >72 hr/wk)	5
	Slight fatigue (>8 hr per day; ***normal value for process industry***)	2
	Nominal	1
Work Processes & Supervision	Poor	2
	Nominal	1
	Good	0.8
Work Environment	Extreme	5
	Good	1
Communcation	No communication or system interference/damage	10
	No standard for verbal communication rules ***(normal value for process industry)***	3
	Well implemented and practiced standard	1

If all of the human error factors shown above in Table 1 are controlled very well, then the optimized human error rates listed in Section 5 of this document are achievable. Alternatively, if one or more of these factors are compromised, the human error rate will increase by the values shown in this table. As an example, an individual whose fitness for duty rating is unfit due to the excessive work hours shown in the table will make errors at a rate 20 times greater than an individual whose fitness for duty is normal.

With excellent control of each of the human factors listed above, a company can begin to approach the lower limits that have been observed for plant worker 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**

Excellent control requires superior design and implementation of management systems, which is enabled through a thorough understanding of these factors, as outlined below.

5. Strengthening Human Factors for Plant Workers

In order to achieve the lowest practical plant worker human error rates noted above, comprehensive management systems must be developed for each of the Human Factors provided in Table 1. Key elements for each of these Human Factors are provided below.

A. AVAILABLE TIME and STRESS / STRESSORS

The **Available Time** for the task refers to the time the task is expected to be required for completion. In many cases, the time determined for a process is determined using the theoretical times where the conditions are “ideal” and not necessarily realistic. When task and process duration are not realistic plant workers tend to “find the best and easy way” to get it done, ultimately creating latent conditions for error occurrence. **Work Stress** refers to the emotional response that arises when work demands exceed the plant worker’s capacity and capability to cope. Some processes have been designed paying little attention to job design, work organization and management systems. Failing to fulfill this requirement eventually results in work stress.

Staffing levels directly impact both factors. Staffing is the process of assessing, 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 plant worker 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.

Three key issues must be considered when staffing decisions are made; the first of which is selecting the right staff for a job. Each organization requires the proper amount and type of expertise to operate the plant safely and competently 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.

The second key issue is avoiding staff overload. 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.

The third key factor is rotating staff every 1 hour or less for tasks that require high vigilance. 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 following figure illustrates the rapid decrease of vigilance with time.

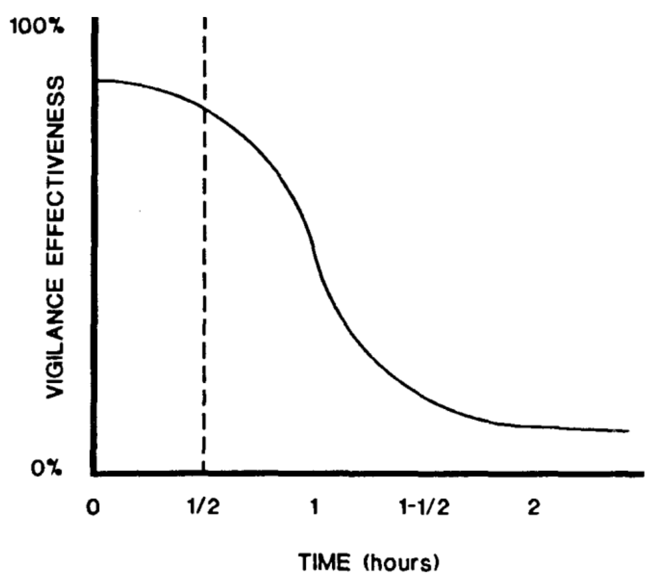

Figure 4: Vigilance as a Function of Time

Placing a worker in situations requiring extended, uneventful vigilance may lead to accidents. Therefore, it is important to design control systems in a manner that requires regular operator interaction so that the operator will remain attentive.

B. COMPLEXITY & 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. Factors to consider in assessing **task design** adequacy (i.e., minimizing the likelihood of plant worker human error during its completion) include:

- Complexity of the task
- Probability of repeat errors (coupled error) on redundant aspects of the design
- Error Detection and Error Recovery

Complexity of Task (procedure-based or a call for action) – If the task is too complex, then plant workers 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 (in which plant workers serve as the Independent Protection Layer (IPL)), there are 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.

Probability of Repeat Errors (Coupled errors) – For many maintenance tasks, making a repeat error or "common cause error" or "dependent error" can lead to failures of all backup systems. Such errors have led to MANY airplane crashes and major process safety accidents as well.

Coupling represents the probability of repeating an error (or repeating success) on a second identical task, given that an error was made on the first task. The increased probability of failure on subsequent tasks given that an error has already been made is known as dependence. The list below provides some starting point guidance on values to use:

- 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 the same two tasks are performed back-to-back, and if a mistake is made on the first step of two. 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.
- 8/10 to 10/10 – if the same three tasks are performed back-to-back and strong visual cue is present (if you can clearly see the first devices you worked on), if a mistake is made on the first step of the two or more

- Two or more plant workers 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.

These factors are based on the relationships provided in NUREG-1278[1] and the related definitions of weak and strong coupling provided in the training course by Swain (1993)[1] on the same topic, as shown below in Table 2.

The following relationship is for errors of omission, such as failing to reopen a root valve or failing to return a safety instrumented function (SIF) to operation, after bypassing the SIF. The qualitative values in Table 2 are based jointly on Swain[1] (1993) and Gertman (SPAR-H, 2005 which is NUREG/CR-6883)[2].

One can readily conclude that staggering of maintenance tasks for different channels of the same SIF or for related SIFs will greatly reduce the level of dependent errors. Unfortunately, most sites PII visits do not stagger the inspection, test, or calibration of redundant channels of the same SIF or of similar SIFs; the reason they cite is the cost of staggering the staff. While there is a perceived short-term higher cost, the answer may be different when lifecycle costs are analyzed.

Simple Rule: Staggering of maintenance can prevent a significant number of plant worker human errors in redundant channels. In the airline industry, the US Federal Aviation Administration (FAA) requires staggering of maintenance for aircraft with multiple engines or multiple control systems (i.e., hydraulics) (*FAA Advisory Circular 120-42A*, as part of Extended Operations (ETOPS) approval).[6]

Table 2: Guideline for Assessing Dependence for a within-SIF Set of Identical Tasks (based partially on SPAR-H, 2005 [1,2], and partially on field observations by PII) Courtesy Process Improvement Institute, Inc., All Rights Reserved

Level of Dependence	Same Person	Actions Close in time	Same Visual Frame of Reference (can see end point of prior task)	Worker Required to Write Something for Each Component
Zero (ZD)	No; the similar tasks are performed by different person/group	Either yes or no	Either yes or no	Either yes or no
Zero (ZD)	Yes	No; separated by several days	Either yes or no	Either yes or no
Low (LD)	Yes	Low; the similar tasks are performed on sequential days	No	Yes
Moderate (MD)	Yes	Moderate; the similar tasks are performed more than 4 hours apart	No	No
High (HD)	Yes	Yes; the similar tasks are performed within 2 hours	No	No
Complete (CD)	Yes	Yes; the similar tasks are performed within 2 hours	Yes	Either yes or no

Once the level of dependence is known, the probability of either repeat success or repeating errors on identical tasks can be estimated. For these probabilities, we use Table 3, which is a re- typing of Table 20-17 from NUREG-1278[1] (and the similar table in SPAR-H [Gertman, 2005][2]).

Table 3. Equations for Conditional Probabilities of Human Success or Failure on Task N, given probability of Success (x) or Failure (X) on Task N-1, for Different Levels of Dependence *Courtesy Process Improvement Institute, Inc., All Rights Reserved*

Level of Dependence	Repeating Success Equations (but shown as error probability)	Repeating Failure Equations
Zero (ZD)	$P_{Success@N} = x$	$P_{Failures@N} = X$
Low (LD)	$P_{Success@N} = (1+19x)/20$	$P_{Failures@N} = (1+19X)/20$
Moderate (MD)	$P_{Success@N} = (1+6x)/7$	$P_{Failures@N} = (1+6X)/7$
High (HD)	$P_{Success@N} = (1+x)/2$	$P_{Failures@N} = (1+X)/2$
Complete (CD)	$P_{Success@N} = 1.0$	$P_{Failures@N} = 1.0$

Error Detection and Error Recovery – Is there enough feedback in the process to allow the plant 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?

C. EXPERIENCE/TRAINING

Training is necessary for general functioning of management systems and for task-specific skills such as how to start up a compressor, repair a pump, lead a root cause analysis, perform a proper Lock-Out/Tag-Out, etc. Organizations normally do a good job of training, including hands-on training. Training systems can be weak (inadequate), however, if the training system does not adequately:

- Address how to troubleshoot the process (i.e., handle process deviations or upsets).
- Provide plant workers with a mental model(s) of the process so they can perform the assigned tasks correctly, diagnose process upsets properly and quickly, and understand the consequences of their actions.
- Provide plant workers with enough practice of critical tasks.

Ironically, 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.

D. PROCEDURES

Many procedures do not follow best practices for controlling human error, and so the written procedure actually "contributes" to increased plant worker error rates. Further, many organizations are missing 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)***[3, 7, 8]. Below is a checklist based on the current set of best practice rules for developing operating, maintenance and other work-instructions (procedures):

TABLE 4: 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 describe the topic?	
3	Are the document control features the smallest items on the page?	
4	Are temporary procedures clearly identified?	

#	Issue	Response
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 12 point font or larger?	
7	Is serif type 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	

#	Issue	Response
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 many reasons that plant 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 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 plant workers may not use procedures include:

- Procedures are out of date
- No procedure has been written for the task
- Plant workers cannot find the procedure they want to use
- Plant workers don't need a procedure because the task is simple
- Plant workers need more information than the procedures contain
- Plant workers 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 plant worker not to use the written procedure.

E. HUMAN-MACHINE INTERFACE (INCLUDING TOOLS)

The **Human-Machine Interface** (also known as the Human-System Interface, or HSI) is defined as the technology through which plant workers 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.

Plant worker 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 the HSI. These are:

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

  The wide-spread adoption of distributed control systems has provided many advances in process control. However, if implemented improperly, these systems can greatly reduce the operability of the facility. Although they were unable to provide as much information, old analog panels were typically laid out in a manner such that experienced plant workers were able to monitor the entire process and effectively identify conditions meriting attention. Due to space limitations, and their cost (e.g., hardware and installation), alarms were typically limited to those deemed to be associated with a significant process upset.

  The advent of distributed control systems has eliminated the space limitations associated with alarms, and greatly reduced their costs (in many cases, alarms can be added merely through programming). Without proper alarm prioritization, configuration structure and discipline, this can lead to “alarm flooding” (an excessive number of simultaneous alarms) during abnormal operating conditions. The human error of failing to respond properly to an alarm increases by a factor of over 1,000 if ten alarms activate simultaneously compared to a single alarm activation.

  Therefore, it is critical that control and alarm system designers in facilities with distributed control systems properly prioritize information so that plant workers can respond appropriately to abnormal conditions. Further, trouble-shooting guides should be readily accessible via the distributed control system to reduce human error in alarm response.

  Beyond the topic of alarms, the proper design of the visual displays can also reduce human error. Certain color combinations, such as a light gray background with darker gray equipment and black lines coupled with a flashing red indication for those components in an alarm state effectively draw the plant workers’ attention to the relevant part of the process requiring attention. Further, an effective display should include:

  - Safety systems that are bypassed, impaired, or out of service
  - Process alarms that are disabled
  - Process conditions that are not within established limits
  - Backup systems that are unavailable
  - Special maintenance or testing activities that are currently in progress

- **Design for maintainability** refers to designing the HSI and associated plant equipment to ensure that plant workers are able to perform necessary maintenance activities efficiently. Weaknesses in the design process can result in systems that impose excessive demands on plant workers 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 plant worker to perform functions and tasks in new ways. Skills that the plant worker 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 plant workers 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 plant worker to adapt to temporary configurations that are different from both the original and final configurations. Weaknesses in HSI implementation can increase plant worker workload and the likelihood of errors.

Tools are a special category of HSI, which typically refers to hand tools or devices that are generally designed with the plant worker 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). The following are some factors to consider when mistake-proofing in designs:

- **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 plant worker training, perform more reliably, and can be repaired more quickly.
- **Consult plant 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 plant workers.

The following are some factors to consider when mistake-proofing in process/operations:

- **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 plant worker to perform an illegal operation. For example, if a plant worker 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 plant worker 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 a plant worker 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.

F. FITNESS FOR DUTY

Successful task performance requires that the capabilities that plant workers bring to the task fall within an expected range. **Fitness for Duty** issues include reduction in a plant worker's mental or physical capabilities due to substance abuse, fatigue, illness, or stress, which increases the likelihood of errors. Types of possible impairments include:

- Physical attributes – strength, reach, eyesight 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 plant 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 supervision or not receiving pay for extra overtime.

Company programs that may be implicated in errors caused by plant worker impairment include:

- **Fitness for Duty Program** – Company fitness-for-duty programs are primarily responsible for detecting and preventing impaired plant workers 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. Impaired plant workers can be prevented from performing tasks by establishing protocols for instances in which a plant worker is believed to be unfit for duty, training for supervisors on detection of and response to fitness for duty issues, and employment guidelines for personnel who voluntarily enter drug or alcohol treatment programs. Weaknesses in a Fitness for Duty 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)***[15]**.**

- **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 results in the same error rate 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 plant workers. Further, a practice of excluding training or meetings that occur outside of a plant worker's normal work schedule from work-hour limitations will also contribute to fatigue. In ***US NRC's 10 CFR 26*** (***2005)***[15], 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 plant workers 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.

G. WORK PROCESSES AND 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 plant 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 plant 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.

Organizations are typically structured to have sufficient supervision of the job, but many times the delineation 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 plant workers related to fitness for duty or fatigue.

H. WORK ENVIRONMENT

The **Work 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, as summarized below:

- There are two types of **vibration** that may cause errors. The first is whole-body vibration, in which vibration is transferred to the plant 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 plant workers. 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 plant workers will be affected by heat depends on many factors. These include their 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.

I. COMMUNICATION (most importantly, verbal 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. However, there are many potential errors in both sending and receiving the communication:

- Sending Errors
    - *Content wrong*
    - *Content inconsistent*
    - *Content inappropriate for the job*
    - *Content inappropriate for the receiver*
    - *Standard terminology not used*
    - *Familiar terminology not used*
    - *Message production inadequate or interfered with*
    - *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*.

Communication errors may be reduced in the following ways:

- Structuring messages in a standard format, which alerts the receiver if important information has been skipped
- Providing written instructions or procedures for complicated tasks
- Establishing protocols to repeat key parts of verbal communications
- Preceding special or nonroutine activities with a pre-job briefing
- Using structured protocols, checklists and logs to supplement written instructions

One key opportunity for communication errors is when a new shift takes over responsibilities from the previous shift. An effective tool to reduce these errors is a properly designed shift handover process that includes appropriate checklists and logs of activities, and a structured and consistent method for verbally reviewing this information. Additionally, the logs and discussions need to include:

- Routine operations
- Transition operations (e.g., changes to produce a different product or switch to a different raw material source)
- Nonroutine operations (e.g., maintenance activities or temporary operating conditions)

6. Establishing a Safety-Principled Organizational Culture

To ensure the success of the management systems created to improve Human Factors for plant workers, the proper culture of the organization must be developed so that this can be done effectively. Merriam Webster defines culture as "the set of shared attitudes, values, goals, and practices that characterizes an institution or organization". An organization's culture ultimately reflects the collective values of individuals and groups and can be influenced by the personalities of charismatic leaders, by shifting priorities based on the perceived scarcity of resources or actions necessary for survival, or by a sustained history of successes, behaviors, and beliefs. In an especially sound culture, deeply held values are reflected in the group's actions.

Organizational Culture is a somewhat intangible attribute of a company that is evident by the words and actions of management and all employees – including the plant workers. It is further defined informally as "how we do things around here", "what we expect here", or "how we behave when no one is watching". Reducing human error by plant workers therefore requires that the proper organizational culture be built and maintained.

A Safety-Principled Organizational Culture is one in which the actions of the entire organization are driven by the genuine desire to complete every task and achieve every objective in a manner that protects employees, plant equipment, and the community in which the plant is located to the greatest extent possible. While profitability and production targets are also important goals for the organization, the entire organization understands that these are enabled by continuous safe operations, rather than despite them.

Establishing a strong Safety-Principled Organizational Culture is a long-term process that requires dedicated resources for as long as the organization exists. Additionally, it is the result of the quality and quantity of effort put into its implementation. A solid, sensible effort by management and technical staff to establish a culture of this nature will be noticed by the plant workers and they will want to help. This will have the effect of catalyzing the program, thereby helping to ensure its success. Alternatively, merely stating the objective of building this culture will have little effect on creating excellent organizational safety culture if the implementation and control of safety is weak.

Establishing a strong Safety-Principled Organizational Culture will minimize safety incidents, and this will save lives. Since essentially all accidents begin with a human error, the actions or inactions of the plant worker can be the limiting factor in determining overall safety performance.

The proper culture helps plant workers understand why strict adherence to procedures is the right thing to do. Further, it helps to enable thoughtful compliance and to alert management when procedures are wrong. In this way, a sound culture is essential to maximizing the results of ALL safety activities.

Establishing a strong Safety-Principled Organizational Culture can be achieved by successfully pursuing 5 Key Strategies – each of which are described below.

Strategy 1: Establish Safety as a Core Value

Attaining the goal of superior plant worker performance (i.e., low human error rates) begins by providing strong and consistent communication about the importance of safety **from the very top of the organization**. This is achieved by setting an appropriate tone that safety is equal to or greater than production and by not diluting the message with a lot of other high priority core values. The first step in setting the tone is by clearly stating the importance of safety in a high-level mission statement. Then, this mission statement must be communicated to the organization, along with the related goals and plans for achieving it. An important aspect that must be communicated is the key role of controlling plant worker human error by focusing on Human Factors. Additionally, it is critical that this effort not be reduced to a "program of the month" – it must be spoken about frequently and consistently to all levels of the organization.

Of course, words are hollow without consistent corresponding actions. Therefore, strong leadership must be provided by demonstrating the commitment to safety excellence through actions and decisions. Replace slogans and banners with high standards, shared values, and core beliefs which sustain the organization regardless of who is in charge. To help ensure these values propagate throughout the entire organization, managers must be educated in this culture, vision, and related standards, as well as the expectations for their roles and responsibilities in this critical effort.

A strong Safety-Principled Organizational Structure relies upon high standards of performance that are consistently enforced. This is achieved by first defining appropriate safety goals – namely, those that provide an indication of the organization's capability to perform their work safely. Too often, organizations tie the success of their safety programs on the lagging indicator of incident rates. While this is of course the ultimate goal of the organization, this isn't necessarily a reliable indicator of safety for the organization. Consider how many ways a plant worker can be hurt completing a single task, then multiply that by the number of tasks the individual completes per day, and then by the number of plant workers within the organization. Clearly there are thousands of opportunities for injury each day. Fortunately, however, for nearly all organizations the number of incidents that occur is very small compared to the number of opportunities for an incident. Therefore, unless incident rates are abnormally high, a change in an organization's injury rate is typically due to factors outside of their control. It is much more valuable, then, to establish goals centered around the organization's work in improving their safety-related management systems.

Another aspect of establishing safety as a core value is to establish responsibilities and accountabilities for process safety roles. Every individual within the organization should be held accountable for steadfastly adhering to the newly established expectations. While it may be tempting to overlook seemingly minor deviations from these expectations, this can lead to normalizing deviations which can potentially lead to serious incidents due to a relaxed response to these warning signs of potential hazards. Therefore, the leaders of the organizations must hold direct reports accountable for demonstrating behavior consistent with this value and set expectations for each level of the organization to hold their direct reports to this same behavior.

Finally, it must be recognized that improving the organizational culture involve costs and benefits that are both long-term in nature and sometimes difficult to measure. By establishing appropriate goals as noted above that focus on management system health, however, the organization has the means to continuously improve its performance.

Completing all of the above will help ensure that the core value of safety is consistently embraced throughout the entire organization, including the plant workers.

Strategy 2: Provide the Necessary Resources to Ensure Success

Providing resources to transform the organizational culture is the most tangible way to demonstrate to the plant workers that safety is indeed an organization's core value. In this context, resources constitute monetary commitments, as well as those of personnel.

The place to begin is to fund and allocate personnel to enable good safety performance by creating and effectively implementing the Human Factor management systems described above. Done properly, these will close any gaps in the control of Human Factors as well as those evident in existing systems that don't meet a critical need such as performing a PHA of procedures to find scenarios unique to non-continuous modes of operation as described by Bridges and Marshall[26]. Adequate personnel must also be allocated for completing safety-related tasks to support these management systems (inspections, maintenance, etc.), for maintaining these management systems as changes or newly identified requirements occur, and for training and educating personnel.

It is also important to designate a high-ranking leader for safety who can help ensure that major decisions are based upon a proper consideration of safety. But it is also important to provide the positional support necessary to promote strong safety performance throughout the organization. This is achieved by identifying resources on paper and filling with effective and competent people. For example, if a trainer is shown on an organization chart, it should be ensured that this is their full-time job and that they aren't responsible for other unrelated tasks. This demonstrates that the organization places a high value on training and development of people and groups. This can be further enhanced by ensuring that training materials are maintained current, and by maximizing the use of instructor-led training, rather relying than too much on the use of Computer-Based Training.

Furthermore, a properly designed and implemented training program will allow the organization to demonstrate that it places a high value on safety knowledge and expertise. This can be enhanced by identifying and providing the proper mix and amount of expertise for its most important tasks (for example, by pairing an individual with a high level of expertise with one who has the potential, but not yet the experience, to develop this same level of expertise). To properly ensure optimum prevention of human error, the organization should focus on building expertise in Human Factors and seek out expertise for critical decisions.

Finally, since excessive overtime impacts employees' abilities to perform their jobs safely and increases safety risks, the organization must devote sufficient manpower resources to properly control overtime.

In summary, the overarching approach here is to ensure that a structured, strategic approach is developed to properly allocate funds and personnel to create, implement and maintain the management systems needed for safety enhancement opportunities.

Strategy 3: Establish a Blame-Free and Learning Environment

It is critically important that the organization commit to a blame-free culture for all plant worker human errors, including for near misses reported and investigation findings. At an intellectual level, everyone understands that no one is perfect and that zero human errors are not possible. Plant workers are no exception. A key driver for the creation of a blame-free environment then is driven by how the organization responds to the inevitable human errors that plant workers will make.

The response to plant worker errors can be thought of as a continuum that spans two extremes; on the left side the response is one of blaming or fault-finding, while on the right side the response is one of trying to understand or learn why the error was made. Quite often people will automatically default to the "blame" side of the continuum for plant worker human errors, saying something to the effect that if only the plant worker had handled the situation differently the error would not have occurred. While this is true at face value, it is not a helpful response. After the fact, it is easy to see what should have been done differently because the outcome is now known. But when the plant worker was taking actions, this outcome was not obvious to him or her. Significantly, people do not come to work planning to make errors; instead, they come to work to complete their tasks in the most efficient manner possible. It is only after an incident occurs that the benefit of alternate actions is clear. Thus, the more productive response is to try to understand the context of the plant worker's action – what was it that made this particular action appear to be correct? It is only by taking this approach that the lessons from the incident can be fully understood.

Each person in the organization needs to understand where on the human error response continuum they reside and make every effort to move as far to the right side as possible. As shown in Figure 5, there are three aspects to an individual's response to a plant worker human error: the **internal response** (what we say to ourselves when we are made aware of a human error), the **external response** (what

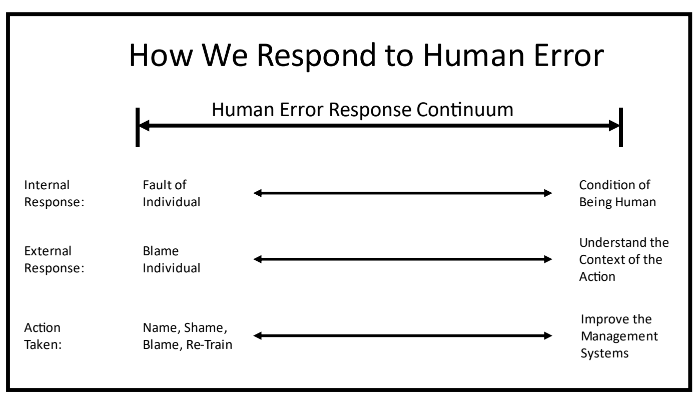

Figure 5: How We Respond to Human Error

we say out loud when we are made aware of a human error), and the **action taken** (what we do when we are made aware of a human error).

The internal response continuum ranges from thinking that the error was the fault of the plant worker, to recognizing that the error was a condition of that plant worker being human. The best approach for an individual to move to the more productive right side of this spectrum is to consider experiences in their own life in which they have made an error, which in retrospect seems to have been easily avoided. With this perspective, it is easier to understand that the plant worker who made the error in question was doing the best job possible but did not fully understand a specific hazard associated with it.

The external response continuum ranges from blaming the plant worker, to understanding the context of the action (i.e., why it made sense for the plant worker to take the action he or she took). Only by understanding the context of the action is it possible to develop measures so that another plant worker faced with the same choice does not repeat the error. As an example, a major chemical company experienced an acid spill from a tank truck one very cold evening. The truck driver was directed by the chemical company's guard to the wrong operating unit and began unloading the acid into that unit's tank. The operator from the unit soon emerged from the local control room and informed the driver that no acid was needed there. After a few phone calls, it was learned that the delivery was for a different unit which was located about ½ mile away. Accordingly, the driver disconnected his truck but failed to properly tighten the unloading hatch on top of the tank truck (most likely due to the cold ambient temperature). Therefore, as the truck was driven to the other unit, acid was spilled along the entire route. The chemical company's response to this incident was to inform the delivery company that that driver was no longer allowed on company property – in essence, blaming the driver for the spill. But this decision left many questions unanswered. Why was the driver directed to the wrong unit by the company's guard? Why was the driver allowed to unload directly into a company tank without checking in to the local control room (which is a requirement even for company employees visiting from a different plant area)? Only by answering these questions – understanding the context of the action – could assurance be provided that future spills of this nature would not occur.

The action taken response continuum ranges from a combined action of naming the plant worker responsible, shaming the person for making the error, blaming them for the consequences, and then re-training them, to making improvements to the underlying management systems. Using the acid spill example, the driver most certainly knows how to correctly complete all of the tasks needed to safely unload product; therefore, training would provide no real benefit other than to make him feel worse than he already did. However, by improving the management systems (strengthening the process for directing drivers to the proper locations, enforcing the rule to check in to the local control room before unloading) a better assurance that the human error could be prevented from recurring is possible.

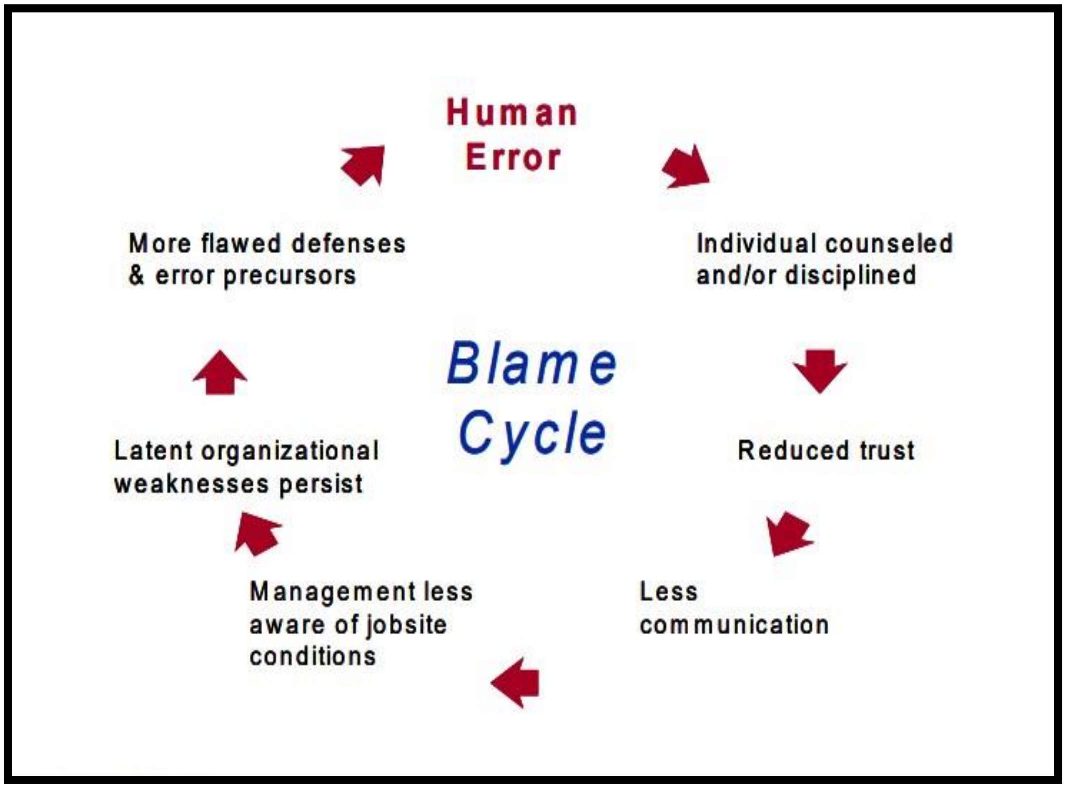

Figure 6: The Blame Cycle

The above discussion highlights the fact that residing on the "blame" end of the human error response continuum prevents an organization from truly learning about the root causes of incidents, thereby potentially leading to a recurrence of the error. However, blaming plant workers pose further risks to the organization. This is illustrated by the "Blame Cycle" that was developed by the US Department of Energy[27]. This cycle establishes a phenomenon that when a plant worker is blamed for a human error, this results in this individual ultimately not reporting future errors, which the organization is therefore unaware of and is unable to address. This then leads to future human errors due to these latent weaknesses, which are unreported, and the cycle repeats itself potentially leading to very serious consequences.

With this perspective then, a blame-free and learning environment can be achieved by ensuring that the first questions following an incident are what and why, not who. Those are followed by asking how we can improve the procedures, task design, practices, equipment, and other management systems to prevent this from happening again. With this environment, all incidents (especially near misses) are reported and investigated without blame, which results in root causes (management system failures) being identified, and corrective measures being taken to implement sustainable and permanent solutions. Trust and collaboration are high because the culture is blame-free when it comes to mistakes and people ask for help when they need it and give help without being asked.

Some key approaches to establishing a questioning/learning environment include properly performing risk reviews, conducting thorough incident investigations, performing table-top drills, and sharing and seeking lessons inside of and outside of facility. Significantly, plant workers should be highly involved in each of these activities. It is also critical to maintain a high awareness of hazards and consequences and remain vigilant for indications of system weaknesses. This can be achieved by ensuring that all plant workers are educated on the hazards of the operation, that they understand how safety hinges on control on Human Factors, that they all are educated on the consequences of deviation from safe practices, and that they share lessons learned.

A final aspect is to provide timely response to, and communication of, safety issues and concerns and lessons learned from incident investigations, audits, risk assessments, employee concerns and discrepancies between practices and procedures.

In summary, an organization must ensure that a blame-free and learning environment is consistently embraced throughout the entire organization. This can be achieved by reinforcing this at all opportunities through words and actions by personally seeking solutions instead of blame. Furthermore, top management must hold direct reports accountable for demonstrating behavior consistent with this value and set expectations for each level of the organization to hold their direct reports to this same behavior.

Strategy 4: Enhance Employee Empowerment and Involvement in Safety

Plant workers can best contribute to the Safety-Principled Organizational Culture and thus successfully fulfill their safety responsibilities by having the necessary authority and accountability for safety responsibilities. Leadership can enable this by reinforcing that all employees have responsibilities to themselves, fellow employees, company, and community and by involving the plant workers in safety management systems to ensure that they are widely understood and supported. This approach has the added benefit of recruiting additional resources to support the many tasks required.

A prerequisite to this is for the organization to ensure open and effective communication – both vertically and horizontally. Strategically, this can be achieved by emphasizing the need to promptly observe and report non-standard conditions. A key management system to enable this is a properly deployed near miss reporting program. Bridges[28] outlines an approach for creating a program of this nature, as well as specific, common hurdles that must be overcome to ensure its success. Key items in a properly designed program include first providing means for all plant workers to communicate hazards to management (in a blame-free environment) and for management to consistently act on these stated concerns.

Related to this, plant workers should be involved in identifying hazards and deciding how they should be addressed. In certain situations, plant workers should be authorized to take action to address hazards without management involvement. A very important example of this is that plant workers should have the authority to question decisions which are being made about process safety, including a "Stop Work Authority".

Ensuring optimum plant worker involvement in the safety management systems must be intentional. Therefore, the organization should develop an Employee Participation Plan, which lists key components of the management system that plant workers can best contribute to. A few examples to include identifying and controlling deficiencies in Human Factors, writing and reviewing operating and maintenance procedures, and participating in Process Hazard Analyses, Root Cause Analyses, and audits. Other opportunities can be developed by critically reviewing components of all safety management systems (including those developed for Human Factors) that will benefit by having the specialized knowledge of plant workers.

Strategy 5: Drive Continuous Improvement in the Safety Management Systems

Even the best designed safety management systems are not perfect (because they are developed and managed by humans). Therefore, the best Safety-Principled Organizational Cultures undertake specific activities to understand gaps in the systems and then take actions to close these gaps. This is achieved by establishing relevant metrics on the health of the management systems, which as noted previously, should predominately be leading metrics. Typical examples include the timeliness of correcting deficiencies, adherence to ITPM schedules/procedures, and the expansion of problems detected in one area to investigate similar applications in other areas.

Over time, trends should be developed of these metrics, presented to management who should then direct actions to improve these Key Performance Indicators. Further, these metrics should be shared within the organization so that all employees – including plant workers – have a clear sense of how well their efforts to contribute to the success of these programs are working. It is important to remember that many of these safety-related metrics have long-term results, rather than an immediate impact. Therefore, continued diligence in these continuous improvement efforts are needed to ensure a sustained Safety-Principled Organization Culture, and ultimately outstanding safety performance for the organization.

7. Closing

Human error is inevitable. And the human errors that are typically thought of as the ones that lead to serious accidents are often attributable to those made by plant workers. Although this assessment is unfair (as other members of the entire organization contribute in meaningful ways to these incidents), it is nonetheless very important for organizations to undertake measures to reduce plant worker human errors.

The means to do this are outlined in this paper. It relies first on the organization having the proper culture – one that doesn’t react to plant worker errors by blaming them; rather, it seeks to understand why the error was made and taking actions to fix the issue instead of the plant worker. It recognizes that to do this requires that the error must be traced to the underlying Human Factors that increased the likelihood of this error’s occurrence, and that the best way to improve these Human Factors (and thus reduce plant worker human errors) is to develop and implement robust management systems for them.

The information provided in this paper to strengthen the plant worker Human Factor management systems is the most important method to reduce plant worker human errors. However, even with perfectly implemented management systems human errors will still occur – albeit at a lower frequency and likely with a smaller adverse impact than before. Therefore, in cases in which the consequence of a human error is unacceptably high, the organization should implement solutions that will lower the residual risk further. These solutions can be designed to either help prevent the error or compensate for the error, but **they must be independent of the human error initiating event**. Bridges and Bridges [25] have compiled a list of the best remedies for human error for these situations. In a similar vein, plant worker human error can be further reduced by performing the previously mentioned PHA of procedures to find scenarios unique to non-continuous modes of operation as described by Bridges and Marshall[26].

Finally, a small fraction (about 15%) of plant worker human error is attributable to acquired habits, or behaviors; the remedy for which is a properly designed and implemented plant worker observation program. The reader is encouraged to review these other important documents and methodologies to obtain a fully comprehensive understanding of the best ways to reduce plant worker human errors.

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