How to Design Human Factors into a PSM System to Ensure Effectiveness and Deliver Risk Reduction Performance

Minu Shikha Mathur, PhD, AEP
JCL Risk Services LLC
16225 Park Ten Place, Suite 500
Houston, Texas 77084
mmathur@jclsc.com

David A. Jones
JCL Risk Services LLC
16225 Park Ten Place, Suite 500
Houston, Texas 77084
djones@jclsc.com

Prepared for Presentation at
American Institute of Chemical Engineers
2016 Spring Meeting
12th Global Congress on Process Safety
Houston, Texas
April 11-13, 2016

How to Design Human Factors into a PSM System to Ensure Effectiveness and Deliver Risk Reduction Performance

Minu Shikha Mathur, PhD, AEP
JCL Risk Services LLC
16225 Park Ten Place, Suite 500
Houston, Texas 77084
mmathur@jclsc.com

David A. Jones
JCL Risk Services LLC
16225 Park Ten Place, Suite 500
Houston, Texas 77084
djones@jclsc.com

Keywords: human factors, human error, process safety management system, risk reduction performance, continual improvement

Abstract

This paper will present a practical application of a design process for developing and implementing effective process safety management (PSM) systems. Management system deficiencies are often the root causes leading to process safety incidents. Such deficiencies can be attributed to inadequately designed management systems, primarily since standards and regulations do not provide detailed specifications for their design. A methodology based on proven quality management principles will demonstrate how human factors can be incorporated directly into the design specification for a PSM system to assure effectiveness and deliver sustainable risk reduction performance. As such, they can have a dramatic impact on how individual management processes can be used to ensure that design, operational and maintenance activities are conducted in a safe and environmentally responsible manner.

Applicable to both onshore and offshore facilities, this design methodology takes process safety beyond regulatory compliance and enables organizations to sustain performance for managing risk, reliability and resilience as part of an integrated operational risk management framework. It applies to both new and modified designs for engineered process systems, as well as individual management processes. Application of human factors to the management system design also allows for continual improvement in response to changes to regulations, technology, and operating practices.

This paper will present a practical step-by-step procedure on “how to” incorporate human factors into the PSM system design, including: leadership, safety culture, human factors engineering and human-machine interfaces, employee engagement and empowerment, communications, etc. Examples will show how quality aspects for human factors are addressed in key management processes within the PSM system in order to improve risk reduction performance.

Introduction

A well-established design concept for management systems is the continual improvement life cycle involving the steps: Plan-Do-Check-Act. Based on standards for managing quality, environment, occupational health and safety, and security [2,22,25,27], design models for effective process safety management (PSM) systems also utilize the Plan-Do-Check-Act life cycle model [28,29]. Even though the implementation of PSM has seen a significant improvement in the recent years, it can be taken a step further by using the knowledge of how humans interact with the facilities, equipment, and management systems within their work environment and within a culture to improve PSM systems. This synergistic integration of human factors and PSM may result in fewer incidents along with higher efficiency and a more productive workforce.

This paper aims to show the human factors deficiencies within the design or implementation of current management processes that can have a cumulative degrading effect on performance results. Failing to properly address these deficiencies leads to higher probabilities for human error. The U.S. Occupational Safety and Health Administration (OSHA) PSM Standard requires that human factors be addressed when conducting process hazard analyses (PHAs). Further, the U.S. Bureau of Safety and Environmental Enforcement (BSEE) notes for its Workplace Safety Rule, or Safety and Environmental Management System (SEMS) regulation, that: "A SEMS program is a comprehensive system to reduce human error and organizational failure" [4]. Since PSM encompasses controlling risks by minimizing human error, applying human factors principles to PSM systems should be included in the design, procurement activities, risk assessments, incident investigations, and virtually all aspects of PSM.

Thus, key processes for managing plans (policies, programs, procedures), managing changes (organizational, procedural, technical), managing performance (conformance, compliance, results) and managing actions (corrections, corrective actions, preventive actions), can each benefit from increased human interaction and input. Engaging the entire workforce through leadership and employee participation is seen as a key driver for integrating human factors in a PSM system.

Human factors implementation to any process requires an understanding of human capabilities and limitations as it applies to facilities, equipment, and management systems [37]. The effect of working environment and culture is well documented and is the key factor in determining how effective implementation of human factors will be to a process or management system [31].

The concepts and examples in this paper will address aspects of the five tenets of "Vision 20/20" from the Center for Chemical Process Safety (CCPS): *committed culture, vibrant management systems, disciplined adherence to standards, intentional competency development, and enhanced applications of lessons learned*, which were developed to demonstrate what perfect process safety will look like in the near future when it is championed by industry [9]. This integration of human factors directly into the design of the PSM system can take the practice of managing process safety to the next level of performance for the industry [9,35].

This paper will draw upon the authors' extensive practical experience in applying the principles and practices of human factors, designing and developing comprehensive PSM systems, conducting PSM system audits, and leading incident investigations.

1. Human Error – The Need for Integrating Human Factors

1.1 Who are the Humans?

Humans are already fully integrated into the life cycle of the engineered processes that produces chemical products. The entire workforce is comprised of humans. Managers who make decisions are humans. Engineers who design and improve the processes are humans. Contractors who construct the processes are humans. Operators who operate the processes are humans. Maintenance personnel who maintain the processes are humans. Support personnel, including those involved with contracts, purchasing, receiving, stores, laboratories, planning, scheduling, logistics, and security, are all humans. In all cases, these humans can affect process safety performance, either negatively or positively. That is, humans are responsible for making the business and the processes run successfully since facilities do not run on their own. Humans are a source of process safety risks through human errors that are possible from their activities. Conversely, they are also the key source of risk control, through their risk management activities.

1.2 What do these Humans do?

All management processes center around human activities; that is, they involve people who manage, perform, and verify the work, and then take action to continually improve quality and performance [22-24]. For example, some of the words we encounter for the management of process safety using the Plan-Do-Check-Act continual improvement life cycle model include:

- Plan (planning & organizing) – a wide variety of humans *manage* tasks for planning and organizing the resources and activities for all processes, in order to prepare for the effective and efficient execution of work. Example human activities include: allocating, acquiring, compiling, defining, determining, developing, encouraging, establishing, gaining, identifying, initiating, obtaining, planning, preparing, selecting, etc.

- Do (implementing & performing) – humans *perform* numerous job tasks on a daily basis, in order to achieve organizational objectives related to their work and the overall business. Example human activities include: accessing, advising, conducting, consulting, communicating, completing, demonstrating, deploying, documenting, employing, executing, explaining, implementing, informing, instructing, issuing, obtaining, performing, responding to, retaining, training, utilizing, etc.

- Check (measuring & evaluating) – humans often engage in specialized tasks to *verify* that actual activities and results are achieved against planned arrangements and objectives, in order to identify any gaps or deficiencies that need to be addressed. Example human activities include: analyzing, ascertaining, assessing, checking, confirming, evaluating, investigating, measuring, monitoring, revalidating, reviewing, verifying, etc.

- Act (reviewing & improving) – humans also *act* to correct identified gaps or deficiencies, in order to improve conditions, behaviors, processes, and performance results. Example human activities include: assuring, certifying, controlling, resolving, correcting, improving, etc.

It is these activities within the PSM system that provide an opportunity to integrate human factors.

1.3 What is Human Factors?

CCPS defines *human factors* as: "A discipline concerned with designing machines, operations, and work environments to match human capabilities, limitations, and needs. Among human factors specialists, this general term includes any technical work (e.g. engineering, procedure writing, worker training, worker selection) related to the person in the man-machine systems." [7].

The UK Health & Safety Executive (UK HSE) defines *human factors* as: "Human factors refer to environmental, organisational and job factors, and human and individual characteristics, which influence behaviour at work in a way which can affect health and safety" [20]. Thus, integrating human factors into the PSM System requires an understanding of: who these humans are, the work activities in which humans are engaged, and the factors needed to be addressed to improve human performance at work [36].

1.4 What are some Human Factors?

Human factors can be conveniently grouped into three interacting groups of performance influencing factors (PIFs) [8,20]:

- Individual Factors (who is doing it?) – e.g. competence, skills, personality, fatigue, stress, attitude, risk perception, etc.
- Job Factors (what are people asked to do and where?) – e.g. task, workload, complexity of task, clarity of procedures, system interfaces, work environment, displays and controls, procedures, etc.
- Organizational Factors (how are they doing it?) – e.g. culture, leadership, resources, work patterns, manning levels, communications, etc.

Human activities and individual behaviors on the job are influenced by each of the PIF groups. Combined with the human tendency to make errors, PIFs are the factors responsible for creating error-likely situations. While humans do not usually make intentional mistakes, misinterpreting situations are far too common and often result in errors. Human decision making is also questionable if they are overworked or are put in stressful situations. On the other hand, with proper experience and training human intervention under certain levels of stress during process upsets and emergency response can be beneficial [6].

Analysis of PIFs can help to determine how effective human performance will be. For example, if an operational procedure for a job provides complete clarity for what needs to be done, how it needs to be done, what may go wrong or require special attention, and how to correct a deviation if it happens, the chances of higher performance is more likely. PIFs can also be utilized for designing a system to increase usability and decrease error probability. For instance, designing a Human Machine Interface (HMI) for the control room operator that displays alarms that have undergone an alarm prioritization to only show those alarms that allow operators time to act upon, would help the operator make better decisions. Alarm prioritization also allows the system to produce fewer alarms and results in operators trusting the alarms to be genuine and provides them with sufficient time to process them and provide corrective action without experiencing a clutter of nuisance alarms that need to be continuously silenced.

1.5 Why integrate Human Factors into the PSM System?

Existing deficiencies within either the engineered process system or the management system create process safety risks through ineffective risk controls intended to prevent or mitigate process hazards. Addressing human factors to reduce incidents is not a novel concept since it has been shown that nearly all incidents (including near misses) can be traced back to deficiencies from a human cause, since humans are responsible for the design, construction, operation and maintenance of the process as well as the development and implementation of the PSM system. However, just stating that human error from human factors is the cause of an incident does not provide any real method to prevent the recurrence of such an event [15,31].

These deficiencies, once identified, represent areas of opportunity for improving the integration of human factors, particularly in designing features of the PSM system to reduce human error, or at least in providing for the recovery of errors through mitigation measures [31]. In fact, being able to trace the human error back to a PSM system deficiency and improving the system can be beneficial on several levels. It can improve communications within the facility, eliminate or at least reduce human error and hence future incidents, and improve human performance and overall PSM system efficiency [6].

A human factors approach can be proactive or reactive leading to differences in cultures observed for implementing changes to reduce risks. Even though a proactive approach can come with limitations of being prescriptive, it is an improvement over a reactive approach where all actions are a direct result of past events. Taking a proactive human factors approach involves a paradigm shift and needs a strong foundation of checklists, auditable improvements, and a structured plan to consistently implement these changes by integrating them with the existing PSM system.

The Baker Panel report following the Texas City incident in 2005 mentions that a majority of incidents in the process industry are a result of failure to minimize or prevent *process* as well as *personal safety* risks. It is a combination of process and personal safety risk reduction that ultimately determines how effectively all the risks are to be managed [5]. The report also cautions against having checklists that groups the risk factors into too tight of categories to really understand the root causes needed for effective risk reduction. In addition, inadequate tracking and implementation of human factors deficiencies identified by PHAs led to inconsistencies in addressing these issues [5].

Existing regulatory and standards references such as the Contra Costa County (California) Human Factors Program [13], UK HSE Human Factors guidelines [16-20], Norsok standards developed by the Norwegian petroleum industry (e.g. NORSOK S-001, S-002) [33,34], and international standards (e.g. ISO 17776) [26], to name a few, provide good guidance for implementing human factors as a means to manage and reduce risks associated with the process industry. These documents refer to human reliability, human error, safety culture, training, operating procedures, organizational factors, process hazard analysis, and incident investigation as important topics to be covered to ensure a complete approach towards understanding the capabilities and limitations of the human element interacting with systems and the need to design these systems accordingly.

Human factors in PSM can be identified by analyzing each element of the PSM system to recognize the opportunities for human interaction with the system and to forecast where these interactions have a probability of producing human error [6].

1.6 Where can Human Factors be integrated into the PSM System?

Human activities already associated with typical PSM system elements (see Table 1) demonstrate the potential for integrating the principles of human factors for all PIF groups to be straightforward, cost-effective, and beneficial in closing a gaps in an existing PSM system where deficiencies exist.

Table 1: Human Activities and Example PSM System Deficiencies by PSM Element

PSM Element	Human Activities	Example Deficiencies	HF PIFs
Employee Participation	Safety culture survey	Inadequate communications	Organizational
Process Safety Information	Design reviews P&ID walk-downs	Inaccurate piping & instrument diagrams (P&IDs), missing data	Job
Process Hazard Analysis	Evaluation of process hazards and safeguards	Inadequate safeguards, incomplete design basis, and design deficiencies	Job
Operating Procedures	Periodic review for currency and accuracy	Outdated operating procedures	Job
Operator Training	Testing / re-testing, on-the-job evaluation	Inadequately trained operators	Individual
Contractors	Pre-job/periodic performance evaluation	Unqualified or under-performing contractors	Individual
Pre-startup Safety Review	Review of design, procedures, training, etc.	Construction and equipment not in accordance with design specs	Job
Mechanical Integrity	Equipment tests and inspections	Equipment deficiencies outside of acceptable limits	Job
Management of Change	Technical review for proposed change	Impact of change on safety and health not assessed or not acceptable	Organizational
Incident Investigation	Causal factor analysis and root cause analysis	Various management system deficiencies as findings	Organizational
Emergency Planning/Response	Post-drill/incident response evaluation	Inadequate planning, lack of resources, inadequate equipment	Organizational
Compliance Audits	Interviews, records reviews, inspections	Various management system deficiencies as findings	Organizational

Some PSM elements already incorporate human factors to some extent, including Operating Procedures, Operator Training, and Employee Participation. Previously referenced regulations, industry standards, and guidelines can be used to provide specific design requirements to implement human factors in other parts of the PSM system. These encompass good industry practices originating as a part of lessons learnt over several decades giving this approach a substantial foundation to build upon for improving the existing PSM system [40].

Additional areas such as Safety Culture Surveys, Communications, Safety Critical Task Analysis, Human Reliability Analysis, Fatigue and Staffing Level Assessment, and Fitness for Duty, can be added to enhance the PSM system and improve productivity and risk reduction performance [6]. For example, Fatigue Assessment studies of staffing levels and workloads provide key information to understand the risks associated with mental and physical workload of a control room operator.

2. PSM System Design – The Solution for Integrating Human Factors

2.1 PSM System Background

A popular definition for the term *process safety management (PSM) system* is a "comprehensive set of policies, procedures, and practices *designed* [emphasis added] to ensure that barriers to episodic incidents are in place, in use, and effective" [7]. This definition implies that a PSM system needs to be adequately designed in order to achieve its objectives of managing process safety risks. Quality management systems have traditionally involved the practice of "say what you do, and do what you say". That is, by documenting what you plan to do, then implementing that plan to achieve results, one can "design in quality" as the basis for a proactive management system aimed at achieving performance, including process safety risk reduction performance.

Borrowing from international standards for quality management systems, the design process for delivering a product (e.g. a PSM system) requires as a starting point the development of design inputs, documented as a design specification [22]. A design specification is a set of requirements, related quality characteristics and performance criteria, translated from identified customer needs and performance objectives; with a procedure being a special type of specification [21]. A design specification is critical for integrating requirements into a management system in order to achieve the overall quality objective of meeting specified requirements [21]. Without defining all of the requirements needed for effective management, we cannot hope to achieve the desired performance results of the management system.

Unfortunately, most international standards for management systems related to quality, health, safety, environment, and security, as well as regulations governing process safety management, do not define detailed specifications for the management system itself, nor do they state specific criteria for its performance [13]. For example, an international standard for occupational health and safety management system states: "… It does not state specific OH&S performance criteria, nor does it give detailed specifications for the *design of a management system* [emphasis added]" [2]. Rather, these "performance-based" standards and regulations define "what" but typically not the "how to" requirements for effective management. These apparent gaps however allow flexibility for determining how best to design the management system in order to meet the general requirements and achieve overall performance.

Further, some PSM regulations (with industry standards incorporated by reference) require that human factors be "addressed", but provide no specifics or guidance on how to meet this requirement [1,3,4,38].

Therefore, in order to benefit from the application of human factors to the management of process safety, we must integrate the principles of human factors directly into the design of the PSM system by defining the requirements in the form of a specification.

This section will address a practical step-by-step procedure on "how to" incorporate human factors into the PSM system design. Examples for a few system components will show how quality aspects for human factors can be addressed in key management processes within the PSM system.

2.2 PSM Design Basis

Borrowing from two of the eight total quality management principles which form the foundation of several international standards for management systems for quality, health and safety, environment, and security, an effective PSM system design basis utilizes [21]:

- Process Approach – A desired result is achieved more efficiently when activities and related resources are managed as a process.
- System Approach to Management – Identifying, understanding and managing interrelated processes as a system contributes to the organization's effectiveness and efficiency in achieving its objectives.

At a higher level, the PSM system is structured with a dozen or so individual management processes (or elements), each one designed to achieve certain objectives which when integrated into a comprehensive system serve as a management tool for use by humans aimed at reducing or controlling process safety risks. At a lower level, each management process is designed as an interrelated set of resources and activities that transforms inputs into outputs (results). Many of these processes are interrelated with their inputs, outputs, and informational resources comprising documented policies, procedures, plans, programs, work instructions, standards, specifications, records, etc.

For each of the management processes within the PSM system, the aim is for humans to perform specific activities on a continual basis that improves the quality of the PSM system resources and outputs and that contributes to its overall effectiveness in reducing and controlling process safety risks. Therefore, the design intents for each PSM element should support the overall performance objective for the PSM system (see Table 2). For people to effectively perform, the PSM system design should define why (the intents or objectives), who (persons responsible), what (the tasks), when (the schedules), where (the applications), and how (the methods).

Table 2: Example PSM Performance Objectives

PSM Element	Performance Objectives to Reduce & Control Risks
Employee Participation	To improve participation and ownership
Process Safety Information	To improve information quality
Process Hazard Analysis	To improve the process design & safeguard effectiveness
Operating Procedures	To improve operational control
Operator Training	To improve competence and performance
Contractors	To improve qualifications and performance
Safe Work Practices (Hot Work Permit)	To improve control of work
Pre-startup Safety Review	To improve the adequacy of PSM elements before startup
Mechanical Integrity	To improve the asset integrity
Management of Change	To improve the control of changes
Incident Investigation	To improve the system and prevent incident recurrence
Emergency Planning & Response	To improve response capability
Compliance Audits	To improve the effectiveness of the PSM system

2.3 PSM Design Process

A proven procedure for designing management processes includes the following steps [28]:

1. Identify Output(s) – define the products or results to be produced.
2. Identify Customer(s) – define who will use or benefit from the outputs.
3. Identify Customer Requirements – define stated and implied requirements.
4. Translate Requirements into Specifications – define specifications for inputs/outputs.
5. Identify Process Steps – define the steps for Plan-Do-Check-Act activities.
6. Select Measurement Criteria – define measures of success and performance criteria.
7. Determine Process Capability – define the resources and requirements to produce results.
8. Evaluate Results – assess conformance and performance results, and evaluate gaps.
9. Improve Results – review and improve on results.

Each of the above steps are described in further detail below, with an emphasis placed on integrating human factors into the PSM system design.

Step 1 – Identify Outputs

All too often, standards and regulations are written based on describing certain activities (e.g. incident investigation, PHAs, compliance audits, etc.) without identifying the purpose of the process or the output expected. However, to design quality (and human factors) into the PSM system to achieve desired results, the output or product of each process activity should be explicitly identified.

For the example activities above, the outputs from the management processes would include: lessons learned with root causes as findings and recommendations for corrections and corrective/preventive actions, documented in an investigation report; process hazards/risks as findings and recommendations to further reduce risks, documented in an PHA report; and management system deficiencies as findings and recommendations, documented in an audit report. Properly defining the process outputs helps to identify their relationships to human factors as both causes of deficiencies and solutions for improvement.

Step 2 – Identify Customers

All processes ultimately exist to deliver products or results to a customer who has expressed needs. Internal and external stakeholders may include: those who are accountable for the results, a third-party such as a regulatory authority or the community, a contract employee or visitor, or for the most part, the end user of the product or the results who needs to be satisfied that they get what is needed in order to subsequently utilize the outputs. For example, an Emergency Response Plan is intended for multiple customers who have defined roles and responsibilities for executing the plan in case of emergency. Such customers may include: the incident commander, any one of several emergency responders, internal and external emergency services providers, operators of process units requiring specific steps for emergency operations, security personnel, etc.

Recognizing that individual humans fill all of the roles of “the customer” establishes a basis for identifying specific needs for job factors within the plan for coordinating, communicating, and controlling the emergency. In addition, identification of all customers helps to define

organizational factors interfaces for communications, lines of authority for decision making, and requirements for on-scene and post-incident reporting.

Step 3 – Identify Customer Requirements

Customer needs are expressed in a variety of ways, but mostly fall into two categories: stated and implied requirements, typically expressed by someone other than the customers themselves [28]. *Stated requirements* are often viewed as prescriptive and answer specific questions about the product or results to be delivered or the method of delivery. For example, regulatory requirements for the process of Management of Change may provide detailed requirements on what constitutes a change, what types of changes are addressed, and general steps for managing and documenting the change, including records and communications to those affected by a change. *Implied requirements* on the other hand, are related to specific expectations expressed by a more general requirement. For example, regulations for Management of Change may state that written procedures shall assure that the certain considerations (e.g. authorization) be addressed prior to implementing any change.

However, due to the performance-based nature of some regulations, they may not define how the procedures are to provide such assurance, either in form or content. Rather, it is left up to the operating company (i.e. employer) to determine their own specific requirements as a means to achieving the end result. Thus, requirements play a crucial role in determining the success of a management process since the fulfilment of identified requirements is essentially the definition of *quality* and this fulfilment is the basis for measuring the degree to which desired results are achieved [21].

Step 4 – Translate Requirements into Specifications

Even when customer requirements have been defined, simply having a list may not be that useful. Therefore, requirements are often translated into documented specifications used for communicating information and controlling the update of such information. This translation of requirements may be accomplished by specifying design criteria, by defining qualification expectations, by defining steps in an operating procedure, by providing a checklist for field verification, by devising a flowchart which incorporates decision points, or by providing other documented means to effectively communicate specific needs to other humans. Thus, translating customer needs/requirements into documented specifications or within a procedure or other PSM system component is essential for establishing what humans do, when they do it, where they do it, how they do it, and to what level of quality or performance they need to do it.

Without documented requirements to define specific job factors, there is no hope that humans will be able to consistently achieve the desired results from a given management process, in order to design, construct, operate or maintain a safe and environmentally sound engineered process. Rather, poorly specified requirements may lead to human error that could lead to immediate consequences when the process is implemented, or could remain latent until such time that critical information is called upon to prevent an incident.

Step 5 – Identify Process Steps

Once the process outputs and the customer requirements have been fully defined, the process steps for producing the outputs, products or results should be determined and documented. These steps can be written or expressed in flowcharts or other means to communicate how the process should work. More detailed steps (e.g. work instructions) may be required for more complex management processes.

In some cases, prescriptive requirements of the outputs may dictate the process steps. For example, processes involving the development of safe work practices (e.g. permit-to-work systems) have steps that are more prescriptive in nature since standards or regulations have been well-defined (e.g. confined space entry).

In other cases, the requirements defined by implied needs may offer a wide range of flexibility for carrying out the process, as long as the results are achieved. For example, requirements for Employee Participation may only require that a plan be developed and implemented based on consultation with employees. However, the steps needed to achieve employee participation should also be defined if employees are to have a key role and positive effect in managing process safety. Beyond meeting minimum compliance requirement for a plan, organizational factors such as empowerment and job enrichment can be incorporated into the Employee Participation process as a means to strengthen the safety culture of the organization.

Step 6 – Select Measurement Criteria

Another set of requirements needed to be defined includes criteria for quality characteristics and performance. These can relate to the outputs themselves or the process steps for achieving the outputs; that is, criteria for the product and the process activities and resources. In some cases, an implied need for qualified auditors, PHA facilitators or lead investigators, all of who are expected to possess certain knowledge and/or familiarity, may require operating companies to establish their own criteria for competence, an individual factor. However, without criteria being defined or without even the requirement for defining such criteria, the quality of results for certain critical management processes may fall short of their expectation to employ humans who can positively impact process safety performance.

On the other hand, other areas of process safety have already evolved within industry standards which contain specific criteria. For example, criteria for the Mechanical Integrity management process may need to incorporate an extensive set of acceptance criteria in order to accommodate the tests and inspections for a wide variety of process equipment. Such requirements can be derived from recognized and generally accepted good engineering practices, or otherwise developed as in-house standards for special applications.

Step 7 – Determine Process Capability

Once all of the requirements have been specified for the quality of resources and the outputs, and for the performance of process steps with performance criteria for both the activities and the outputs, the capabilities for each process must be determined. In order to achieve the desired results with expected quality and performance, the organization's leadership has the most influence over commitment of the time and resources necessary to effectively implement the PSM processes.

From a human factors standpoint, all three groups of PIFs (individual, job, and organizational) are relevant, as they can be negatively or positively affected by process capability fulfilment. For example, individual factors such as assigning personnel to a critical operating position before they have been fully qualified puts the individuals and the facility at risk. Hence, the management of organizational change has come to play a more important role in managing process safety performance.

Similarly, failure to allocate sufficient resources for staffing qualified personnel to carry out plans and safely execute procedures has the potential to adversely affect job factors such task and workload. For example, extended work shifts or overtasking of personnel without proper planning during turnarounds results in increased risk of human error. Conversely, leading by example and "walking the talk" can have a profound positive effect on the organizational factors of safety culture and achieving open communications.

Step 8 – Evaluate Results

Based on the specified requirements for quality and performance criteria, measurement of actual results against such criteria offers the opportunity to identify and improve inadequacies, deficiencies, or substandard results, before they manifest themselves as process safety incidents. From a human factors perspective, all three groups of PIFs (individual, job, and organizational) are relevant, as the results from process measurements can be evaluated against defined criteria. For example, individual factors such as competence and refresher training can be measured, and action taken to improve results in order to minimize risks.

Similarly, periodic verification and validation of work products (e.g. currency of operating procedures from reviews, effectiveness of emergency response plans from post-drill evaluations, accuracy of drawings from walk-downs) allow the quality of process safety information to be confirmed and corrected in order to minimize future human errors. Proactive measures, or leading indicators, enable an organization to address organizational factors by monitoring degradations in the PSM system through process design reviews involving identification, evaluation and control of hazard and their associated risks; or through PSM system audits to identify and correct identified deficiencies. Reactive measures, or lagging indicators, can also provide opportunities for improvement, through organizational lessons learned and corrective/preventive actions to prevent recurrence of actual (or near miss) process safety incidents.

Step 9 – Improve Results

From this point forward, continual improvement of the process and overall system is made possible by stating requirements within the process that any identified inadequacies, deficiencies, or substandard results will be improved through responsible actions to close the gaps.

2.4 Examples of Designing Human Factors into the PSM System

A PSM system can be comprised of several documented components which are used to manage the activities within the various processes. Examples of these system components and opportunities where human factors can be integrated include:

- Principles – values and beliefs that address why (e.g. Code of Ethics).
- Policies – management expectations for what to do (e.g. Stop Work Authority policy).
- Plans – written plans on strategy and objectives (e.g. Employee Participation plan)
- Procedures – steps for who, what, when, where, how (e.g. operating procedures).
- Products – outputs of activities that involve people (e.g. reports for PHAs, audits, etc.).
- Processes – inputs, outputs, resources and activities (e.g. incident investigations process).
- Programs – means of achieving objectives, schedules, etc. (e.g. training program)
- Performance – metrics for results of management processes relating to how well objectives are being met (e.g. risks, incidence rates, etc.).

Three examples are presented below (see Table 3) to demonstrate how to design human factors into a PSM system component. Each one uses the Plan-Do-Check-Act continual improvement life cycle model to define the management process, and each one addresses a different human factors group. These examples address three of the "top ten human factors issues facing onshore major hazards sites in the chemical and allied industries, based on research, consultation with industry and intermediaries and inspection experience," as identified by the Energy Institute [14]:

1. Organizational change (and transition management)
2. Staffing arrangements and workload
3. **Training and competence (and supervision)**
4. Fatigue (from shiftwork and overtime)
5. Human factors in design (alarm handling, control rooms, ergonomics)
6. **Procedures (especially safety critical procedures)**
7. **Organizational culture (and development)**
8. Communications and interfaces
9. Integration of human factors into risk assessment and investigations
10. Managing human failure (including maintenance error)

Table 3: Examples for Designing Human Factors into PSM System Components

PSM Element	Component	Example	HF PIF Group
Operator Training	Process	Competence Assurance Process	Individual
Operating Procedures	Procedure	Standard Operating Procedures	Job
Employee Participation	Policy/Program	Stop Work Authority Policy/Program	Organizational

Example #1 – Designing Human Factors into a Process

Human factors can be designed into each management process of the PSM System by specifying the requirements for the key process components: inputs, outputs, resources and activities. This example demonstrates how *individual* human factors requirements can be specified for the process of assuring the competence of personnel, namely those who operate engineered processes.

This management process places emphasis on developing qualified operators as a critical human resource for operating the engineered process. Thus, an unqualified operator is the process input

and a qualified operator is the process output with the specified quality characteristic of competence. A competent operator qualified through this process is more likely to reduce the potential for human error and therefore the process safety risk of operating the facility.

The customer in this process is the operator, who has a vested interest in being qualified to fulfill the job; the process unit supervisor or facility management are also customers of this process, as they are accountable for assigning qualified personnel to critical positions. The regulator can also be considered a customer, as they have a stake in the outcome from a compliance standpoint.

Regulatory authorities often only focus on establishing requirements for the training activity of the competence assurance process. For example, the OSHA PSM Standard requires that employees involved in operating an engineered process shall be trained in an overview of the process and in the operating procedures [38]. A process for training is not even required, although it is implied. Further, there are no regulatory requirements established by OSHA to prescribe how an operator should be trained, nor the criteria for determining how they are qualified. The PSM Standard only requires that "the means used to verify that the employee understood the training" is documented as part of the training records [38]. The term *competence* is not even used in this regulation, whereas international health and safety and environmental management system standards require that persons performing tasks shall be competent on the basis of appropriate education, training and experience [2,25]. Quality management system standards define competence as "demonstrated ability to apply knowledge and skills to achieve intended results" [2,21].

Therefore, to assure that qualified operators are competent to perform their assigned tasks of operating the process, a robust competence assurance process should be based on specified requirements, such as: defined competencies with specific criteria for measuring competence, methods for delivering training including qualifications of trainers, and methods for verifying competence and qualifying operators [16]. Such requirements should be specified for each of the process activities for assuring competence. For example, the Plan-Do-Check-Act continual improvement life cycle model can be used to define the steps of the process, as follows:

- Plan – specify requirements for planning and organizing training (e.g. training program, training matrix, training schedule, etc.)
- Do – specify requirements for delivering training (e.g. qualifications of trainers, content and format of training material, training facilities, etc.)
- Check – specify requirements verifying competence (e.g. testing methods and criteria, etc.)
- Act – specify requirements for improving competence (e.g. re-testing, refresher training, management of change, etc.)

Example #2 – Designing Human Factors into a Procedure

Human factors can also be designed into specific procedures for the PSM System by specifying the requirements for how work should be performed. This example demonstrates how *job-related* human factors requirements can be specified in a process for delivering operating procedures.

This management process involves developing, using, and maintaining operating procedures as a critical informational resource for operating the engineered process. Thus, the process output is a set of operating procedures with specified quality characteristics such as accuracy, currency,

comprehensiveness, clarity, usability, accessibility, etc. Operators who are trained on operating procedures can only be as effective as the quality of the tools at their disposable. So, having operating procedures with quality designed with the end user in mind is more likely to reduce the potential for human error and therefore the process safety risk of operating the facility.

Besides the process operator as the obvious customer in this process, the regulator can also be considered a customer, as they have a stake in the outcome from a compliance standpoint. As a minimum, the OSHA PSM standard requires that the operating procedures "provide clear instructions for safely conducting activities involved in each covered process consistent with the process safety information", that they address each operating phase (e.g. startup, shutdown, etc.), and that they address several other provisions for the safe operation of the process [38].

One of the ways human factors can be incorporated in writing operating procedures is to conduct a thorough task analysis to understand which job tasks need detailed instructions and which hazards are associated with the tasks before writing the procedures [39]. In order to ensure an effective procedure is drafted, an error analysis may be conducted by experienced personnel to add precautionary notes and warnings immediately prior to a step [13].

In addition, using consistent writing style that explains the purpose of the procedure (e.g., training material, emergency shutdown procedure, normal operation, etc.), references to other supporting documents (data sheets, manuals, etc.), and precautions that must be taken to avoid hazards and undesirable consequences, demonstrate good human factors practices. Avoiding long steps, double negatives, very small font sizes, and steps without any actions associated with them is recommended. The operating procedures should include "who" does "what" and "when" as well as quantitative values and limits for additional clarity [17].

To assure the availability of reliable operating procedures, a robust process should be based on specified requirements, such as: defined quality characteristics with criteria for verification, methods for accessing and using the procedures, and methods for reviewing and maintaining the procedures. For example, the Plan-Do-Check-Act continual improvement life cycle model can be used to design quality into the process and its product, as follows:

- Plan – specify requirements for designing and developing the operating procedures (e.g. task objectives, format, content, quality characteristics, etc.)
- Do – specify requirements for accessing and using the operating procedures (e.g. accessibility, back-up versions, document control, variance authorization, etc.)
- Check – specify requirements verifying and validating the operating procedures (e.g. periodic review frequency and methods to ensure reliability and usability)
- Act – specify requirements for improving operating procedures (e.g. document control for updates and approvals, management of change, etc.)

Example #3 – Designing Human Factors into a Policy/Program

Further, human factors can be designed into specific policies and related programs within the PSM System by specifying the requirements for how policies should be implemented through these programs. Having a safety policy issued by management does not guarantee its success; it must be supported, implemented, evaluated, and continually reinforced to be effective. This example

demonstrates how *organizational* human factors requirements can be specified in a management process for a program intended to implement a *stop work authority* policy for preventing incidents.

This management process encompasses developing, implementing, and sustaining a program to support a policy for empowering workers with the authority and responsibility to stop work where work situations may present an imminent risk or danger. Thus, the process output is a program which when successfully implemented not only provides a tool for reducing a process safety risk and potentially preventing a process safety incident, but also affords the opportunity to continually reinforce a workplace safety culture which recognizes process safety as a priority. It allows employees a mechanism to speak up when they see a problem, i.e. "see something, say something", as expressed in the committed culture tenet of the CCPS Vision 20/20 [9].

The customer in this process is the employee or contractor who is equipped with a tool supported by management to be used to protect themselves and others in cases that warrant stopping work. The regulator can also be considered a customer, in that they have a stake in the outcome from a compliance standpoint. Although OSHA's PSM Standard does not address this subject, BSEE's SEMS regulations for offshore operations have recently been revised to require stop work authority to be implemented by operating companies for their facilities [4]. Accordingly, "These procedures must grant all personnel the responsibility and authority, without fear of reprisal, to stop work or decline to perform an assigned task when an imminent risk or danger exists." [4].

Human factors is inherently embedded in this type of policy implementation; starting from a positive change initiation in how safe behavior is encouraged, and leading to being sustained by gaining the trust of every person involved in the policy implementation. This type of policy implementation requires good communication that reinforces a level of credibility that an employee will not be punished when stop work authority is actually utilized [18]. To achieve the credibility and attitude change needed for success of this program, several actions are recommended, such as: regularly stating clear information on safety policies, investigating incidents that lead to a change and informing employees of this change, including employees in a dialogue to improve ownership of the policy, and visibly demonstrating commitment of management to safety [18,32].

To assure that the stop work authority policy is successful, a robust program should include specified requirements, such as: the purpose of the policy, the means to communicate and reinforce the policy, methods for rolling out and using the policy, and methods for monitoring and sustaining its implementation. Such requirements should be specified for each of the process activities for assuring it success. For example, the Plan-Do-Check-Act continual improvement life cycle model can be used to design a program to implement a stop work authority policy, as follows:

- Plan – specify requirements for establishing a stop work authority (e.g. policy, procedures, success criteria, etc.)
- Do – specify requirements for implementing the stop work authority program (e.g. communications and awareness training, stop work authority cards, recordkeeping, etc.)
- Check – specify requirements for monitoring use and effectiveness of stop work authority (e.g. metrics, safety culture surveys, etc.)
- Act – specify requirements for sustaining stop work authority (e.g. reinforcement campaigns, refresher training, etc.)

3. Lessons to be Learned from Process Safety Incidents

Previous sections discussed that human factors can be integrated with key quality aspects into management processes within the PSM System, such as employee participation (e.g. safety culture), operating procedures (e.g. reliability), and training (e.g. competence). A historical perspective can reveal that the lack of human factors integration can contribute to management system deficiencies as the root causes leading to process safety incidents. Examples of three process safety incidents from U.S. Chemical Safety and Hazard Identification Board (CSB) investigation reports show how deficiencies in PSM systems pertaining to human factors led to system failures and how such these situations can be improved to prevent incidents from recurring.

3.1 Plastics Manufacturing Facility Incident (2004) [12]

An explosion and fire resulted in five fatalities and three injuries at the Formosa Plastics Corp. plastics manufacturing plant in Illiopolis, Illinois on April 23, 2004. The CSB reported that a large quantity of highly flammable vinyl chloride monomer (VCM) was released from a reactor.

The CSB noted that this incident resulted from human error by an operator opening the wrong valve that resulted from the inadequate layout of valve controls placed in the facility. The layout of controls made it easier for the operator to make a fatal mistake. The location of valve controls also did not provide feedback of the tank levels for operators to visualize. Further, there were no means for the operators to communicate between the levels where controls were located versus where the tanks were located.

Another cause cited by CSB was a more recent workload change due to staffing reductions. An operator was often required to make decisions without proper supervision since the supervisory positions had been eliminated. Depending on the experience and workload of the operator, as well as the level of stress or fatigue at the time of decision making, not having a supervisor available to check their decisions could lead to a higher probability of committing an error.

3.2 Pesticides Manufacturing Plant Incident (2008) [11]

An explosion at the Bayer CropScience pesticides manufacturing plant in Institute, West Virginia resulted in two fatalities and injured eight persons on August 28, 2008. The CSB reported that "this incident occurred during a lengthy start-up process resulting in a runaway chemical reaction inside a residue treater pressure vessel. The vessel ultimately over pressurized and exploded. The vessel careened into the methomyl pesticide manufacturing unit leaving a huge fireball in its wake."

The CSB noted that several shortcuts were taken during the start-up process that included not completing process hazard analyses (PHAs), bypassing checking valve line-ups, not conducting proper operator training, use of improper operating procedures, and inadequate safety critical equipment. Operator fatigue was also a significant issue leading to poor performance and decision making. In addition, Bayer CropScience management did not communicate properly with the emergency response team leading to exposure of first responders.

3.3 Petroleum Tank Terminal Incident (2009) [10]

A large explosion occurred at the Caribbean Petroleum Corporation (CAPECO) facility in Bayamon, Puerto Rico on October 23, 2009. There were no fatalities but the significant blast pressure generated by this incident injured forty-three (43) persons and caused an estimated $1.5 billion worth of damage to commercial and residential property.

The CSB described that "During an operation to transfer gasoline from the vessel Cape Bruny tanker ship, Caribbean Petroleum Tank 409 overflowed with gasoline, resulting in a vapor cloud that encompassed 107 acres of the CAPECO tank farm." In addition, "Multiple physical causes likely contributed to Tank 409 overfill:

- Malfunctioning of the tank side gauge or the float and tape apparatus during filling operations led to recording of inaccurate tank levels;
- Variations in the gasoline flow rate from the ship may have contributed to the overfill;
- Potential failure of the tank's internal floating roof due to turbulence and other factors may have contributed to the overfill."

The CSB noted that several human factors and safety management issues were at play during this incident. For example, the design of valves made it difficult to determine whether the valves were open or closed. Also, insufficient lighting did not allow the operators to see the overflowing of the tank. Finally, the tank filling procedures were inadequate and the tank gauging equipment was also unreliable, resulting in operators being prone to making errors.

Several similar incidents were also cited for discussion during this investigation. Crucial lessons from these were ignored, pointing towards a poor safety culture and systematic failure to learn from past incidents. Further, management had reduced several positions, leading to operators to being forced to leave their positions during tank filling procedures in order to complete other duties. A lack of emergency preparedness and firefighting equipment on site were also a result of reduced investment in safety by management.

3.4 Summary of Human Factors Causes

The CSB investigation reports from the above process safety incidents point to a singular theme of missing the central driving aspect of how humans interact with their work environment. Risk assessment from a human factors perspective in retrospect during an incident investigation yields a clear path towards enhancing existing PSM system designs by including additional safety measures to allow for recovery from human error and providing a clear feedback of such errors.

In order to allow for minimization of human errors, a conscious effort should be made to ensure good human factors design of equipment, training operators to recognize where to expect higher chances of making errors and how to recover from them, and training operators to use the operating procedures to not only consistently follow a procedure stepwise but also to ask for a revision when the procedure is known to be inaccurate. In addition, management support for improving the safety culture and including human factors in the discussion is crucial to success [36].

Similar lessons to be learned related to the inadequate treatment of human factors within PSM systems can be derived from many other process safety incident investigations [30].

4. Conclusions

This paper has:

- Presented concepts and examples aligned with regulations, standards, and industry guidelines for process safety management and human factors principles and practices.
- Identified the humans and their activities within the PSM system.
- Defined human factors within three key groups of individual, job, and organizational performance influencing factors (PIFs).
- Demonstrated a practical step-by-step design process for "how to" integrate human factors into the PSM system design using the proven quality management design concept of the Plan-Do-Check-Act continual improvement life cycle.
- Shared examples for designing PSM system components which address three of the Top 10 issues for human factors: competence, operating procedures, and organizational culture.
- Presented lessons learned from three process safety incidents which show how human error inherent in management systems can lead to catastrophic failures and how these can be minimized by applying the knowledge of how humans interact with their work environment.

This paper has shown that:

- PSM system deficiencies resulting from human error in design lead to higher probabilities for human error in operation and therefore higher risks of process safety incidents.
- Most process safety incidents can be traced back to management system deficiencies with their root causes related to human factors.
- Identified deficiencies represent areas of opportunity for integrating human factors into the PSM system design for improved human and overall system performance.
- Human activities are already inherent in an existing PSM system, but the application of a structured and systematic approach of human factors principles and practices allows for a successful implementation that can be measured, evaluated, and continually improved.
- Human factors can be integrated directly into the PSM system through detailed design specifications of requirements for quality aspects and performance criteria.
- PSM system processes can be enhanced by defining the humans in the system, their roles, and how their errors can be minimized, then designing the work activities and management tools to accommodate the objective to improve performance.
- Implementation of the PSM system can be used as a means to promote the application of good human factors practices for training and empowering personnel to allow them to recognize avenues for high error probability and how to recover from such errors.
- Safety culture improvement can lead to positive changes in producing policies, procedures, programs and other components that reduce human error potential and lead to the workforce being more engaged in achieving higher human and process safety performance.

5. References

[1] API. API RP 75, *Recommended Practice for Development of a Safety and Environmental Management Program for Offshore Operations and Facilities*, Third Edition, American Petroleum Institute, Washington DC, May 2004 (Reaffirmed May 2013).

[2] BSI. BS OHSAS 18001:2007. "Occupational health and safety management systems – requirements", BSI (British Standards Institution) OHSAS 18001:2007. London: BSI, 2007.

[3] BSEE. Workplace Safety Rule (SEMS), 30 CFR Part 250, "Oil and Gas and Sulphur Operations in the Outer Continental Shelf, Subpart S – Safety and Environmental Management Systems (SEMS)", Bureau of Safety and Environmental Enforcement (BSEE), Federal Register, October 15, 2010, (75 FR 199).

[4] BSEE. Workplace Safety Rule (SEMS II), 30 CFR Part 250, "Oil and Gas and Sulphur Operations in the Outer Continental Shelf, Revisions to the Safety and Environmental Management Systems", Bureau of Safety and Environmental Enforcement (BSEE), Federal Register, April 5, 2013, (78 FR 68).

[5] Baker, James A. , III, et al. *The Report of the BP U.S. Refineries Independent Safety Review Panel*, January 2007.

[6] Bridges, William and Tew Revonda, "Human Factors Element Missing from Process Safety Management (PSM)," 6th Global Congress on Process Safety, AIChE, San Antonio, Texas, March 2010.

[7] CCPS. *Guidelines for Auditing Process Safety Management Systems*, 2nd Edition, ISBN: 978-0-470-28235-9, Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AIChE) and John Wiley & Sons, New York, New York, 2011.

[8] CCPS. *Guidelines for Preventing Human Error in Process Safety*, 1st Edition, ISBN: 978-0-8169-0461-7, Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AIChE) and John Wiley & Sons, New York, New York, 2004.

[9] CCPS. "Vision 20/20", Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AIChE) and John Wiley & Sons, New York, New York. http://www.aiche.org/ccps/resources/vision-2020,
Accessed March 15, 2016.

[10] CSB. "Investigation Report – Caribbean Petroleum Tank Terminal Explosion and Multiple Tank Fires" (Caribbean Petroleum Corporation (CPECO)), Bayamon, Puerto Rico, October 23, 2009), No. 2010-02-I-PR, U.S. Chemical Safety and Hazard Identification Board (CSB), June 2015.

[11] CSB. "Investigation Report – Pesticide Chemical Runaway Reaction Pressure Vessel Explosion" (Bayer CropScience., Institute, West Virginia, August 28, 2008), No. 2008-08-I-WV, U.S. Chemical Safety and Hazard Identification Board (CSB), January 2011.

[12] CSB. "Investigation Report – Vinyl Chloride Monomer Explosion" (Formosa Plastics Corp., Illiopolis, Illinois, April 23, 2004), No. 2004-10-I-IL, U.S. Chemical Safety and Hazard Identification Board (CSB), March 2007.

[13] Contra Costa County. Industrial Safety Ordinance Guidance Document, "Human Factors Program, Section B", June 15, 2011.

[14] Energy Institute. "Human factors – Top ten issues", https://www.energyinst.org/technical/human-and-organisational-factors/human-factors-top-ten, Accessed March 15, 2016.

[15] Gambetti, Fabrizio, Casalli, Andrea, and Chisari, Vladimiro, "The Human Factor in Safety Management", Chemical Engineering Transactions, Vol. 26, 274-284, DOI: 10.3303/CET1226047, 2012.

[16] HSE. "Human Factors Briefing Note No. 2 – Competence", UK Health and Safety Executive (HSE), http://www.hse.gov.uk/humanfactors/topics/02competency.pdf, Accessed March 15, 2016.

[17] HSE. "Human Factors Briefing Note No. 4 – Procedures", UK Health and Safety Executive (HSE), http://www.hse.gov.uk/humanfactors/topics/04procedures.pdf, Accessed March 15, 2016.

[18] HSE. "Human Factors Briefing Note No. 7 – Safety Culture", UK Health and Safety Executive (HSE), http://www.hse.gov.uk/humanfactors/topics/07culture.pdf, Accessed March 15, 2016.

[19] HSE. "Procedures Audit Tool", UK Health and Safety Executive (HSE). http://www.hse.gov.uk/humanfactors/topics/procedures-audit-tool.pdf, Accessed March 15, 2016.

[20] HSE. "Reducing Error and Influencing Behaviour", UK Health and Safety Executive (HSE), 1999, http://www.hse.gov.uk/pubns/priced/hsg48.pdf, Accessed March 15, 2016.

[21] ISO. ISO 9000:2015, "Quality management systems –Fundamentals and vocabulary", International Organization for Standardization (ISO), Geneva: ISO, 2015.

[22] ISO. ISO 9001:2015, "Quality management systems – Requirements", International Organization for Standardization (ISO), Geneva: ISO, 2015.

[23] ISO. ISO 9004:2009, "Managing for the sustained success of an organization – A quality management approach", International Organization for Standardization (ISO), Geneva: ISO, 2009.

[24] ISO. ISO 10018:2012, "Quality management – Guidelines on people involvement and competence", International Organization for Standardization (ISO), Geneva: ISO, 2012.

[25] ISO. ISO 14001:2015, "Environmental management systems – Requirements with guidance for use", International Organization for Standardization (ISO), Geneva: ISO, 2015.

[26] ISO. ISO 17776:2000, "Petroleum and natural gas industries – Offshore production installations – Guidelines on tools and techniques for hazard identification and risk assessment", International Organization for Standardization (ISO), Geneva: ISO, 2000.

[27] ISO. ISO 28000:2007, "Specification for security management systems for the supply chain", International Organization for Standardization (ISO), Geneva: ISO, 2007.

[28] Jones, David A. “How to Design Effective EH&S Management Systems for Continual Improvement of Risk Reduction Performance”, ASSE Safety 2002, American Society of Safety Engineers (ASSE), Nashville, Tennessee, June 2002.

[29] Jones, David A. "ISO 9000: A Framework for Integrating Safety, Health & Environmental Management Systems," 28th Annual Loss Prevention Symposium, AIChE, Atlanta, Georgia, April 1994.

[30] Jones, David A., Kay Modi, “A Call to Action: Understanding the Key Driver for Continual Process Safety Performance Improvement”, American Institute of Chemical Engineers, 12th Global Congress on Process Safety, Houston, Texas, April 10-13, 2016.

[31] Kletz, Trevor. *What Went Wrong? Case Histories of Process Plant Disasters and How They Could Have Been Avoided*, 5th Edition, ISBN-13: 978-1856175319, ISBN-10: 1856175316, Butterworth-Heinemann/IChemE, 2009.

[32] NOPSEMA. “Human Factors: Safety Culture”, N-06300-IP1506, Rev 0, National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA), December 2014.

[33] NORSOK. NORSOK Standard S-001, “Technical safety”, Edition 4, Standards Norway, Lysaker, February 2008.

[34] NORSOK. NORSOK Standard S-002, “Working environment”, Edition 4, Standards Norway, Lysaker, August 2004.

[35] OGP. Report 368, “Human Factors”, International Association of Oil & Gas Producers (OGP), 2005.

[36] OGP. Report 434-5, “Risk Assessment Data Directory”, International Association of Oil & Gas Producers (OGP), March 2010.

[37] OGP. Report 454, “Human Factors Engineering in Projects”, International Association of Oil & Gas Producers (OGP), August 2011.

[38] OSHA. “Process safety management of highly hazardous chemicals”, 29 CFR 1910.119, (e), Process Hazard Analysis, Occupational Safety and Health Administration (OSHA), *Federal Register*, February 24, 1992 (57 FR 6356).

[39] Parker, Christopher W. and Gandhi, Minu Shikha, “Task-Based Approach to Addressing Human Performance in Design,” 10th Global Congress on Process Safety, AIChE, New Orleans, Louisiana, April 2014.

[40] Poblete, Benjamin R., Gandhi, Minu, Parker, Christopher W., and Ranasinghe, Sam, “Lessons Learned from the Application of Human Factors Engineering (HFE) in Process Safety Assessments”, Mary Kay O’Connor Process Safety Center 17th Annual International Symposium, College Station, Texas, October 2014