Outlook for Human Factors and Impact on Inherent Safety for the Process Industries

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Abstract: It has been well understood by safety professionals that human factors greatly contribute to the success or failure of process safety programs in the chemical process industries as well as represent the area needing the most emphasis to reduce risk. But in the recent past, most of industry has been preoccupied in initiating the development of process safety management programs and conducting PHA studies to measure hazards from process deviation from design intent or design shortcomings, and has not developed special initiatives to comprehensively address human factors.

As such, industry may not have fully addressed what has often been characterized as the area that should receive the most attention and where there are ripe opportunities for risk reduction. For the industry to embrace human factors in a committed way, more practical guidelines are required and additional information is needed for industry to understand how to expend their efforts on this cause.

This paper introduces the human factors concept, describes how current regulations address it, and proposes a strategy for better incorporating human factors into process safety management and inherently safer design. Special attention will be offered to the recent Contra Costa County (east of San Francisco) ordinance as an example of regulatory initiatives that address human factors in a more substantive manner and the CMA document from which it draws much of its material.

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Introduction

It has been well understood by safety professionals that human factors greatly contribute to the success or failure of process safety programs in the chemical process industries as well as represent the area needing the most emphasis to reduce risk. But in the recent past, most of industry has been preoccupied in initiating the development of process safety management programs and conducting PHA studies to measure hazards from process deviation from design intent or design shortcomings, and has not developed special initiatives to comprehensively address human factors.

Reasons for this include perhaps a broad lack of understanding of what constitutes human factors issues, the lack of specific regulations addressing expectations of government, and the perception that this is a very comprehensive and difficult issue to address. It appears that many of us are prone to procrastinate until a clearer picture is in view.

As such, industry may not have fully addressed what has often been characterized as the area that should receive the most attention and where there a ripe opportunities for risk reduction. For the industry to embrace human factors in a committed way, more practical guidelines are required and additional information is needed for industry to understand how to expend their efforts on this cause.

Definition of Human Factors and Human Error

In order to properly manage human factors, it has to be clear what is involved. Accepted definitions of human factors are:

1. A discipline concerned with designing machines, operations, and work environments so that they match human capabilities, limitations, and needs.[1]
2. [E]nvironmental, organizational, and job factors, and human and individual characteristics which influence behavior at work in a way which can affect health and safety.[2]
3. Departure from acceptable or desirable practice on the part of an individual that can result in unacceptable or undesirable results.[3].

There are several approaches available to facilitate human error reduction:

A. Microergonomic Approach

Microergonomics address the relationship between human, equipment, and the physical environment.[4] It is focused on the human-machine system level and is, for example, concerned with the design of individual workstations, work methods, tools, control panels, and displays. Microergonomic considerations address:

- Materials handling
- Machinery design
- Workstation design
- Handtool design

B. Macroergonomic Approach

Macroergonomics is focused on the overall people-technology system level and is concerned with the impact of technological systems on organizational, managerial, and personnel systems.[5] The human system interface is comprised of three different dimensions:

- Situation based – those related to the immediate work environment in time and space (e.g., complicated workstation, wet work surface)
- Management based - (e.g., failures in communication, leadership, failure to train people, rewards system)
- Human based – (e.g., emotional states, moral, motivation)

Human and organizational factors can be related to the individuals that design, construct, operate, and maintain the system.[6] The actions or inactions of these individuals are influenced by four components:

1. The organizations that they work for
2. The procedures (formal, informal, software) they use to perform their
3. activities
4. The structure and equipment involved in these activities
5. The environments in which the individual conducts activities.

Malfunctions can occur with the individual, with one of the preceding four components, or at the interfaces between the components and the individual.

As it relates to process environments, it is recognized that management decisions and programs, and operational procedures, training, and actions can all contribute to human errors. In addition to these parameters, consideration should be given to incorporating human factors into inherently safer design practices and to improvements in the work environment to reduce the number and likelihood of situations to produce error.

Current Regulatory Requirements

OSHA and EPA refer to both human factors and human error in their Process Safety Management (PSM) and Risk Management Plan (RMP) regulations respectively (see Figures 1-3). However, neither regulation defines human factors; in general they require only that human factors be "addressed" as part of the process hazard analysis. There is no specific requirement that a human factors management system be developed, or any guidance as to how human factors should be addressed.

In evaluating PSM programs for compliance, OSHA's PSM compliance directive, briefly describes that a human factors review ". . . may include a review of operator/process and operator/equipment interface, the number of tasks operators must perform and the frequency, the evaluation of extended or unusual work schedules, the clarity and simplicity of control displays, automatic instrumentation versus manual procedures, operator feedback, clarity of signs and codes, etc." [7]

Of course it is doubtful that OSHA would agree that this list is a complete list of issues, but it shows the depth of human factors and defines some of the work to be done. It is expected that as industry safety practices evolve and mature, that improved human factors management will be scrutinized more closely. While there is presently no regulatory activity from OSHA and EPA in this area, additional clarification, regulatory opinion, and even rulemaking is quite possible. Industry should be aware of any new interpretations and citations as they arise.

Contra Costa County (CCC) Human Factors Ordinance

Evidence of interest in strengthening human factors requirements includes the recent enactment of a human factors ordinance in Contra Costa County, California, east of San Francisco.[8] This area has been the scene of several serious accidents recently and local concern for safety at seven large petroleum and chemical facilities there prompted a more rigorous approach to hazard analysis and the evaluation of human factors issues. Adopted in December 1999, this first-of-its-kind law extends the county industrial safety ordinance to require that these large facilities conduct a root cause analysis for specific incidents, and that a written human factors program be prepared in accord with a detailed guidance document. (A complete copy of the regulation and guidance can be obtained from www.acusafe.com under the Regulatory Center link titled "U.S. State and Local.") The human factors component in particular is unique and may become influential in creating similar requirements at other jurisdictions. Measuring the success of the program, however, will have to wait until after the January 2001 compliance date for submission of the written human factors programs.

The ordinance contains a number of requirements that are valuable risk reduction methods and may be considered for risk reduction and prevention at facilities more generally. The regulation requires stationary sources to develop a written human factors program within one year of the issuance of a guidance document developed or adopted by the department. The human factors guidance document draws heavily on previously published guidance documents from the Chemical Manufacturer's Association and the AIChE's Center for Chemical Process Safety[9] for the written program components. It requires that all of the following be addressed:

- The inclusion of human factors in the Process Hazards Analysis process;
- The consideration of human systems as causal factors in the incident investigation process for Major Chemical Accidents or Releases or for an incident that could reasonably have resulted in a Major Chemical Accident or Release;
- The training of employees in the human factors program;
- Operating procedures;
- The requirement to conduct a Management of Change prior to staffing changes for changes in permanent staffing levels/reorganization in operations or emergency response. Employees and their Representatives shall be consulted in such Management of Changes;
- The participation of employees and their representatives in the development of the written human factors program;
- The development of a program that includes, but is not limited to, issues such as staffing, shift work and overtime; and
- The inclusion of a human factors program description in the Safety Plan.
- Section 450-8.030 allows for an annual performance review and evaluation. Therefore, CCC Health Services representatives felt that there would be a natural avenue for reviewing and improving the human factors program requirements and guidance.

- Together these elements form the foundation of the human factors program.

In expanding the requirements for PHA's, the guidance document includes suggestions for when procedural PHA studies are appropriate. Facilities should consider conducting procedural PHA's for two distinct situations. First, there are certain processes or activities for which a procedural PHA can provide a more thorough and efficient review than a traditional PHA (e.g., unloading/loading, complex valve configurations). Second, there are certain activities or procedures within a process that the source can identify as having "high active failure likelihood and high hazard potential." For these activities, the stationary source should conduct a traditional PHA on the process, but may also elect to conduct procedural PHA's on specific procedures conducted within the process (e.g., sampling).

Other suggestions were made to improve operating procedures. The suggestion is made in Chapter 6 of the guidance document that facilities must determine which operating procedures to write or to verify that they have written procedures for every task of the operation deemed necessary. The procedures must be written to avoid the latent conditions that could cause active failures (i.e., format, conciseness of statements, written for the user). This chapter applies to all operating procedures. Maintenance procedures and safe work procedures (e.g. hot work permits) were not explicitly included in the human factors element of County Ordinance; however, stationary sources should consider applying the basic principles of this chapter to all procedures. Stationary sources must develop a process for procedure development that includes identifying the hazards associated with the tasks and incorporating input from personnel with expertise in the process.

One method for developing comprehensive task descriptions and procedures is to conduct task analyses. Task analysis techniques may be applied during the design mode, audit mode, or retrospective mode. Task analysis can help to ensure that the most efficient method is identified and that discrepancies between individuals and shifts are eliminated. Task analysis results may be used as input to the content of operating procedures, training, and operating manuals. Task analysis results may also be used during incident investigations to explicitly identify differences in the prescribed way of performing a task and the actual way it was performed. Several acceptable task analysis techniques exist, such as Hierarchical Task Analysis, Tabular Task Analysis, and Timeline Analysis.

The CMA's Management of Safety and Health During Organizational Change is relied upon in the section that applies to managing organizational changes. It requires that each facility develop criteria or guidance to assist appropriate personnel in determining when an MOC for an organizational change should be initiated.

One such requirement is for a "reduction in the number of positions, or number of personnel within those positions in operations, including engineers and supervisors with direct responsibilities in operations; positions with emergency response duties; and positions with safety responsibilities." Still another is "substantive increase in the duties in operations for those positions." Some facilities in Contra Costa have already developed their internal procedures and started using these techniques in optimizing staffing levels on processing units.

The CMA publication advocates the use of a team to scrutinize staffing changes and the County guidance advises that this will satisfy the requirement that employees and their representatives be consulted in the Management of Change of organizations. The team should include employees and their representatives, as appropriate, from engineering, maintenance, and operations as well as safety and health.

Three approaches to safety management exist to address the different dimensions or components described in Sections 2.3.3, 2.3.4, and 2.3.5 of the CCC Ordinance. These approaches are referred to as the person model, the engineering model, and the organizational model. The person model is widely applied and uses tactics such as rewards and discipline, training, and writing procedures. The engineering model focuses on the influence of the physical workplace on the performance of individuals (e.g., operators at a refinery being influenced by the control panel and the information provided by the control system). The organizational model focus on the human error being a consequence of existing latent errors in the system.

In conclusion, stationary sources must evaluate the execution of unsafe acts and improve upon existing safeguards that reduce risk. The source must conduct a PHA that incorporates the results of the latent conditions review or that poses and analyzes the question "why" when an active failure or unsafe act resulting in a hazard is identified. Stationary sources should perform procedural PHA's on those activities for which it would be more appropriate than performing a traditional PHA. Stationary sources may

elect to conduct a procedural PHA, in addition to traditional PHA's, on those tasks that have a "high active failure likelihood and high hazard potential."

In total, the Contra Costa County Human Factors Program may be too prescriptive and burdensome to industry. The proof will come later as the ordinance is enforced, but undoubtedly the requirements are comprehensive with the inclusion of a management system to address human factors, and an exhaustive self-assessment on policies, procedures, training, and facility design for human factors. This new program is expected to invoke numerous questions on the adequacy of design and programs to address these issues.

Recommendations

So if we all agree that human factor's consideration is so important to our safety performance, why has it mostly been ignored during process safety management efforts of recent past? It is the authors' opinion that this is the case because human factors are both challenging and vague. It is challenging to address human factors since the topic involves consideration of issues outside of the normal scope of an engineer's background, such as management sciences, psychology and human behavior, ergonomics, and other areas. Addressing a wide array of issues is possibly labor intensive, and it is not easily compartmentalized into a succinct, and yet comprehensive analysis. The PHA requirements of OSHA and EPA were identical in their requirements of human factors, and both regulations and agencies have been imprecise in their expectations. It is vague since it seems to be so pervasive, and most discussions on human factors describe a wide-ranging set of issues as part of the scope. Human factors covers issues from design to operation to management.

Clearly there is room for improvement in reducing risks through more frequent and clever use of human factors methods. A simple, yet effective approach is needed that can be well recognized, accepted and practiced by a wide spectrum of industrial companies. Components of an effective program that incorporates human factors issues into existing process safety programs should include:

1. Management knowledge and commitment
2. Written human factors policy
3. Management system for implementing the human factors program
4. Employee knowledge and involvement on human factors
5. Training on human factors issues
6. Incorporating human factors into hazards analysis and risk assessment
7. Human factors in process design and process change
8. Incident investigation and human factors root cause assessment
9. Consideration of human factors in written work procedures
10. Measurement and auditing of the human factors program performance

Management commitment is essential for incorporating human factors issues, especially because many of the program suggestions are not explicitly required under the law. A full explanation of the benefits is essential, along with the costs involved. An ongoing

management system should be put in place for implementing and supervising the program, ensuring its quality, measuring its success, and providing ongoing training so that expectations under the program are understood. The management system should also include written procedures with designated roles and responsibilities, program requirements, implementation schedule, communications procedures, documentation requirements, and technical procedures.

One of the essential human factors program requirements is that it be incorporated into ongoing hazard analysis and risk assessment efforts. Human factors program development will require that procedures be adopted conduct the analyses, as well as tools and technical approaches (documentation formats, checklists). In most cases, human factors considerations may be incorporated into existing PHA studies, but for selected studies, specific human factors methods should be adopted. Large facilities or groups of facilities may also consider expediting the typical 5-year PHA cycle in order to review human factors more quickly at areas where human error is likely, or when the consequences of an event are especially high. In developing a workable program, facilities may consider starting with a pilot study before widespread implementation takes place in order to refine procedures and improve long-term implementation efficiency.

Incident investigations are an opportunity to investigate and document human factors issues leading to incidents. Human factors issues are often the root causes of incidents and as part of an overall program to examine human factors issues more closely, more thorough root cause analysis should be incorporated into investigation methods.

Scrutiny of human factors in work procedures is another essential area to an effective PSM program. In some fashion, work procedures represent management risk tolerances, the desired path to safe work practices, process objectives, and hazards. A special effort is recommended to evaluate at least all critical work procedures for human factors issues.Inherent safety includes the consideration of more than just design features of a process. Inherent safety principles include human factors, in particular the opportunities for human error given the design and operating conditions and parameters. Finding situations likely to produce errors, such as controls being too difficult to access or too complicated, and working to reduce their clutter and confusion or to improve the accessibility are all examples of inherent safety in action.It is hoped that the adoption of improved consideration of human factors will improve overall plant safety. If accepted by management and implemented faithfully, it could lead to a reduction of the thousands of chemical incidents reported each year where the initiating event was some type of human error. These events lead to significant fatalities, injuries, property damage, business interruptions, lawsuits, all of which could be significantly reduced.

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2. Reducing Error and Influencing Behavior, HSG48, HSE (1999)
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4. 20 CFR 119.119 Process Safety Management of Highly Hazardous Chemicals, OSHA
5. 40 CFR Part 68 Risk Management Plan, EPA
6. CPL2-2.45a, PSM Compliance Directive, OSHA
7. Section 450-8.016(B) of County Ordinance 98-48, Contra Costa County, California, December 3, 1999.
8. AcuSafe News, February 2000, http://www.acusafe.com/ Newsletter/Stories/0200CCC-Written-Human-Factors.htm
9. CCPS (1994), *Guidelines for Preventing Human Error in Process Safety*.
10. Meshkati, Najmedin, "Human Factors in Process Plants and Facility Design" Chapter 6, Cost-Effective Risk Assessment for Process Design (1995)
11. Reason, J., Managing the Risks of Organizational Accidents (1998)

Figure 1 - OSHA PSM Requirements

for Human Factors

29 CFR 1910.119(e)(3)

(3) The process hazard analysis shall address:

(i) The hazards of the process;

(ii) The identification of any previous incident which had a likely potential for catastrophic consequences in the workplace;

(iii) Engineering and administrative controls applicable to the hazards and their interrelationships such as appropriate application of detection methodologies to provide early warning of releases. (Acceptable detection methods might include process monitoring and control instrumentation with alarms, and detection hardware such as hydrocarbon sensors.);

(iv) Consequences of failure of engineering and administrative controls;

(v) Facility siting;

(vi) ***Human factors***; and

(vii) A qualitative evaluation of a range of the possible safety and health effects of failure of controls on employees in the workplace.

Figure 2 - EPA RMP Requirements

for Human Factors

40 CFR Part 68

Sec. 68.50 Hazard review.

(h) The owner or operator shall conduct a review of the hazards associated with the regulated substances, process, and procedures. The review shall identify the following:
(1) The hazards associated with the process and regulated substances;
(2) Opportunities for equipment malfunctions ***or human errors*** that could cause an accidental release;
(3) The safeguards used or needed to control the hazards or prevent equipment malfunction ***or human error***; and
(4) Any steps used or needed to detect or monitor releases.

(i) The owner or operator may use checklists developed by persons or organizations knowledgeable about the process and equipment as a guide to conducting the review. For processes designed to meet industry standards or Federal or state design rules, the hazard review shall, by inspecting all equipment, determine whether the process is designed, fabricated, and operated in accordance with the applicable standards or rules.

(j) The owner or operator shall document the results of the review and ensure that problems identified are resolved in a timely manner.

(k) The review shall be updated at least once every five years. The owner or operator shall also conduct reviews whenever a major change in the process occurs; all issues identified in the review shall be resolved before startup of the changed process.

Figure 3 - EPA RMP Requirements

for Human Factors

40 CFR Part 68

Sec. 68.67 Process hazard analysis.

(c) The process hazard analysis shall address:

(a) The hazards of the process;

(b) The identification of any previous incident which had a likely potential for catastrophic consequences.

(c) Engineering and administrative controls applicable to the hazards and their interrelationships such as appropriate application of detection methodologies to provide early warning of releases. (Acceptable detection methods might include process monitoring and control instrumentation with alarms, and detection hardware such as hydrocarbon sensors.);

(d) Consequences of failure of engineering and administrative controls;

(e) Stationary source siting;

(f) ***Human factors***; and

(g) A qualitative evaluation of a range of the possible safety and health effects of failure of controls.

Endnotes

[1] Lorenzo, D.K. (1990). *A Manager's Guide to Reducing Human Error*s. Washington, DC: Chemical Manufacturers Association, Inc.

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[3] Bea, Holdsworth, and Smith, "Human and Organization Factors in the Safety of Offshore Platforms", a paper presented at the 1996 International Workshop on Human Factors in Offshore Operations.

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[6] Bea, Holdsworth, and Smith, "Human and Organization Factors in the Safety of Offshore Platforms", a paper presented at the 1996 International Workshop on Human Factors in Offshore Operations

[7] U.S. OSHA. CPL 2-2.45A CH-1 - Process Safety Management of Highly Hazardous Chemicals--Compliance Guidelines and Enforcement Procedures. September 13, 1994. § III.A.

[8] Section 450-8.016(B) of County Ordinance 98-48, Contra Costa County, California, December 3, 1999.

[9] CCPS (1994), *Guidelines for Preventing Human Error in Process Safety.*