CHEMICAL ENGINEERING TRANSACTIONS
VOL. 26, 2012
Guest Editors: Valerio Cozzani, Eddy De Rademaeker

ISBN 978-88-95608-17-4; ISSN 1974-9791

A publication of
AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet

DOI: 10.3303/CET1226047

The Human Factor in Process Safety Management

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Human behaviour and performance are cited as causal factors in most accidents on process plants. The human factor in the decision making process is the main cause of incidents, even involuntary, directly connected with the use of the product itself. If the accident rate is to be decreased, human factor must be better understood and the knowledge more broadly applied. Purpose of this article is to present an overview and summary of experiences acquired over the years in the different phases of the lifecycle of projects and incidents analysis.

1. Introduction

Efforts dedicated to the human factor analysis are increasing. The incident investigation process at the beginning was aimed to understand the evolution in the different phases of the incident to identify the component whose failure caused the event. When it was realized and found that machines and systems surpassed in complexity and sophistication the human capacity to operate them, it was clear the need to address the problems with new methods and tools. The interactions between human activities, system organization and equipment are more complex and sophisticated and the technical analysis of incident sequences become more difficult requiring multidisciplinary interventions to identify the root causes of causal factors. Only recently, due to serious accidents, the regulations started to address the need for Companies to pursue, in a more effective identification of potential human errors to mitigate their causes and / or consequences.

2. Ergonomics

The Human Factor is a discipline aimed at studying the behaviour of man in the organizational environment to better understand their motivations and identify the causes of errors. The first studies were relevant to both physiological as well as those psychological/behavioural linked with the fly, establishing the foundations of modern aviation medicine (attitude, fatigue, stress). Today there are basically two different views (Dekker, 2002) on human error and the human contribution to accidents. One view, recently dubbed "the old view", sees human error as a cause of failure. In the old view of human error:

- Human error is the cause of most accidents.
- The engineered systems in which people work are made to be basically safe; their success is intrinsic. The chief threat to safety comes from the inherent unreliability of people.
- Progress on safety can be made by protecting these systems from the unreliable humans through selection, procedures, automation, training and discipline.

The other view, also called "the new view", sees human error not as a cause, but as a symptom of failure. In the new view of human error:

Please cite this article as: Gambetti F., Casalli A. and Chisari V., 2012, The human factor in process safety management, Chemical Engineering Transactions, 26, 279-284 DOI: 10.3303/CET1226047

- Human error is a symptom of a trouble deeper inside the system.
- Safety is not inherent in systems. The systems themselves are contradictions between multiple goals that people must pursue simultaneously. People have to create safety.
- Human error is systematically connected to features of people tools, tasks and operating environment. Progress on safety comes from understanding and influencing these connections.

3. Process Safety

During over twenty years of experience in the design in the up and downstream oil and gas plants, after analysis carried out with the aim to identify possible sources of hazard, risk assess, incident investigation from serious to simpler, there is increasingly need to improve the quality of the analysis carried out during all the phases of the life cycle of a project, regarding to our capability of ergonomic analysis. The simple assignment of an incident at the "human error" without any assessment about the possible root causes could lead to the conclusion that errors are inevitable, unpredictable and uncontrollable. Nothing could be further from the truth. Experts to understand how “human error” arises adopt frameworks like *human fallibility, context* and *barriers* (Sharit, 2006) or factors that combined which determine the likelihood of error or effective human performance that may be related to *Job, Organisation, Person* (Embrey, 2000). Some factors may be identified in the component context like (the list is not exhaustive):

- Culture
- Time constraints
- Workload
- Environmental conditions
- Event frequency
- Motivation
- Deficient procedures;
- Training ineffective;
- Inadequate supervision;
- Poor man-machine interface;
- Insufficient staff;

However some of the above situation variables may be assigned to the performance influencing factors of organizations. In a research report authors identified 72 qualitative and quantitative techniques to assess the human reliability (Bell and Holroyd, 2009), methods and tools are available. Re-reading the report of the well-known incident in Texas City Refinery (U.S. Chemical Safety Board, 2007) some of the root causes identified by the experts were the following:

- Poorly understood risk because of the mistake belief that the operators would do the right thing and always follow the procedures
- A workplace tolerant of deviations of procedure:
  - Procedures did not reflect current practices.
  - Procedural changes without analysis of change (MOC).
  - Start-up procedure with inadequate instructions.
  - Emergencies procedure not followed.
- Communications ineffective and insufficient.
- Automatic control not used and display poor.
- Ineffective supervision and technical assistance during the start-up of the unit.
- Inadequate staffing during start-up.
- Fatigued operators.
- Inadequate training.
- Failure to establish effective security limits.
- Poorly maintenance of the blow down and stack
- Following the above list of identified causes these questions may arise:
- Could these root causes be identified before by the experts of the Safety Management System?
- How could analysts identify them?
- What does it mean to "consider" the "Human Factors" for the process safety?

To answer I think we should make an effort to critically analyze why our analysis are unsatisfactory. Normally in processes hazard identification, against a system deviation, we identify possible causes associated with the consequences, we break the analysis at the causal factor level, when we should instead try to identify the possible root causes of the deviation. We should review our strategy of analysis and, better fix its goals. To avoid making heavier the analysis you may consider to split the activities according to their goals and the required expertise, following a simple workflow like:

1. Review of the design process, through the use of standard techniques of hazard identification (i.e. HAZOP, What-if, etc.) to identify the casual factors.
2. A deep analysis of each identified casual factor with operation and human factor specialists with the available tools to identify the root causes category and the associated potential human errors associated with routine operations and not. It would make a root analysis using the results of the previous phase.
3. An assessment of management and control systems (including those in steps Step 1 and Step 2) using interviews, questionnaires and checklists.
4. A detailed analysis of human reliability (HRA) used to resolve any outstanding issues raised in steps from Step 1 to Step 3
5. Understand the sequence of events, the types of causal factors, or barriers that may arise as a result of a root cause and how to transform into a sequence of events.

4. Analysis tools

During the design phase the activity for the identification of possible hazardous scenarios and process unit incidents are typically focuses on normal operating conditions. Not always the team projects analyze all possible operating conditions such as: starting and shutdown operation, plant running with different equipment alignment, etc.

If we compare the incident investigation report with the loss prevention analysis carried out during the design phase (HAZOP, FMEA, etc.) the latter analysis show only some of the protective barriers and normally only instrumental. Rarely the experts identify or deal with issues such as:

- Mechanisms of metallurgical damage associated with the operational running of the equipment or change in the plant charge;
- Management of different operating conditions due to the change of quality charge of the unit, some time outside the range of the design basis of the project. At best they are treated superficially and with little added value.
- Management System. All issues related to the management item and with impact on the safety of the plant (i.e. like maintenance, emergency plan, asset integrity, MOC, operational issues for start-up and stop, etc.)

The human factors in these analyses, when identified are generically classified as “human error”. The reasons why these points are not discussed in detail during the engineering phase may be:

- Problem underestimation;
- Lack of experience in the analysis team;
- Complexity of the subject. Difficulties in identifying a possible matter solution;
- Lack of information or knowledge in the management system.
- Poor evaluation or consideration about the advantages, not only in term of cost-benefit, of the analysis tools.
- Lack of knowledge about the plant owner safety management system, during the design phase.

Despite those difficulties, specialists should try to include appropriate considerations about human factor regardless of the used technique. Normally during the review of the process design, most human factor deficiencies identified are those related to human-machine interface. Currently, the regulations recognize the importance of this category of causes of human error and require clearness and simplicity in the control displays, automatic instrumentation and manual procedures i.e. “Ergonomics, general approach, principles and concept” (EN ISO 26800, 2011) and “Safety of machinery” (EN 13861, 2011). Guidance for the application of ergonomics standards in the design of machinery”, etc.) Restrict the analysis to the interface issues is too simple or generic; the problem in this way does not take into account the other elements of the process safety management system affected by the human factor. We should try to identify the root causes from the design phase to set the possible constraints at the process safety management system; if a root cause could be a possible source of an incident it may make easier to justify the need to adopt from the beginning of the plant life those barrier tools that

can help to improve the management of safety process. Much of the accidents occurred in plants are caused by loss of containment of hazardous materials from secondary lines like by-pass, utility lines or dead lines whose maintenance is sometimes less accurate or reduced than the main lines. All these issues are deal in a different way in the design phase, based on the owner maintenance procedure.
We could use checklists to include human factor considerations and, once expanded, could help in identifying possible weakness associated with the process safety management system. We could prepare checklists to verify the adequacy of protective barriers provided, remembering that human error may be viewed as arising from interplay between the human fallibility and context.
Questions like these can be easily incorporated into a checklist:

- Are controls accessible and easy to identify?
- Are controls accessible for maintenance and operation?
- Is required experience to control the process unit? What kind of expertise?
- Are Operator provided with sufficient training and information about the possible causes of an alarm? Are operator trained to take right decision in an emergency? Do they have enough time to put the plant in safe condition?
- All displays are easy to see and read?
- Associated controls and displays are grouped together?
- During an emergency, are possible critical conditions like light, temperature and noise taken into account?

We could use a checklist during a PHA meeting or in dedicated sessions. We could analyse the possible operational errors with questions such as:

- What happens if the operator operates the valve incorrectly?
- What happens if you add too much catalyst?

The team should not accept answers like "a careless operator". The questions really can reveal a number of possible problems, the team should really ask:

- Why should open an operator wrongly a valve?
- Why should add an operator too much catalyst?

We should then examine more specific answers, such as:

- Operators have difficulties to correctly identify the valve under certain lighting conditions or operational situations.
- Operator was not trained or received poor training.
- The outgoing shift did not report the correct position of the valve or failed to communicate with the incoming shift,

If we try to answer these questions the team might move toward the possible root causes of the human factor, suggesting possible solutions, such as:

- A more rigorous training for new operators or those transferred,
- Develop a checklist to help operators keep track of where in the implementation of a procedure,
- The annotation of each addition of a catalyst;
- The maintenance personnel of the instrument could verify and calibrate the weight scale periodically.

The introduction of considerations about the human factor in the Hazardous Analysis will be similar to a what-if analysis or Six Sigma concept. Each time the team identifies "operator error" as the cause of each deviation, the leader of HAZOP analysis should ask: "Why?" in order to continue the brainstorming process.
The FMEA analysis approach is different since this tool focuses on hardware failure, and therefore the integration with the considerations of human factor may be more difficult than other techniques. Undoubtedly this type of analysis is useful to identify possible solution to the issues of human interface machine. The identification of human factor should be inherent issues such as:

- Hardware failures that may mislead the operator to take inappropriate actions,
- Hardware failures that could prevent an operator to perform the desired action, and
- Hardware failures that can be caused by inappropriate operator actions or inaction.

To examine successful the human factor, a FMEA should characterize the equipment in small parts for a deep investigation to identify the above issues. Indeed we have to deal not only with possible concerns related to a single operator, but identify the hazards related to the team and organization performance and assess them. In short term we have to take into account the "System" and not limited our efforts to the man / machine interface problems only. Issues are undoubtedly complex, but it could be helpful to try to manage complex system and potential problems may arise, to identify in the different project lifecycle steps possible constraints related to the human factor.

5. Job Organization and procedures

In the previous paragraph we mentioned some problems with tools that experts have to qualify the human factor in process safety analysis. However, we should remember how the human factor in its turn may influence the performance of ongoing analysis as an external interference factor that might affect the quality of the activity. Difficulties to identify human factors in the process safety analysis sometimes may be due to the job organization or lack in procedure. Hereafter I quote some principles listed in an old article by Lawley and Shepherd (1987) to implement the HAZOP procedure and sometimes, on the basis of my experience, not always entirely respected:

- A HAZOP study can be undertaken at any subsequent stage during the design or operation life of the project (conceptual design study, design freeze study, pre-commissioning check, early post commissioning review, control of major post-commissioning changes, control of minor modifications)
- The team must be carefully chosen to provide a sufficient spread of expertise and experience for all aspects of the system to be properly investigated.
- For the case of full HAZOP studies team meeting should not exceed 3-4 h.

The external factors that may obstruct our process safety analysis so are not only cultural but also contractual obligations like timing of the project, human resources availability, scheduling of activities, budget, our management since not always we are able to justify the advantages of the activity in terms of cost/benefit.

We have to find opportunities in other job activities to go beyond the gap like forecast different analysis stage (coarse, freeze study), Safety Reviews and Management of Change sessions to perform a cross check in order to better characterize the human factor. In a project I had the opportunity to carry out a coarse HAZOP before the official one with the customer, we had a lot of benefits, some can be summarised in:

- Understanding the possible operational risks and identify the more adequate safeguard;
- More accurate emergency and operating manuals;
- Characterize basic design deficiencies with reduced acquisition time;
- Reduce the number of process and instrument diagrams revision increasing quality and accuracy.

For the above reason we should force to better utilize all the possibilities that loss prevention management system offers us till the activities planning. The results sometimes fail to meet the expectations, since required changes are not carefully vetted. Often carried out recommendations are extra costs and add complexity to the system. Incorporate comments and evaluations about the human factor in the risks assessment deals with only a portion of the potential problems that may arise in the relationship between human and system. Documentation to set up and begin to introduce the human factor evaluation are easily available, for example a recent European study (OECD, 2008) explored human factors related to management and operation of hazardous installation addressing the following topics with interesting conclusions: 1. Type of human error; 2. Assessment of safety culture; 3. Appropriate human factor competence; 4. Interface between safety systems and operators; and 4. Human factors in alarm management.

Further examples of the above are procedures, during the audit activities sometimes, we realize that procedure was not written by people with operational experiences and/or revised according to safety criteria. Job Safety Analysis or Operation Manuals are a great starting point for an assessment because they identify activities that operators or workers should perform and the protection equipment necessary to protect them from the typical industrial hazards. Unfortunately these documents usually do not identify process safety issues or concerns about the human factors. One or more operators in the team in this case are critical and an active participation required. For any deviation from the intention / purpose team should dig up beyond the obvious cause, "human error", and identify the root causes, such as "inadequate emphasis on this step during the training," "inadequate labelling of valves" or "visualization tool confusing or unreadable." The key word “deficiency, lack” recall causes like "any procedural step written or formal training to obtain a hot work permit prior to this step," or "lack of written procedures or formal training to open the drain valve before starting the pump ". Checklist with overall issues should be developed and used to ensure that are considered. For example we could use the four levels of failure as identified in the aeronautical field: 1) unsafe acts, 2) preconditions for unsafe acts, 3) unsafe supervision and 4) organizational influences and for each of these levels identify proper guidewords like the following examples:

- To leave, to omit, to skip = the step is not done or partially done. Possible reasons include the employee has forgotten to take the step, did not understand the importance of the step, or procedures did not include this crucial step, etc.
- Incorrect, improper = the intent of the employee was to perform the step (do not omit it), although the step was not performed as expected. Some possible reasons may be that the employee is too much or too little of the work provided, the employee handling the element of the wrong process, the employee or reverses the order of steps.

Any procedure (including software) may be analyzed using this technique. Changes in the routine procedures are important, but even more important on non-routine. The non-routine nature of the procedures means that operators have less experience with them. In addition, during non-routine operations many safety devices are bypassed or switched off.

All management system procedures should be included in this type of review since are related to Resource/Acquisition Management, Organizational Climate, and Organizational Processes. Organizational Influences are factors in a mishap if the communications, actions, omissions or policies of upper-level management directly or indirectly affect supervisory practices, conditions or actions of the operator(s) and result in system failure, human error or an unsafe situation.

6. Conclusion

Regulatory requirements for the consideration of human factors in process safety and risk management are motivating companies to address this subject and the importance of considering human factors in the process life cycle is beginning to be recognized by the process industries. However a number of issues must be addressed for the consideration of human factors become standard. In particular, human factors needs to be more widely understood and tools need to be provided so that studies can be performed more routinely

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