

ASSESSING HUMAN INVOLVEMENT IN CHEMICAL MANUFACTURING: A HUMAN FACTORS TOOLKIT

Helen Jones*, Steve Shorrock*, Peter Bull[†] and Debby Hallett[†]
*DNV Consulting, Highbank House, Exchange Street, Stockport, Cheshire, SK3 0ET, United Kingdom; [†]Ciba Specialty Chemicals, PO Box 38, Bradford, West Yorkshire, BD12 0JZ, United Kingdom.

The paper outlines a methodology that has been developed for assessing human factors within the process domain. The approach systematically examines how human factors can impact on safety critical tasks. The method comprises six steps that lead the assessment team though task analysis and human error assessment, and then on to evaluate the safeguards in place to prevent a major accident hazard (MAH) and the likelihood of human recovery. The effectiveness of the approach is discussed along with potential improvements that could be made to enable wider application of the approach in the future.

Human factors; process; safety critical; task analysis; manning; safeguards.

INTRODUCTION

Addressing human factors issues has always presented a challenge to the chemical industry, and until recent years, the approach to human factors has often been fragmented or solely reactive. Increasingly, it has been recognised that a systematic, proactive process is more in line with the recent transition from a reactive "fire-fighting" approach to proactive safety management, and that such approaches can also add value by helping to optimise efficiency and productivity. Furthermore, the COMAH regulations now make it clear that human factors must be taken into account in risk management. Although the need for systematic, proactive human factors assessments has been recognised, the approaches available can often appear to be too industry specific, too broad or beyond the reach of non-human factors professionals.

DNV Consulting and Ciba Specialty Chemicals have jointly developed an approach to provide a standard methodology for human factors assessments for Ciba's UK sites. Although the methodology focuses on safety critical tasks, it also provides a framework for a more holistic assessment of how human factors impact on the safety management system. The approach aims to be practical and participative, involving key site personnel with a responsibility for safety.

METHODOLOGY

The methodology integrates and adapts existing tried-and-tested approaches, whilst ensuring that the whole process can be applied with limited training in human factors. The six key steps are shown in Figure 1. These are described in further detail below.

STEP 1: IDENTIFY MAJOR ACCIDENT HAZARD SCENARIOS FROM COMAH SAFETY CASE

The MAH scenarios identified within the existing site safety case should be extracted and a MAH description noted. This description provides the focus for the subsequent stages of the assessment and establishes the activities and site areas to be assessed. The assessment is most effective when applied to MAH scenarios that have been classified as ALARP. Any MAH scenario where the risk has been found to be intolerable are likely to require engineering solutions to reduce the risk before human factors interventions can be applied effectively. The MAH scenarios assessed to be ALARP can be subjectively prioritised according to the level of human action and human recovery involved. These can then be carried forward to Step 2.

STEP 2: IDENTIFY SAFETY CRITICAL TASKS

Once the MAH scenarios have been identified, an inventory of all the related tasks is compiled based on the site procedures. Each procedure identified is then rated on the basis of how frequently the task is performed, its duration, how much operator action/ intervention is required, and the likelihood of the worst credible consequence. This rating allows the procedures to be ranked according to their criticality and hence allow the assessors to prioritise their efforts on the most safety critical first. N.B. all the critical procedures should be investigated before repeating the process on the next MAH scenario.

STEP 3: QUALITATIVELY ASSESS CRITICAL TASKS AND POTENTIAL ERRORS

This step consists of five stages: task observation; task analysis; human error assessment; concurrent task analysis and gathering information about the additional roles of shift personnel. This step is performed by a team of assessors including health and safety personnel, site managers and a human factors professional. Most importantly, site personnel with experience of the tasks under investigation must be involved throughout this step.

Observation

The tasks are observed during routine operations to gather information that could not be inferred from the procedures. This includes details of the duration of task steps, the environment in which the task is performed and the roles and responsibilities of the operator that performs the task. Any roles or concurrent tasks that have the potential to impact on task performance should be recorded for use in the concurrent task analysis. Control system prompts (if applicable) and safeguards relating to the task should also be noted.

Hierarchical Task Analysis

A hierarchical task analysis (HTA) is conducted on the task. This allows the task to be broken down into functional steps which can then be analysed for potential human failures. This analysis is vital, as the steps of the procedure may not necessarily correspond to the human actions that comprise the task.

Human Error Assessment

Each task step from the HTA is analysed to determine the potential for human error. Factors that could impact on human performance such as workplace design, tools and equipment, time pressure, workload and training are considered. These factors should correspond to those recorded during the observation, although additional factors (e.g. that could occur during non-routine operations) can be included where appropriate. Once the potential errors have been identified, they are classified as either slips (of action), lapses (of memory), mistakes or violations (i.e. not following the procedure). The consequences of each error are determined, and the safeguards in place and human recovery requirements are recorded.

Concurrent Task Analysis

This analysis has two parts: within task and between tasks. The within-task analysis examines the critical task steps that may be performed whilst simultaneously conducting the primary critical task step under investigation. This demonstrates how operator attention may be split within a critical task.

The between-task analysis examines other tasks that may be performed whilst simultaneously conducting the primary critical task step under investigation. These concurrent tasks may have been recorded during the task observation. However, the operators and site personnel should be consulted to identify all the possible concurrent tasks. This demonstrates which secondary tasks may be attempted during a critical task step, thus requiring the operator to leave the critical task unattended or be distracted from the primary critical task.

If there are a large number of potential concurrent critical tasks, these can be classified into task groups. The concurrent critical tasks or task groups are recorded in a matrix to show the extent to which the secondary task can be conducted according to three categories –

1) the task can be completed
2) part of the task can be conducted or
3) the secondary task cannot be attempted while conducting the primary critical task step under investigation.

An example of the recording sheet is shown in Figure 2. The matrix highlights concurrent tasks where the operator's ability to recover from a problem with the primary critical task may be impaired. If any of the critical task steps highlighted rely on human recovery, then more in-depth investigation may be required to determine whether the operator would be absent long enough to allow the situation to escalate and whether there would be sufficient time remaining for the situation to be recovered.

Shift Information

A list of shift personnel is compiled outlining their job roles and responsibilities. Any additional duties are noted, e.g. first aider, fire crew or emergency warden. This information outlines the number of people available per shift, any dual roles and whether the team members are multi-skilled. This indicates whether individuals must leave tasks unattended when performing other roles. The information also indicates whether sufficient staff are available to cover breaks, etc. The shift information is simply intended to provide additional information to consider when evaluating the safeguards.

STEP 4: EVALUATE THE SAFEGUARDS

Alarm Checklist

The existing techniques for alarm evaluation were found to be relatively complex and suited for separate alarm studies rather than the initial high-level assessment required within this approach. This checklist (Figure 3) was developed to capture the same key issues by asking questions in "everyday" language that allows operators to undertake the assessment with assistance from the human factors professional if necessary. This checklist was developed from industry best practice[1,2,3] and covers issues such as alarm design, alarm inputs and processing, operator interface, operator response required, alarm type, environment, communications, alarm logs, and change management. The checklist is designed to highlight potential weaknesses within the alarm system that might degrade the effectiveness of the alarms as a safeguard. The checklist outlines the standards that must be attained if the alarms are safety critical. Although the checklist is applied to the alarm system as a whole the issues should also be considered in relation to each safety critical task step where alarms have been listed as a safeguard.

Procedure Checklist

The procedure checklist was again developed from industry best practice[4,5,6]. The existing guidance was collated into the same format as the alarm checklist (Figure 4). Once again, the language was screened to avoid obscure terms to ensure that it could be easily applied by operators. This checklist assesses procedure design, language, layout, etc and also the management of procedures within the organisation. Therefore issues such as accessibility, adherence, responsibility for co-ordinating and updating procedures and training can also be taken into consideration. The checklist also explores the extent to which the workforce is involved in the writing and development of procedures on the site. This checklist is designed to determine whether the procedures in place are of a sufficiently high standard to be considered as safeguards and to highlight areas for improvement where necessary. The checklist is applied to the procedures that have been recorded as safeguards in Step 3.

Staffing Assessment Flowchart

The flowchart was based on a HSE staffing assessment methodology[7]. The flowchart examines whether the task is constantly attended by a member of staff. If the task is left unattended at any point, the flowchart leads the assessor to investigate the other safeguards in place to either attract the operator's attention (e.g. alarms) or to control any process upset (e.g. automatic shutdown systems). The flowchart steers the assessor to one of three levels of staffing adequacy:

- Level 0 – staffing or control measures in place are likely to be inadequate. Immediate measures should be taken to improve staffing or control measures
- Level 1 – staffing or control measures may be insufficient. If there is a reliance on trips, slam-shuts or other fail-safe mechanisms, reliability must be justified. Staffing levels should be considered to ensure that essential monitoring, control and incident response activities can be conducted.
- Level 2 – staffing or control measures are likely to be adequate. Monitoring systems should be established to ensure that staffing remains adequate.

The staffing flowchart (Figure 5) is applied to the task steps where training or operator intervention etc have been recorded as a safeguard.

These tools are used to evaluate the effectiveness of the safeguards identified in the error analysis and to provide a rapid "healthcheck" of the alarm system, procedures and staffing levels on site. The tools are not designed to provide a comprehensive assessment of any of the systems in place although they could highlight areas where such assessments would be beneficial. The outcome of each healthcheck assessment gives an indication of whether the reliance on the respective safeguards is justified.

STEP 5: IDENTIFY RISK CONTROL MEASURES

The next step is to improve the safeguards that have been identified as being less than adequate. This may involve, for example, improving the procedures and training, prohibiting certain concurrent tasks, improving alarms, increasing staffing levels or introducing engineering controls to avoid human failures resulting in a MAH. The safeguard evaluation tools should highlight areas for improvement. It is also important to consult with the operators to explore other potential improvements. An action list is compiled to ensure that all the proposed improvements are allocated to the relevant parties, considered and then either followed through to completion or justification provided as to why the improvement should not be adopted. A cost benefit analysis may be required to provide such a justification.

STEP 6: INCORPORATE RELEVANT RESULTS INTO COMAH SAFETY CASE

The results of this team-based process and the improvements adopted are then incorporated into the site's COMAH Safety Case report. The records taken throughout the assessment can be used to demonstrate that human factors issues have been systematically considered.

The six steps must be repeated for each of the MAH scenarios identified in Step 1.

APPLICATION

One of the aims of this joint partnership approach to human factors assessment was to transfer knowledge of human factors to the people who actually deal with these issues on a day-to-day basis on each site. By raising awareness of the issues that can affect human performance, the site personnel can identify issues beyond the scope of this assessment and proactively target new areas for improvement that would be missed by external contractors with a limited knowledge of the site and its operations.

Initially, the assessment team was formed consisting of three health and safety personnel, the site manager, one chemist, three operators and a human factors professional. This resulted in a multidisciplinary team who could provide different perspectives on the issues under consideration. The Ciba team were all experienced in the operations to be assessed. However, in order to enable them to complete the assessment, two days of training were provided in human factors and techniques involved in the assessment.

The methodology was translated into a spreadsheet format to allow the data to be captured effectively and to maintain an overview of the entire approach throughout. This format also provided easy access to all the data captured.

The assessment was conducted on the site over a period of one week. Although this restricted the amount of time available for each step, it ensured that the members of the team were able to participate throughout the assessment. If the assessment had been conducted over a longer period, team members would have been forced to miss sessions due to work commitments and shift patterns. The Ciba team took ownership of the assessment throughout, with guidance and support provided by the human factors professional where necessary. This encouraged the team to use the training that had been provided and to explore the human factors issues on the site.

EVALUATION

The study illustrated how simple, practical and effective methods can be used to assess how human failures contribute to risk. This approach is flexible enough to incorporate existing hazard identification and risk assessment information. For companies where previous evaluations of alarm systems, control systems, staffing levels and procedures have been conducted, these could be included in place of the checklists and flowcharts used in this study. Therefore the flexibility within this approach can avoid the need to revisit issues and perform repeat assessments. However, it is important to ensure that any previous assessments used within this approach are still relevant to the current tasks and current task environment. If minor changes to the site or the tasks have occurred since the previous assessments were conducted, then a partial update may be sufficient. However, if the assessments are outdated then a full re-assessment will be required.

The staffing flowcharts proved to be less effective than the other tools at providing direction for improving low scoring tasks. It was decided that although this flowchart is useful for diagnosing staffing deficiencies, it is not applicable within this methodology as the same information is collected elsewhere within the assessment. This flowchart is to be replaced by a diagnostic flowchart that will allow the assessment team to consider possible improvement measures and select the most appropriate option. Ordinarily, an organisation's first choice when searching for risk-reduction measures will not be to increase staffing levels. Other measures e.g. restructuring job roles may prove to be more effective in reducing the risks. The new flowchart aims to determine whether any benefit would be gained by having the task constantly attended. After all, if human monitoring is not the most reliable safeguard and the consequences are potentially severe, then an alternative solution may be more appropriate.

The concurrent task analysis proved to be one of the most useful exercises within the whole assessment process as this highlighted the situations where a simple human failure could escalate into a major accident hazard due to the human defences being defeated. However, it became clear following the initial assessment that the recording matrix did not include sufficient detail to allow others to interpret how the analysis had been conducted. For example, the coding system states that "P" denotes that part of the secondary task can be attempted whilst conducting the primary task. However, there is no way to distinguish which part of the secondary task can be attempted and whether there is a conflict that prohibits the "other part" (and hence completion of the secondary task). Therefore, the matrix has subsequently been updated to allow a greater level of detail to be recorded.

The method has proven to be ideal for the application it was designed for. However, it is important to recognise that other methodologies may need to be employed subsequently to investigate further the issued identified; e.g. a full alarm handling assessment may be required if the alarm safeguards are found to be inadequate. Therefore it is important to be aware that the checklists used do not necessarily replace existing assessments. Instead they provide an indication of where efforts should be focused for the greatest benefit in terms of risk reduction.

Although this method was originally designed for use within the chemical process industry, it could easily be applied to other industries to facilitate the inclusion of human factors into their safety cases. Although this approach has task analysis and human error assessment as its foundation, it has been specifically designed to be sufficiently flexible to incorporate other assessments and issues where necessary. If the safeguards in place do not take the form of alarms, procedures or manning, but instead are e.g. software-based safeguards, then an appropriate assessment tool could be included to evaluate these.

DISCUSSION

The feedback from the assessment team was positive and the potential improvements uncovered by the process proved the benefits of the systematic approach. However, the approach does require commitment from the organisation in order to succeed. It proved difficult to arrange for all the participants to be available at the same time for the sessions and therefore in some cases two people were trained to fill the same role within the team.

When this methodology is applied to other sites, different safeguards may be noted e.g. ones relating to the DCS control system. Therefore, an interface evaluation would be required rather than simply applying the checklists and flowchart outlined in this paper. Training and competence assurance may also be noted as safeguards. If so, the organisation must be able to demonstrate the training provided meets the specific need identified and that appropriate measures are in place to ensure that the training is effective and competence is maintained. The methodology is still evolving to fulfil such requirements and Ciba are continuing to develop the assessment process.

As with all assessments, it is important that the information gathered throughout the study is utilised effectively. The recommendations improving the safeguards should be fed forward into the design of new process systems and work environments as well as providing solutions to immediate issues.

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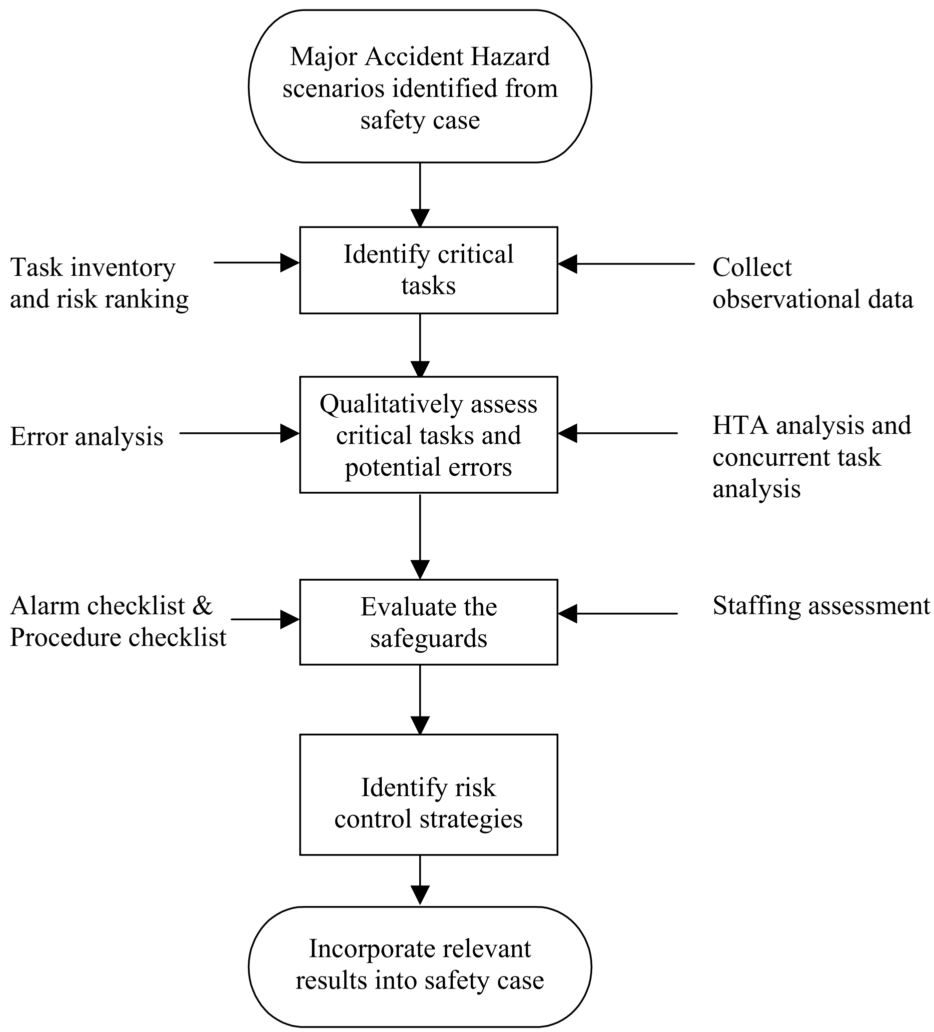

Figure 1. Six stages of the assessment process

			...which of these tasks can be performed concurrently?											
			Critical (HTA) Tasks											
			Make Monomer						Charge Monomer					
	Task No	Task Step	1	2	3	4	5	6	7	8	9	10	11	12
Whilst performing these tasks…	1	Charge to Vessel		A	P	X	X	A	A	A	A	P	A	A
	2	Transfer to Vessel	A		P	X	X	A	A	A	A	P	A	A
	3	Add	A	A		P	P	A	A	A	A	P	A	A
	4	Sample to lab approva	X	X	S		P	X	X	X	X	X	X	X
	5	***Set up suplhuric sotz***	X	X	P	S		X	X	X	X	X	X	X
	6	Transfer to Vessel	A	A	P	X	X		A	A	A	P	A	A

Key: X = None of the task can be simultaneously performed

P = Part of the task can be simultaneously performed

A = All of the task can be simultaneously performed.

Figure 2. Concurrent task analysis matrix

Auditory alarms		
Can all auditory alarms be heard from all parts of the plant that the operator may be, even when wearing ear protection?	BP	An assessment has been performed to ensure that all alarms can be heard from all parts of the plant. When wearing ear protection, another operator is available to deal with alarms.
	S	No problems have been reported with alarm audibility throughout the plant. When wearing ear protection, another operator is available to deal with alarms. No assessment has been performed.
	P	Certain alarms cannot be heard from certain parts of the plant, or when wearing ear protection.
Are all sound signals easily distinguishable?	BP	Different sounds are used for different alarms (e.g. safety-critical vs. operational) or priorities, and designed according to ergonomic guidance.
	S	A small number of variations are used or a single tone is used where the use of different tones is not essential.
	P	A single tone or no tone used for a large number of different signals. Operator has to search to identify the reason for the tone sounding. OR there are too many different auditory alarms, which cannot be distinguished reliably in operating conditions.

Figure 3. Alarm checklist

A. Procedure Design		
Is the procedure of an appropriate length?	BP	Procedures are kept as concise as possible whilst still conveying all the necessary information. The length of the procedure has been designed with the context of use in mind.
	S	Procedures are generally of a usable length, but may not be sensitive to the context of use.
	P	Length of procedures makes them very difficult to use. No account taken of context of use.

Figure 4. Procedure checklist

Figure 5: Staffing Level Decision Flow Diagram