HAZOPS AND HUMAN FACTORS

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INTRODUCTION

In this paper, I propose to consider the need for a focus on Human Factors in Hazard and Operability Studies (HAZOPs) and then restate the basic principles of HAZOP in order to show how the established Guide Word driven method can be used for HF issues. We shall also consider the appropriate way to consider HF at other stages of the project within other Hazard Studies.

It is timely to consider this in the context of the theme of this conference. We do know a lot about HAZOPs – the method has been in use now for several decades. But in terms of where we are going, we see increasing emphasis on Human Factors issues in the specification, design, operation and performance of processes – and so we all need to develop an understanding from the Human Factors perspective.

But first we may need to clarify the term HAZOP. If I may quote the introduction to the 2001 International Standard: "The term HAZOP has been often associated, in a generic sense, with some other hazard identification techniques (e.g. check list HAZOP, HAZOP 1 or 2, knowledge based HAZOP). The use of the term with such techniques is considered inappropriate and is specifically excluded from this document." While many of the audience will no doubt agree with this distinction, I know that some organisations do use other terminology. But when I refer to HAZOP I mean the Guide Word-driven method used at the detailed design stage. We shall, in the second part of the paper, consider how to apply HF at earlier stages. Of course, what is important is not what things are called, but that the appropriate activities and decisions are carried out at appropriate time in the project.

Those of you who have had involvement in HAZOPs will know that once the HAZOP Leader has said "let's start the first node" the team will be off – "No Flow, More Flow, As well as flow" all follow automatically in succession. In the many HAZOP training courses that I run for the IChemE, I find that participants often come with a preconceived list of Guide Word and Parameter combinations.

Sometimes this checklist approach may work - but there are many process situations in which these may not be the most applicable. Certainly when it comes to Human Factors, the usual parameters may not be the most helpful to lead to a full consideration of HF issues. It is not for me in this paper to go into the theories of human factors analysis, (and we will hear more of this in the many other papers during this conference) but we need to remind ourselves that Human Factors are not just about the individual operator carrying out a particular task at a particular point in a chemical process plant. They also encompass the higher-level activities: safe systems of work and procedures, training

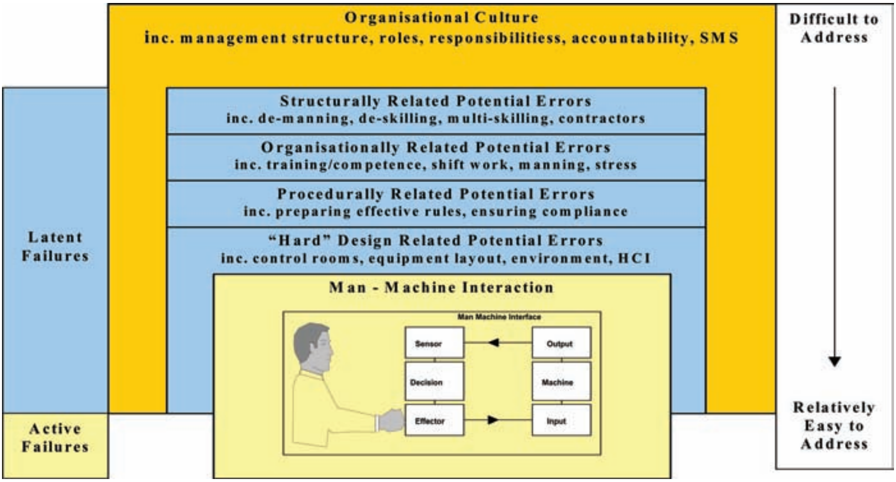

Figure 1. A model for human factors

and competence, organisation of work, management systems, and business culture. Figure 1 shows a typical diagrammatic representation. And, of course, we should not forget the possible Human Factor issues, and the possibility for HF errors, in the design process itself. We shall return to these influencing factors later.

But if we come back to the operator performing tasks, this is where a HAZOP can be a particularly powerful tool. We need to consider the interaction of the operator with the process in any continuous process, to look for errors which can be made at any point in the plant operation. This becomes all the more necessary when we come to look at sequential operations, which often require considerably more operator involvement both through control systems and in actual on-plant activity. I am thinking here particularly of operations such as start-ups and shut-downs, or batch processes.

As with all HAZOPs, the amount of detail we need to go into (the "depth of the study") depends on the consequences if it goes wrong – potential injury to people, effect on the environment, or delay in turn round affecting operating profits. In batch processes, of course, quality of product may also be a key issue.

So the cry goes up – "we need different Guide Words to cover human factors!" But it is my purpose in this paper to show why new Guide Words are *not* necessary.

HAZOP METHODOLOGY

Let us just go back a moment and remind ourselves of some of the basic principles of HAZOPs. Perhaps the most fundamental is that "problems occur when there are unforeseen effects of deviations from the intended design". So we need to begin with an intended design. In a conventional process HAZOP (if I may call it that) we are usually working from a design represented in P&IDs, backed up by equipment datasheets, instrumentation cause and effect diagrams, layouts, chemical data etc – and the intention usually describes process conditions such as flows, temperatures, pressures, levels and the like. It is from these that we derive the "usual" HAZOP parameters. I fear we get so familiar with this conventional list that we often forget to define the intention.

If we are looking at a human activity, the key is again to get the Design Intention right. The team needs to understand what operators actually have to do – the intended activity. These might be represented in operating procedures, start up and shut down manuals, perhaps emergency shut down procedures, maintenance procedures or process batch record sheets. I realise that many of you will have different names for these, such as Standard Operating Procedures (SOPs) or Safe Working Procedures (SWPs).

Let me give you some examples of simple design intentions:

- Charge 50 × 20 kg bags of product to vessel through open access cover
- Set up six manual routing valves for recycle operation around column
- Load individual packages onto rotating belt conveyor at rate of 8 per minute
- Press master stop button on control panel and reduce cooling water flow rate to minimum

So, in a HAZOP we are looking for problems caused by deviations from this intended design of a process – first principle. The second principle is that we generate these deviations which may cause problems, by using the HAZOP Guide Words. The Guide Words never change. I say that to be provocative, as I know you will have slight local variations, but the standard list, as set out in the international standard have stood the test of time (IEC 61882). So I really do not need to remind you of the standard list given in Table 1:

No
Less
More
Reverse
Part of
As Well As
Other than
Sooner
Later
Other

And so we apply the Guide Words to our intention in order to explore possible deviations. I often feel that some confusion does arise when people lose the distinction between the Guide Words and Parameters – especially when both are referred to as "Key Words".

As in all HAZOPs, we need to be thorough and systematic – and we need to be creative – but if we are looking at Human Factors, these require even more imagination and creative thinking. We probably also need someone on the team who is experienced in

Table 1. HAZOP Guide Words

Guide word	Interpretation	Examples
No	Not done, task not completed	Operator omits step in sequence
Less	Do less of the required action	Smaller quantity handled; Not all valves opened in a step
More	Do more than or more of the required action	Larger quantity handled; Valves opened more than requd.
Reverse	Do the opposite of the required action	Closes valves instead of open; Needs to reverse previous action
Part of	Not all tasks in an action carried out	Actions within a step omitted
As well as	Do something in addition to the required task	Additional material handled; Open additional valve
Other than	Do something different from the required task	Acts on wrong valve; Incorrect material handled
Sooner	Carry out the action before the time specified	Changes order of steps: Takes action too quickly
Later	Carry out the action after the time specified	Changes order of steps: Takes action too slowly
Other	Different factors which may influence the action	Change of shift working

the many aspects of Human Factors and can help us to think of the causes of these deviations. But as in any HAZOP it is the Guide Words which do the prompting. Let us go back to one of the examples we used just now.

- Load individual packages onto rotating belt conveyor at rate of 8 per minute

We need to make use of the HAZOP method and apply each of the Guide Words in turn. (Table 2 gives these examples in the form of a HAZOP record sheet). Here are some immediate suggestions – you may be able to think of others:

No	Not loaded
	No packages available
	Not running belt
More	Loads faster
	Packages larger
	Belt running faster
Less	Loads slower
	Smaller packages
	Belt running slower

Table 2. Example HAZOP Table

HAZOP Study	Title Input belt feed			Date 2nd Sept 2005	Leader AA	Team BB, CC, DD, EE
Intention: Load individual 2kg packages onto rotating belt conveyor (variable speed set at 4 m/min) at a rate of 8 per minute						
No.	Guide Word	Deviation	Cause	Consequence	Safeguards	Action
1	No	Not loaded	Operator distracted	Missing object on belt – reduced through put	Assume detected by position sensors later	No Action proposed
2				Operator may try to catch up by loading more	Assume relies on downstream accumulator	1. Review capacity of accumulator to handle large overcharge
3			Operator leaves line	Missing object on belt – reduced through put		2. Review need for breaks and appropriate cover
4		No packages available	Operator leaves line	Missing object on belt – reduced through put	Operator has to collect own stocks	3. Review staffing levels needed to maintain continuous supply
5			May use alternative available packages	Off spec product	Segregation of stocks	4. Ensure all materials cleared from production area at end of run
6		Belt not running	Loads batch to belt in readiness for restart	Possible jam on conveyor – or ejected packages	Relies on training and competence	No Action proposed
7	More	Loads faster	Miscalculates from known belt speed	Bunching of packages on belt	Assume relies on downstream accumulator	5. Provide simple calibration chart. (Mark belt for required spacing)
8			Operator thinks on a different product run	Bunching of packages on belt	Assume relies on downstream accumulator	6. Provide clear batch card with line running conditions
9			Tries to get ahead in order to take a break	Possible jam on conveyor – or ejected packages		See action 2
10		Larger packages	Operator used to previous smaller size	Increased risk of handling injury	Supervisor briefing	No Action proposed
11		Belt runs faster	Speed not reset from previous run	Package pulled from operator's hand - injury		See action 6
12	Reverse	Removes package	Realises error of wrong package	Reaches into machine – possible entrapment	Assume belt has stop protection (e.g. light beams)	7. Provide safe buffer distance for taking corrective action

Reverse	Put package wrong way up
	Remove package after loading
	Belt running backwards
Part of	Damaged package/part missing
As well as	Wrapping material on package
	Objects placed on belt
Other than	Non-standard package
	Loads another object
Sooner	Loads several close together
Later	Loads slower

These, obviously, are just the deviations. The team now needs to carry out a creative search for causes based on HF knowledge and performance influencing factors. So, for example, we need to think about both possible active and latent failures, as well as possible failure modes based on the various behavioural models.

- Human Error Types
  Omission Not done
  Takes wrong reading
  - check on wrong object
  - wrong check on right object

  Misreads
- Psychological factors
  - Familiar association
  - Stereotype takeover
  - Place losing
  - Assumption
  - Forget isolated act
  - Need for information not prompted
- Cognitive error
  - has to work it out
- Violation error
  - deliberate breach

So, again using one of the earlier examples, the causes of "loads faster" might include:

Miscalculating from the known belt speed
Thinking he/she is on a different job
Trying to create spare time by loading all packages as quickly as possible

As always in a HAZOP, we look at the consequences to the individual and to the process, decide whether or not they matter – and ask the question "do we risk a significant failure?" Then we review the safeguards – will the system itself deal with these potential error modes that we have identified, are the safeguards adequate or do we need to make further design improvements. With our focus on Human Factors, we are trying to go beyond the often-heard comment "relies on operator controls" and hence improve reliability and performance.

EARLY CONSIDERATION OF HUMAN FACTORS

We began by reminding ourselves of the fundamental principle of HAZOPs, that "problems occur when there are unforeseen effects of deviations from the intended design" – and that therefore we need an intended design. But we also want the best possible intended design so, as with the process equipment and control systems, the HAZOP is usually too late in the design cycle to be giving a first consideration to Human Factors. This means that we need other ways of ensuring that HF issues are adequately considered early on, and at the appropriate stages.

The method of staged Hazard Studies through the course of a project has become established practice in many industries and companies. There are probably as many variations as there are companies represented here, from the original 6 stage Hazard Studies, to as few as 4, to as many as 8 stages. But the basic principle is the same – to ensure that the right decisions are made at the right time, and hence to assist the flow through the project. In particular this means making key decisions early enough.

It is therefore important that we think about how Human Factors can be considered in the conceptual and preliminary stages, as part of other Hazard Studies, to ensure that Human Factors are taken into account throughout. I must stress that these alternative studies are not HAZOPs – and confusion is often caused by lumping other studies together under this one heading.

We could go into great detail in building up a picture of the life of a project and the many different activities that need to take place. I have included a simplified version in Figure 2 to show the key stages and the sort of activities we need to carry out. Again, I am aware that different industries give different names to the various stages. The two

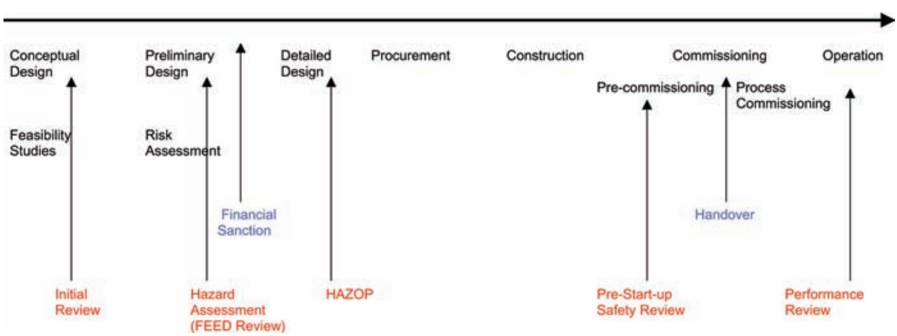

Figure 2. Hazard studies in a project

earliest studies give us the opportunity to include Human Factors issues to ensure they are considered in the design. This could be done either by including a Human Factors section within the established structure of the early studies, or by a separate study, with significant involvement of HF specialists. This can be achieved, for example, by developing a Human Factors section within Hazard Study 1, or covering HF related causes in Hazard Study 2.

As with other early studies, this review process can be driven by a checklist or prompt list of the issues and concerns which need to be considered. Not all will be relevant, but the list can be used to help decide which are, and to decide strategies for dealing with them, or basic principles to be included in the design. The list proposed in Table 3 is by no means exhaustive, but shows the way a study could be structured. It aims to address all significant issues, such as:

Ergonomics	workstations, manual handling
Control rooms	occupancy, activities, alarm handling
Procedures	layout, accessibility, accuracy
Training	quality, delivery, assessment
Management	culture, involvement

Those of you with a Human Factors background would, no doubt, be able to develop such a list further, to make it much more comprehensive. There are clearly different issues which become more relevant at different stages, as the design progresses – and it is

Table 3. Human factors issues (representative)

Type	Issues	*Typical control strategies*
Conceptual Design Stage		
Task	Reliance on human intervention	Operational strategy – extent of automation
Incidents	Review of known past performance	Learning points. Emphasis on review of HF issues (all levels)
Environment	Location	New building/areas modification to existing
Control Room	Location and operation	Extension of existing work stations / new control room
Operation	Duration of production	24 hour?/7 days continuous Shift patterns and organisation
Staffing	Numbers and competence	Recruitment and training requirements

(*Continued*)

Table 3. *Continued*

Type	Issues	*Typical control strategies*
Management	Business organisation	Fit into existing structures/new working groups and organisation
Type	Issues	*Typical control strategies*
Preliminary Design Stage		
Task	Complexity	Task analysis
	Repetition	Work rotation
	Information	Procedures and training
Ergonomics	Complexity of system	Task analysis/labelling
	Access to plant	Process design
	Manual handling	Mechanical assistance
Environment	Noise	Communications methods
	Temperature	Working patterns
	PPE Required	Impact on task analysis
Control room	Work station design	Layout
	Occupancy/work patterns	Task analysis
	Alarm handling	Prioritisation
Procedures	Complexity/clarity	Simplicity/key issues
	Availability	Design for use
	Changes/updates	Design by users
Training	Skill level/competence	Workforce assessment
	Delivery	In house/external/mutual
	Assessment	Skill assessment
Management	Culture	Defined responsibilities
	Supervision	Clear roles
	Involvement	Management audits

important to consider topics at the appropriate time. I have shown this using two stages in Table 3: conceptual design and preliminary design, respectively. The first stage inevitably should address the higher level issues which, by their nature, will affect the context for the design of the whole of the rest of the project. I offer this as a basis for further development.

There are obviously other methods and tools available, such as the Human Factors sections within a structured "What If ?" analysis – although you will recall that "What If?" was developed as an alternative to HAZOP at the post-detailed design stage.

CONCLUSIONS

We have seen how the HAZOP method can be used to address human factors issues in a project, process or design. As with any HAZOP, a clear design intention (or activity intention) is required. The conventional HAZOP Guide Words can then be applied to this to generate deviations for further investigation.

We have made a clear distinction between HAZOPs and other studies, and emphasised the desirability of considering HF issues early on in the design cycle, using a checklist-based approach. Further work would be useful to develop comprehensive HF prompt lists to assist this process.

REFERENCE

International Standard IEC661882: 2001, Hazard and Operability studies–application guide