IS HAZOP WORTH ALL THE EFFORT IT TAKES?

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Some companies have abandoned or curtailed using HAZOP as a technique while others just "go through the motions" of doing HAZOP because it is mandated by their project management procedures. How has HAZOP acquired this negative reputation and what can be done about it? Steve Whitty and Tony Foord describe the problems and how they could be overcome based on practical examples from the numerous HAZOPs they have each facilitated. For example: no prior hazard identification; no prior design review (leading to numerous trivial actions); no agreement about scope (for example, are tie-ins and utilities included?) inappropriate, incompetent or too many team members; no-one available with operational experience; arrogant project managers; defensive designers; multiple chairmen; poor listeners; intermittent attendance; software packages that slow down recording; long hours and 6 day weeks; "coarse scale HAZOP"; HAZOP procedures with endless checklists; and commercial battles between Client and Contractor. Most people think being a HAZOP chairman is easy until they try to do it, but nearly all these problems can be overcome with good preparation and training. Our response to any suggestion that it's not worth HAZOPing a part of a plant is, "let's try it and see; if there is nothing to find, it shouldn't take long as there will be little to discuss". In our experience there has always been something significant to find with a good team and the right preparation.

INTRODUCTION

Ref. 7 states 'In 1963 the [ICI Heavy Organic Chemicals] Division was designing a plant for the production of phenol and acetone from cumene. It was a time when the aim of the Engineering Department was "minimum capital cost" and the design had been pruned of all inessential features. In the Works we felt the pruning had gone too far. It was also a time when method study and, in particular, "critical examination" was popular. Critical examination is a formal technique for examining an activity and generating alternatives.

During 1964 [a team of three] met for three full days a week for four months examining the Phenol Plant line diagrams. They discovered many potential hazards and operating problems that had not been foreseen, modifying the technique as they did so. In essence, a technique designed to generate alternatives was modified so that it generated deviations.'

The name HAZOP (HAZard and OPerability) study was suggested later and has stuck ever since. Although there are numerous books, papers and even an international standard [Ref. 5] there is a wide divergence of understanding of the HAZOP procedure.

DESCRIPTION OF HAZOP PROCESS

IEC 61882 [Ref. 5] states, "An accurate and complete design representation of the system under study is a prerequisite to the examination task." This implies at least:

- a Logical (schematic) Description, usually based on Piping & Instrumentation Diagrams (P&IDs) – sometimes called Engineering Line Diagrams (ELDs); and
- a physical layout of the Equipment, usually General Arrangement scale drawings (GAs)

which, together with any other documents required, define the designer's "design intent" for the system. The HAZOP study then examines "deviations" from the design intent. For example, the system may have been designed to handle ambient temperatures from -10°C to $+50^{\circ}$C. A hot summer of 40°C may be extraordinary, but is not a deviation for the system; whereas a cold winter of -20°C would be a deviation.

The system is then divided into small enough parts (usually called "nodes") so that the study team can all understand possible causes and consequences for each deviation within that node. Listed in advance are:

- the relevant attributes (or parameters) of the system, for example, flow, level, pressure, temperature, composition, and viscosity; and
- a set of "guide-words", for example, no, more, less, reverse, part of, other than and as well as.

A combination of a guide-word and an attribute gives a possible deviation to be considered, for example, "more flow." As illustrated in Figure 1, the study team then discusses possible causes and consequences for each deviation and records them. If the study team consider the safeguards (to eliminate the causes and/or to prevent or mitigate the consequences) are adequate, then these are documented and the next deviation or entity considered. If the study team does not consider that the safeguards are adequate, then a recommendation for action is recorded and assigned to the relevant person. The iterations are repeated until all guide-words and attributes have been considered for all the entities within a particular node.

Thus, it is immediately obvious that, as well as being systematic, HAZOP is a lengthy procedure. Depending on the complexity of the process, a study team may take

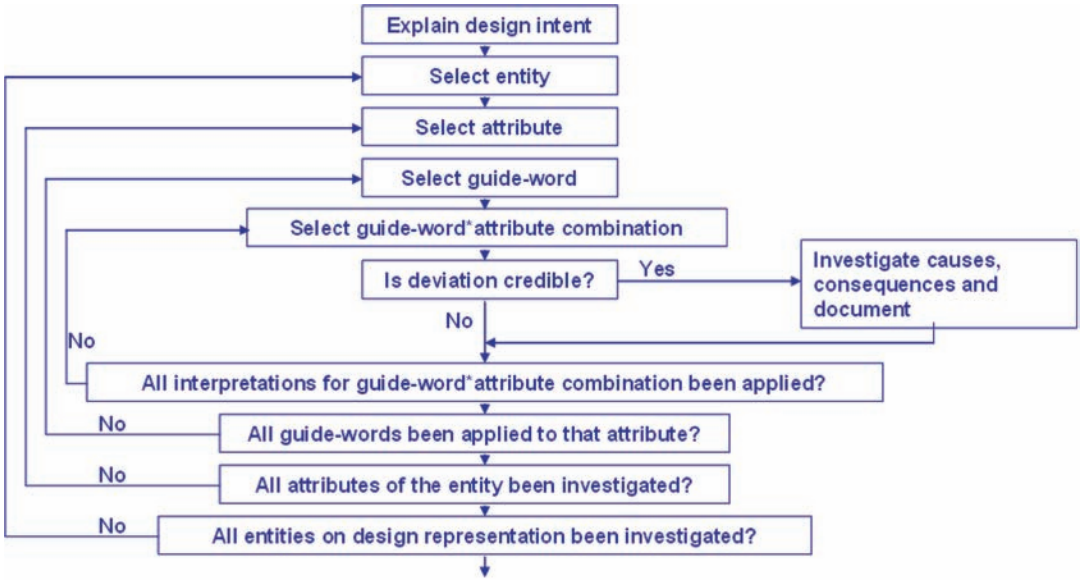

Figure 1. Iterations during the HAZOP study

3 hours or more than a day to consider all the entities and deviations for a single P&ID.

WHEN TO DO A HAZOP STUDY

IEC 61882 [Ref. 5] also states, "The best time to carry out a HAZOP study is just before the design is frozen." The IChemE HAZOP Guide [Ref. 4] states, "A study cannot be carried out on a partly developed design" and describes the six stages of Hazard study where HAZOP is study number 3 illustrated in the bar chart shown in Figure 2.

Trevor Kletz suggests the same [Ref. 6]; yet, repeatedly, we are asked to lead a HAZOP on a concept or an incomplete design. This means that often:

1. the design intent is not clear, leading to protracted discussions about whether or not a particular change is a deviation or within the design intent.
2. numerous trivial actions: particularly if there has not been a design review prior to the HAZOP, or the design review suffered from the same lack of clarity about the design intent because it was done too early in the project.

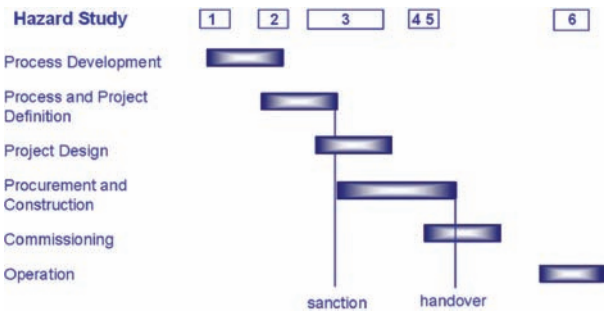

Figure 2. Hazard study 3 = HAZOP study

NO PRIOR HAZARD IDENTIFICATION

Sometimes, HAZOP is done too early because HAZOP is being used as the *only* method of identifying hazards for the particular project. Hazard identification should be completed prior to HAZOP. Trying to do two jobs at same time causes difficulties. This lack of previous hazard identification is easily recognised by a lack of maturity in design (and by the lack of hazard identification report!) Many hazards can be identified as soon as the chemicals, quantities and locations (for example, a simple layout such as a plot plan) are defined. Some companies recognize this and produce Process Safeguarding Diagrams as well as Process Flow Diagrams (PFDs) prior to the P&IDs.

As illustrated in Figure 2, HAZOP should follow Hazard studies 1 & 2 which should include hazard identification. Thus, not only will hazards have been identified early, but many issues that are not best studied during HAZOP will have been identified. Examples are:

- explosion risks that are best tackled by Quantitative Risk Assessment (QRA) or specialist explosion modeling.
- preventing ignition of substances following leakage that is best tackled by Hazardous Area Classification.
- how, and within what timescale operators will respond to alarms that are best tackled by reviewing Alarms Policies and Procedures to ensure they conform to EEMUA 191 [Ref. 2].
- Emergency Shutdown and Blowdown Policies that need to have been agreed as part of the design intent.

All the above need teams that are smaller and require different skills from those needed for HAZOP, though some of the same participants may be involved. It is right to recognise that HAZOP should not be the only examination technique, but it is probably best suited to be the main one; and, if resources are available for only one study, it should be HAZOP. On new plant, HAZOP following hazard identification would be most effective. On existing plant, the hazard identification part should be well-known, and a walkabout, combined with a HAZOP, will uncover problems most efficiently. Identifying actions – for example human factors assessment or Hierarchical Task Analysis is common during HAZOP.

CHECKLISTS

Sometimes, the lack of hazard identification is an unstated policy (i.e. taken for granted), not just a feature of a particular project. This may then result in HAZOP procedures with endless checklists: in one company we have come across, the list of so-called "guide-words" covered eight pages. Inevitably, the list includes issues that:

1. should have been covered by earlier hazard identification: for example, material selection to suit corrosive substances;
2. cannot be tackled until procurement has been done and particular vendors selected – for example access for maintenance and lighting; and
3. need a few specialists rather than the entire HAZOP team.

Although the use of hazard-based checklists (for example fire, explosion, ignition sources, etc) in HAZOP can be useful as an aide memoire (as long as they don't get in the way of the 'main' keywords – as in Ref. 4). It is very rare for teams that we have led to identify significant issues under these peripheral keywords, as they have all been identified earlier.

The psychological effect of such a checklist is often to put a 'straightjacket' on the team's imagination, and some members will spend a lot of effort thinking if something is more appropriate under another word instead of dealing with the issue. The monotonous checking against a long (and usually lengthening) list is dull and can de-motivate the team. We prefer the freer thinking that comes from the 'traditional' keywords as in Ref. 4.

NO AGREEMENT ABOUT SCOPE

People often assume that the scope can be defined simply by providing a list of P&IDs. If only a list is provided and there is no preparation meeting, then the entire HAZOP team has to sit through a discussion of:

- are all the utilities shown on the P&IDs within scope?
- are utilities used that are not shown on the P&IDs – for example, will vessels be steamed-out during maintenance and thus may need vacuum protection?
- what upstream and downstream disturbances are credible; and, are appropriate upstream and downstream P&IDs available?

There are particular issues with:

- flare and drain headers which might include special cold flares where water should be excluded and pressurised (closed) drains as well as open drains.
- emergency supplies of electricity and instrument air to ensure that essential safety systems, including flare and drain systems, are still operational during a power outage.
- tie-ins to existing systems.
- misunderstanding of what HAZOP will do – unrealistic expectations lead to disappointment. Expecting the HAZOP to solve all problems or the HAZOP Team Leader to tell them what to do.
- for a HAZOP of existing plants it is very rare to get drawings that you can have confidence in. Need to check that the drawings reflect the as-built plant. A problem even where there is limited potential for change (so it's not just on regularly modified plants, which could be understood). Particularly beware of teams who say (a) all our drawings are up to date and accurate; (b) we are up to date with scheduled maintenance; (c) we know where all our drains go.

All these issues should be resolved ahead of the main study team meeting to minimize both the potential for confusion and the length of the HAZOP meeting.

MEETING ISSUES

Even with world-class preparation, the participants can still wreck any HAZOP study meeting. Even when the best possible team has been selected in advance, sickness or priorities of the same or other projects may lead to a very different meeting from the one that was planned. Unfortunately, both the preparation and the team are often poor.

INAPPROPRIATE OR TOO MANY TEAM MEMBERS

As independent Chairmen we are often presented with a team and have little say in its composition. To counter this we always ask in some way who people are and why they are at the HAZOP, essentially why anyone should listen to them (although hopefully more politely).

There is no problem with any number of observers who sit around the room behind the participants, but the authors have both been asked to lead HAZOPs where more than 25 people are present and all expect to be involved in the meeting. Wisely, the textbooks suggest a maximum of 10 participants. Too many team members results in the meeting breaking down into 3 or 4 separate sub-meetings. So, the study takes twice as long and with twice as many people as necessary the total cost is multiplied by four!

Occasionally, a specialist is needed for part of the meeting (for example, a materials/corrosion expert or an underground pipeline specialist) and these specialists can be asked to attend, when needed. On the positive side, we

have had excellent specialists who wished to attend the whole meeting, but remained as observers until their particular skills were required. Unfortunately, senior managers who also wish to attend the study rarely exercise the same restraint. On one occasion, the project manager attending for part of the meeting announced that, "this deviation is safe and we should move on!" This did not encourage participation by the more junior staff present (who knew the existing safeguards were not sufficient) even when the suggestion by the project manager was politely but firmly rejected by the Chairman.

A more serious handicap is when the Lead Process Designer is unable to attend and sends a colleague from another project. Even a competent Process Engineer will struggle to answer questions about the design intent for an unfamiliar project. The honest ones admit they don't know and then we have to record additional assumptions or wait while someone finds out the answer.

DEFENSIVE DESIGNERS

A good designer who both understands the design intent and wants to use the HAZOP study to achieve improvements can make for a very successful HAZOP study. We have met designers who regard any recommendation for action as a personal criticism and waste time resisting any actions directed at them. Sometimes, they are under orders to protect their design. We do recognise that some engineers will be defensive about their work but prefer that they are willing to listen to reasoned argument.

We have experienced the design manager for say the electrical, control and instrumentation function (EC&I) who brings his whole design team along with him. This is evidence of the manager lacking confidence and any query that goes to him then goes off into his subgroup and *eventually* a response emerges. Taking the person aside privately during an early break in the study may solve the problem.

MULTIPLE CHAIRMEN

Even with a strong and experienced Chairman, a HAZOP discussion can meander and go off on tangents; it's not an effective way of discussing things. Often there is someone who believes they could do it better than you. Even if there is no such direct challenge, small sub-groups can form easily. As the appointed Chairman, you have to keep on top of things and keep the team focussed. We do that mainly by bringing the team back to the record and confirming their agreement: this regularly breaks up any sub discussions. If they go back into their sub-groups after agreeing with the record, ask them directly what they want to see changed; if they say, 'nothing,' then tell them, 'we've moved on' or ask them to share their discussion with the rest of the group.

Some projects include Project Management Consultant (PMC) acting for the Client as well as a Design Contractor and Vendors. The PMC often leads many other project meetings, so when not chairing the HAZOP, the PMC may find the role of participant difficult. Multiple 'chairmen' slow down the meeting and confuse the participants. Again, taking the person aside privately during an early break in the study may solve the problem.

The boss – can be a problem in meetings and can try to dominate the team members (their employees) or they find that what they want from the study is not what we call a HAZOP study and try to influence the Chairman away from the HAZOP procedure.

We therefore try to discourage bosses from attending, even once telling project manager that we don't want him there. If they come as leader you have to protect people from them, devices we have used to do this include (a) standing between them so that non-verbal lines are cut (b) taking the idea that has just been shot down (verbally or non-verbally) by the boss and making the team run with it (c) having a quiet word with them and pointing out they are damaging the study. If the boss is challenging the conduct of the study then ask to allow the study to flow and discuss outside the meeting if the boss is still unhappy. Again you can then set them straight in private!

Intermittent attendance by senior managers can cause the similar problems. During one HAZOP, the Engineering Manager interrupted the meeting for 15 minutes with an urgent design review, then turned to the Chairman and asked why he was allowing design reviews to delay the HAZOP study!

POOR LISTENERS

Following the logic of a detailed explanation of a possible scenario in order to determine whether there are credible causes is demanding, even in your native language. If the meeting is conducted in the second or third language of many of the participants then such listening is very hard work. The best participants make the effort and admit when they have not followed the logic. Others will digress to another topic, talk over the speaker or disrupt the meeting.

Keeping Team Members focused on the record helps a lot with poor listeners. If they want to add something they can say. If what they want to add is wrong because they haven't listened properly, or they misunderstood something, someone else will correct them. In that respect it is important that it is 'safe' for the members to challenge and disagree with each other (even senior people) during the HAZOP meeting.

GLOBAL SUPPLY CHAINS

Many projects involve clients, contractors, PMC and vendors from two or more continents. Thus even though the textbooks advise not doing HAZOP continuously for weeks on end, the cost of bringing the study team together means that project managers are reluctant to limit the working week as recommended. A HAZOP is intensive and the team needs a rest: continuing endlessly to 'turn the handle on the sausage machine' might produce more records, giving the illusion of progress, but the quality of the study must deteriorate.

When people travel long distances and suffer from jet lag, working long hours and 6 day weeks does not improve

the quality or efficiency of the HAZOP study. The Chairman needs to recognise how often to provide breaks or to end the meeting for the day, particularly in cultures with different attitudes to time-keeping.

It is important to take proper breaks at suitable times throughout the study. During these breaks, the team members should stop thinking about the study – so don't just continue over a coffee. These breaks must physically *and* mentally refresh the team.

COMMERCIAL ISSUES AND VENDOR PACKAGES

Unfortunately, some contracts include clauses, meaning that all HAZOP actions should be resolved at no cost to the client. This can result in serious commercial battles between Client and Contractor and/or Vendor during the HAZOP.

Typically, you may experience customers and contractors in a HAZOP where the Client has recognised deficiencies in the design at Design Review but kept quiet because if formally recorded at the Design Review, the Client has to pay. If recognised at the HAZOP, the Contractor has to pay, so there is an incentive for the Client to behave like this; there may be other contractual pressures at large as well.

It's easy enough to recognise this happening and 'nip it in the bud' if you are alert to it. We always brief our teams at the outset, including the comment that we will not let them 'work back' from the action, and that we have to work forward from the deviation. If the issue arises moving forward from the deviation, all well and good. If not then the record should clarify the derivation of the action.

Another common issue is the whether, and how to HAZOP the numerous vendor packages that are included in most projects. The Client and Contractor will have agreed numerous standards for the design, but, inevitably, these will not always be the same standards that all the vendors have used. Thus, during good HAZOPs there have been useful discussions of which actions should also be applied to similar packages previously supplied by the same vendor to the Client on previous projects. This would ensure that operators had consistent equipment with the latest safeguards.

Poor HAZOPs result in the vendor eventually responding to most recommendations for action with the statement, "Yes, at additional cost we can provide this feature as a one-off. It will make this package different from all those we have previously installed on your sites and, because of the non-standard feature, we would no longer be able to guarantee the reliability." The worst example of this was two days spent HAZOPing a standard diesel engine.

Usually, this conflict arises because the HAZOP is being done after the design has been 'frozen.' These issues may be resolved by taking them out of the HAZOP as actions, but are better tackled during the HAZOP preparation.

OPERABILITY ISSUES

We do insist that the HAZOP study team includes operators (boiler suits not three piece suits). During a single company series of courses the company in question were horrified at the thought of inviting operators to meetings; only senior management attend meetings! It is a shame we still have companies with that sort of attitude and maybe that accounts for some of their difficulties with safety.

Team members quoted in Ref. 3 (Rohm & Haas) provide anecdotal evidence for the perceived benefits of HAZOP:

- "My product is extremely valuable. While it seems like we are spending a lot of time in the HAZOP study, all it has to do is prevent one bad batch and it will pay for itself." – Technical manager of a speciality chemicals plant
- "Just writing down the HAZOP intentions showed several inconsistencies in how different shifts were operating the process." – Operator in a continuous process
- "Great way to learn the process." – Trainee operator who sat in on several HAZOP sessions. (Note: a nearly identical comment was made by a new production manager who had little previous experience with the plant, in a different HAZOP)
- "I've learned more about how this process works in the last week than I did in twenty years of repairing pumps and fixing equipment." – Maintenance foreman in a batch polymer plant.

We have had similar comments of study team members who welcomed the way the HAZOP study enhanced their understanding of both the process and how it should be operated.

A process is rarely so novel that no-one has operational experience but sometimes

- Operations staff are not released to attend;
- A junior replacement with limited experience is sent as a substitute; or
- The whole focus is on hazards so that operability issues are not taken seriously (this is a common problem with HAZOP – see Ref. 3).

Operational experience is essential for a good HAZOP study both for safety and operability issues.

SOFTWARE PACKAGES FOR RECORDING

Many of our customers use software packages to record the meeting. These are particularly useful for generating "Action sheets" after the meeting. However, even an experienced scribe may find that the package

- makes finding earlier entries a slow process;
- does not have fields for assumptions or other notes that need to be recorded.

Software packages are valuable as long as the tail doesn't wag the dog. The point of the record is essentially to produce a clear auditable trail from the recognised

design or other defect to the action. That can be done with pencil and paper (indeed that's how it was done all through the 80s and 90s). The modern-day paper and pencil is a word processing package or spreadsheet and that suits us. There are a number of software packages and, as different companies use their own preferred package, there is often a learning curve for each study.

A spreadsheet works fine and a separate document can be used for other notes. Whatever software is used for recording, the ability to display the record to all the participants is essential. Thankfully modern data projectors are cheap and reliable and we regard them as essential for a HAZOP study.

PREPARATION WELL IN ADVANCE

HAZOP procedures should include different guide-words for:

- different types of process (for example continuous versus batch)
- different uses of HAZOP (for a new project, a modification, or a review of an existing process following several years of experience.)

Thus, a good HAZOP procedure may have several lists of guide-words, but none of them will be long checklists. Instead, the checklists will be part of the hazard identification procedure.

The company policies should include

- training all team members in the methodology of HAZOP
- selecting an appropriate team with representation from all relevant disciplines
- a staffing policy for operations that facilitates the releasing of experienced operators for several weeks to attend hazard identification and HAZOP meetings.
- using an independent Chairman.

The project plan should recognize that key project staff will need several weeks to attend hazard identification and HAZOP meetings.

PREPARATION JUST BEFORE THE HAZOP

In order to prepare fully for the HAZOP, the following questions should be asked:

- Is at least one experienced operator (and a back-up) available for the whole of the HAZOP?
- Has the project reached the appropriate stage for HAZOP?
- Has the hazard identification report and all other documentation been adequately reviewed and are updated copies available for the HAZOP meeting?
- Do the proposed team members understand the HAZOP procedure?

CONCLUSION

The benefits of identifying hazards and operability problems early in the design are self-evident. With a good team and the right preparation, HAZOP is an excellent and cost effective technique.

Companies should revisit their HAZOP procedures to remove the inappropriate checklists, to require attendance of operational personnel and to mandate the completion of a hazard identification study before HAZOP.

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