Generally Accepted HAZOP Rules in the Process Industry

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Summary

Hazard and Operability (HAZOP) study is a widely accepted hazard identification technique used in the process industry. Though the methodology of carrying out HAZOP study is quite simple but the author has personally observed that people have quite a different understanding of the technique when it comes to putting the methodology into practice in the live HAZOP workshops. This was observed by the author while facilitating more than 150 HAZOP studies worldwide for the process industry.

The issues discussed in this paper are based on the author’s own experience and are not intended to be exhaustive.

Keywords: HAZOP, Hazard Identification

Introduction

The methodology and rules of the HAZOP study though seem very simple but still there are wide differences among HAZOP team members in live workshops when it comes to identifying causes, consequences and safeguards. This article focuses on those differences and propose solutions so that the risks to the process can be minimized.

Background

A series of industrial accidents around the world in 60s and 70s led to convince the process industry that hazards must be better analyzed and controlled to avoid major accidents. The HAZOP technique used today was developed in Imperial Chemical Industries (ICI) in UK more than four decades ago. It has been used as a primary tool for identifying hazards in the process design after engineering line diagrams are in final shape. Even though the technique is widely used all around the world for identifying hazards in the newly developed process design for major projects but the question is how successful the technique is in identifying the hazards and preventing incidents?

It raises a further question whether the HAZOP study that is in practice today conforms to the original ICI Hazard Study methodology or if we have lost certain important aspects?

HAZOP Methodology

The Hazard and Operability Study or HAZOP is a detailed, systematic study of the process design and outline operating and maintenance procedures to identify the consequences of deviation from design intent. It may also be applied to other activities or procedures to analyze deviations from design.

ICI Hazard Studies

ICI developed the HAZOP technique in 1960s and then later expanded it into six stages. The brief description of study at each stage is given below:

**HAZOP Study at Concept Stage (HS 1)**

To review in a formal manner the information relevant to Safety, Health and Environmental Protection of the proposed project;

- Review previous incidents on similar plant
- Collect information on hazards of chemicals involved
- Review application of inherent HSE
- Review 'Environmental' and 'Occupational Health' Statements
- Consider interaction of project or plant with site activities
- Review application of national legislation
- Set criteria for Safety, Health and Environmental aspects

**HAZOP Study at FEED Stage (HS 2)**

When the Process Flow Diagrams and basic information are available then with the help of Guide Diagrams;

- Identify significant hazards in the process
- Review possible mechanisms for the loss of containment
- Eliminate hazards by changing the design where possible
- Specify protective measures to meet the relevant criteria

**HAZOP Study at Design Stage (HS 3)**

HAZOP Study 3 is best carried out when firm Engineering Line Diagrams with outline operating, commissioning, maintenance and test procedures are available. The main objective is to review the final design and/or method with the help of guidewords e.g. No Flow, More Flow, Reverse Flow in order to:

- Identify any hazards which could arise due to deviations from design intent
- Define the consequences of such hazards
- Initiate appropriate actions
- Examine control, operability (e.g. S/U, S/D) protective systems and maintenance (e.g. testing, repair) problems with due regard to transients, exposure to chemicals, ergonomics etc.

ICI’s Hazard Study at Stage 3 known as HAZOP, is still widely used today but with significantly reduced scope and depth.

**Hazard Study at end of Construction Stage (HS 4)**

This review is performed at the end of the construction stage. The hardware is checked to ensure it has been built as intended and that there are no violations of the designer's intent. It also confirms that the actions from the detailed design hazard studies 1, 2 and 3 are incorporated, and operating and emergency procedures are checked.

**Hazard Study at Pre-commissioning (HS 5)**

This stage of hazard study examines the preparedness of the operations group for start-up and typically covers training, the final operating procedures, preparation procedures and readiness for start-up including function testing, cleanliness and purging. Confirmation of compliance with company and legislative standards is also done at this stage.

**Hazard Study at Early Operations Phase (HS 6)**

This study is carried out a few months into the production phase and confirms that all outstanding issues from the previous five studies are complete.

The hazard study technique developed by ICI was very comprehensive and applied at different stages of the project life cycle to identify the hazards before the plant was commissioned and started-up. The reports produced for each stage were very descriptive and in depth as compared to checklist and guideword approach which is practiced widely in the industry today.

There is a need to revisit the original 6-stage hazard study methodology developed by ICI more than four decades ago and to ensure that nothing important is being missed out in the way hazard studies are carried out at the present day.

**Step-by-Step Procedure of a HAZOP Study**

When the process design is almost final and engineering line diagrams are ready then a formal HAZOP review can be planned. The step by step procedure is discussed below.

- Select a Section (often referred to as a Node) on an engineering line diagram
- Engineer familiar with section describes its purpose and operation - to familiarize all HAZOP Team and form basis for discussion
- Apply a Guide Word (e.g. No Flow, High Flow, Reverse Flow, High Pressure, Low Temperature etc.) to the node
- Identify the Causes relevant to the Guide Word - must occur within the current Section
- Identify the Consequences - ultimate consequences that may occur across the facility, excluding current safeguards
- Identify existing monitoring devices and/or safeguards

- Decide if current safeguards are sufficient given ultimate consequence - if not identify any Actions to eliminate or mitigate the problems.

**HAZOP rules which are mostly challenged**

The HAZOP rules which are mostly challenged in workshops are discussed below.

**Human Error as a Cause?**

Many team members will instantly object when human error is recorded as a cause in a HAZOP workshop. Their point of view is that operators are highly trained personnel and they will not inadvertently open or close a valve.

**Comment:** It is true that operating personnel are trained and they are not expected to make errors but stress, upset conditions at plant, start-up mode or equipment where frequent change-overs are required can lead to operator making mistake. So, generally the human error as a cause is accepted and used in HAZOP studies.

**Operating Procedure as a Safeguard?**

Most team members agree when operating procedure is taken as a safeguard.

**Comment:** Operating procedure is a first safeguard that comes to mind of most team members when they are struggling to identify safeguards for an accident scenario. I personally resist accepting it as a safeguard and force the team members to do more thinking and propose automatic safeguard rather than a simple operating procedure.

**Double jeopardy**

Double jeopardy is a situation where two independent events occur at the same time. For example, operator closed a valve on a vessel liquid outlet line and a high level alarm on the same vessel failed at the same time leading to overflow.

**Comment:** Generally, double jeopardy situations are ignored in a HAZOP study, however, there are situations where it might be worthwhile to analyze them further. For example, if it is known that a certain product header will be offline periodically and maintenance crew will be required to place or remove blind plates; then in case of inadvertent opening of a valve from the pressurized system to isolated header; material can flow from the pressurized system to the production header where maintenance personnel might be busy installing or removing the blind plates. It can lead to an accident depending upon the material characteristics.
and operating conditions. So, it is advisable to consider double jeopardy events on case to case basis rather than ignore them altogether.

Non-return valve as a Safeguard

Most team members are surprised when I tell them that we are not going to take check valve or non-return valve as a safeguard for reverse flow especially if the reverse flow can cause over-pressurization and rupture due to pressure rating change.

Comment: A check valve is not a tight shut-off device and there can be a certain leakage through it when it is in closed position especially if it is not inspected and maintained on periodic basis. Sometimes, it is recommended that two dissimilar check valves are installed in series to minimize the reverse flow but only in situations where reverse flow can cause contamination issues rather than over-pressurization and integrity threat. If the purpose of the check valve is to protect the low pressure rated system from the high pressure rated system then check valves may not be very helpful. The preferred solution for such situations is to install an automatic shutdown valve on the line which should close on detection of reverse flow or high pressure at the low pressure rated system. Some designers measure differential pressure across the control valve assembly on the line to detect reverse flow and close automatic shutdown valve to protect low pressure rated system.

Passing of Pressure Safety Valve as a Cause?

Many team members are surprised when I tell them we are not going to take passing of a PSV as a cause for a HAZOP scenario.

Comment: It is true that a PSV can pass and there could be a leakage through it causing a reduced flow through the line. However, there are certain safeguards which are considered as our last layer of defense before an accident happens. These are pressure safety valves, blowdown valves, safety instrumented system and a few more. Generally, in a HAZOP study we do not fail our last layer of defense to build a scenario. Therefore, failed condition of pressure safety valve, blowdown valve and safety instrumented system are generally not taken as a cause for building HAZOP scenarios.

Control Loop failure

The failure of a control loop is a valid cause for a HAZOP scenario.

Comment: The control loops are usually connected with plant’s Distributed Control System (DCS). They normally control level, flow, pressure, temperature etc. In its simplest form, they consist of an initiator (e.g. transmitter, analyzer), a logic solver (e.g. PLC) and a final control element (e.g. control valve, trip relay). There could be multiple initiators or final control elements depending upon the design. Failure of a control loop is a valid HAZOP cause but there is a confusion about how it failed, for example, partially or completely. Some team members argue that we should not take failure of both transmitter and control valve at the same time. It’s a double jeopardy. To be on a safe side, when control loop failure is taken as a cause in a HAZOP study it is taken as a complete failure of the loop and we assume that the loop is dead and none of its components is still live or operational. It is because we are not sure where the random failure could develop and lead to control loop failure. It can develop in a transmitter, in a transmission cable from transmitter to PLC, input/output cards, power supply to PLC, PLC itself, software bug, solenoid valve, actuator or valve. Therefore, generally, a complete failure of control loop is considered as a cause in a HAZOP scenario rather than only a transmitter or a control valve.

Double block & bleed for positive isolation?

Can a double block and bleed valve arrangement be considered adequate for positive isolation of an equipment handling hazardous or flammable material?

Comment: It is true that double block and bleed arrangement on piping system can isolate an equipment but what if the bleed valve is plugged? Double block and bleed arrangement on inlet and outlet lines of equipment handling hazardous or flammable material are not considered safe enough and the preferred and safer solution for isolation of equipment is to install spectacle blinds on all inlet and outlet lines except on those line which are open to atmosphere.

Process Design as a Safeguard?

Sometimes there is an argument in a HAZOP study whether we should consider process design feature as a safeguard.

Comment: Process design can be taken as a safeguard in certain situations. Let’s take an example; say there is a process vessel and if it overflowed then the liquid can enter into its vapour line which is connected with compressor inlet. The risk is liquid entering into the compressor and damaging it. However, there is a knock-out drum in between the process vessel and the compressor with the high-level alarm and high-high level trip which will shutdown the compressor in case level increased in the knock-out drum. So, can we take knockout drum as a design safeguard in this case?

Before we can answer that question, we should look at few other things e.g. what will be the quantity of liquid which will overflow from the process vessel and what is the capacity of the knockout drum. Say, the if overflowed quantity is massive and the capacity of the knockout drum
is very small in comparison to that then it would just take a few seconds before the knockout drum will be overfilled and the response time of level alarm and high-high level trip may not warrant safe shutdown of the compressor. So, if that is the case then we should not take credit of the knockout drum and its instrumented controls.

**Maintenance errors as a Cause?**

 Shall we consider maintenance error as a cause in a HAZOP study?

*Comment:* It is known in the process industry that maintenance errors have led to many accidents. A maintenance error could be installation of a check valve in the wrong direction or blind plates or orifice plates which were removed to carry out the maintenance were not re-installed after the maintenance or a locked-open or locked-close valve was not re-installed to its original position after the maintenance.

Any one of the errors mentioned above could lead to a disastrous consequence. Unfortunately, the HAZOP studies do not take into consideration maintenance error as valid HAZOP cause. Can it be helpful in minimizing the risk if we do consider maintenance error as a cause? Well let’s look at an example of restriction orifice (RO) plate. The restriction plates are used to limit the flow in the lines. If the maintenance crew made an error and did not re-install the RO after their maintenance work then flow control from the line has gone and it can lead to a hazardous situation. If this scenario is discussed in a HAZOP study then a possible recommendation could be tack welding of restriction orifice place with a flange so that RO is not misplaced during the dismantling and fixing activity.

**Alarms as a Safeguard?**

 Can we take alarm as a safeguard?

*Comment:* When a process deviation occurs then process control is the first layer which comes into action and try to control the process variable e.g. pressure, temperature, level or flow within the defined limits. However, the process control may not work on all occasions and the process variable can go out of the limits. The second layer of protection is generally the alarm which will get the operator’s attention for manual action so that process variable can be controlled with the limits.

Before taking the credit of an alarm in a HAZOP study several factors should be considered. How much time is available for the operator to take action and bring the process variable within the limits before the next layer of protection kicks in or a dangerous situation arises which can lead to an accident. So, the time available to the operator for completion of his action is an important consideration before taking credit for an alarm. The other factors are requirement of written instructions for operator action, training of the operators and registration of the alarms for periodic maintenance before alarm credit can be claimed.

There is a tendency to propose new alarms in a HAZOP study by the team. The flood of alarms during emergency is not helpful for the operator to quickly diagnose the situation and take appropriate action.

**Manual fire-fighting system as a Safeguard?**

 Shall we consider manual fire-fighting as a safeguard in a HAZOP study?

*Comment:* In a HAZOP study, we generally consider major hazards like for example loss of containment of flammable material causing fire and explosion etc. We do not generally consider small fire events. Depending upon the nature and magnitude of the fire the team can decide whether to take the credit for manual fire-fighting or not. It has been observed in the industry that small fires are difficult to detect due to a number of factors e.g. detectors coverage and wind velocity at the time of release. The manual fire-fighting can limit the extent of damage but how much? It is difficult to predict. The HAZOP team should, therefore, be very careful before deciding to take manual fire-fighting as a safeguard.

**Control valve failure as a Cause?**

 Should we consider control valve failure as a cause?

*Comment:* Yes, a control valve can fail in a number of different ways. It can be stuck open, stuck close, fail open, fail close etc. There is one confusion about its fail action. In Piping & Instrument Diagrams (P&IDs), sometimes fail action of a control valve is shown by a symbol FO (Fail Open) or FC (Fail Close). Many team members debate that if fail action of a control valve is shown as ‘Fail Open’ then only ‘Fail Open’ scenario should be discussed in the HAZOP and not the ‘Fail Close’ scenario. The answer to that is that failure of motive force (e.g. instrument air or hydraulic oil) to the actuator of a control valve will drive the valve to the direction shown on the P&IDs but if there is a control failure then the control valve can go in either direction depending upon the random failure in the control system. Therefore, for the HAZOP purpose both full open and full close positions of all the control valves should be considered.

**Codes & Standards related Recommendation**

 Can we bind the design team to follow certain codes and standards in a HAZOP recommendation?

*Comment:* We believe that the design team is competent and they are fully aware of the codes and standards they have to follow in the light of project scope of work and project specifications. We generally avoid binding the design team to codes and standards in the HAZOP recommendations.
Discussing Equipment & Instrument types in the HAZOP?

Can we challenge the equipment and instrument types being selected by the designer and recommend our preferred design option in a HAZOP study?

Comment: We certainly talk about equipment and instrument types and team members share their experience on advantages and disadvantages of a particular design. Since, these are open ended questions and there could be many different types and design options available with their own advantages and disadvantages, therefore, it is usually not possible to arrive at the best design option during the HAZOP workshop because of limited time available. Therefore, all design related issues are generally recorded in a separate list which is called Parking Lot items for later discussion between the client and the design contractor.

Design related Causes

Can we list design related causes in a HAZOP study?

Comment: The design related causes e.g. 3-inch drain line, 6-inch vent line or 3-metre Tank Diameter are generally not considered as valid causes in a HAZOP study. We believe the design contractor is competent and conversant with the design calculations. So, the HAZOP team generally do not involve itself in design calculations during the HAZOP study.

There is another type of HAZOP study which is known as Knowledge Based HAZOP. In that type of study, the team goes through a design checklist for different items e.g. piping, compressor, heat exchanger etc. and they ensure the design conforms to company’s design standards by actually verifying the design conditions, pressure relief valve sizing etc.

Assigning HAZOP recommendation to a person or party not present in the HAZOP meeting

Can we assign responsibility for an action to a person or party not present in the HAZOP meeting?

Comment: We need consensus among all the team members before a recommendation can be formally recorded. It is not a good idea to assign responsibility to a person or party not present in the meeting.

Amending HAZOP worksheets post Workshop

Sometimes, the comments are received from the client, vendor or contractor after the completion of the HAZOP meeting requesting to amend, delete or add recommendations. Is it allowed?

Comment: HAZOP is a team exercise and all recommendations recorded should be based on consensus of the team. After the completion of HAZOP meeting only typographical errors or equipment names/tag numbers can be corrected but amendment, deletion or addition of recommendations is not allowed. If it is necessary to clarify something then the response can be written in the HAZOP Action Closeout sheet later on.

Instrumentation to be used for performance monitoring

Can we recommend instrumentation to be used for performance monitoring of the plant in a HAZOP study?

Comment: The main objective of the HAZOP study is to review the given design and to identify hazards and review existing safeguards. If the safeguards are not adequate then additional safeguards in the form of recommendations can be listed on HAZOP worksheets. The focus is on hazard and operability issues and not on performance monitoring. Therefore, the requirement of instrumentation for performance monitoring can be captured in Parking Lot item list.

Standby Equipment as a safeguard

Can we consider standby equipment as a safeguard?

Comment: Consider a situation in which there are two process pumps; one operating and the other standby. Each pump is designed to handle the 100% plant capacity requirement. What if the operating pump fails and the standby pump comes on line automatically and prevents production loss? Can we take standby pump as a safeguard for the failing pump?

Let’s first look what is a safeguard? Well, a safeguard can be defined as an engineering or procedural barrier which is capable of preventing a scenario from proceeding to its undesired consequence.

There are two types of safeguards; preventive and mitigative. The preventive safeguards are designed to avoid the accident and mitigative safeguards are designed to reduce the consequence of the accident. What can be done to ensure that the pump does not fail? For example, if seal failure is a frequent problem then the seal type can be investigated, should there be single or double mechanical seal, what about material of construction? What about type of the pump? Should it be Centrifugal, reciprocating or other type? Is NPSH available more than required? Should we have alternate electrical power supply so that pump does not fail because of power outage. These are all preventive measures which can ensure availability of the pump. But if for any reason the pump fails and if the standby pump is not available then there could be a production loss. Therefore, bringing the standby pump online automatically or manually within a short time can prevent production loss and therefore the standby pump can be considered as a mitigative safeguard.

The HAZOP worksheet can be designed to have a separate column for listing preventive safeguards and a separate
column for listing mitigative safeguards. It is prudent to spend more resources on designing preventive safeguards than on mitigative safeguards.

Power outage
Power outage in HAZOP study is node specific or plant wide?

Comment: The power failure is studied under each node and generally it is considered as node specific. What if the power supply fails to the equipment under review? What can go wrong? What are the safeguards? Should we recommend alternate power supply or power from the emergency diesel generator?

Simultaneous operation of more than required pumps/compressors
Shall we consider simultaneous operation of more than required pumps, compressors or other equipment in a HAZOP study?

Comment: Due to human error more than required pumps or compressors can be operated simultaneously. Depending upon the line sizing and backpressure from the system the discharge pressure may increase. If it leads to undesirable consequence than appropriate controls can be designed and implemented to prevent the simultaneous operation of more than required number of pumps or compressors. Generally, simultaneous operation of more than required is considered a valid cause in a HAZOP study for analysis.

Fire Water System HAZOP
Should we HAZOP Fire Water System in the same way as we do HAZOP for Process Units?

Comment: The design of fire water system is generally based on NFPA guidelines and other standards. The HAZOP team might not be knowledgeable enough to properly review the design in line with NFPA guidelines and other international standards.

The design philosophy of fire water system is different than process plant. For example, a pump in a process plant may have low flow protection or low suction pressure protection to protect the pump if it is running below the minimum flow limit and to avoid starvation, cavitation and mechanical damage. However, in case of a fire water pump such protections are not provided because fighting fire at the plant is much more important than saving the fire water pump. Therefore, the HAZOP team should be very careful while recommending anything which can go against the NFPA guidelines or other international standards.

Risk Ranking
Should we do risk ranking in the HAZOP meeting so that we can prioritize the implementation of the recommendations?

Comment: Some companies mandate risk ranking in HAZOP studies so that they can prioritize the implementation of the recommendations. Generally, in many companies risk ranking is done twice. In the first stage, risk ranking is done without taking into account the existing safeguards and in the second stage, the risk ranking is carried out while taking into account the existing safeguards.

For risk ranking, the frequency of the incident and magnitude of the consequence are required.

Normally, there is no one among the team members who has seen a plant where there was no safeguard and could tell the frequency of the incidents. So, coming up with a frequency without safeguards is a big problem when doing risk ranking. The team experience is based on plants with safeguards into place.

There are companies who allow to do risk ranking only once and with existing safeguards taken into consideration. It seems more helpful as the risk ranking can guide whether additional safeguards are required or not. For example, if the risk ranking with existing safeguards gives a low risk than it is clear that additional safeguards are not required.

Non-P&ID related Safety Issues
Some HAZOP team members ask that can they discuss issues which are not related to Piping & Instrumentation Drawings in the HAZOP meeting?

Comment: The main focus of the HAZOP is on Piping & Instrument Diagrams (P&IDs) but what about other safety issues related to e.g. maintenance, layout, control room, sub-stations, storage areas? The design contractors generally object to discussions which are outside the domain of process design. The difficulty faced by the design contactor is on the close out of such actions because the recommendations might be applicable during construction, pre-commissioning, commissioning or operational phase. Therefore, the status of all such recommendations will remain open until the relevant stage of the project comes and that time the design contractor might not be around.

One approach generally followed in the industry is to record all such actions in the Parking Lot Item list. It is the responsibility of the client to pick up all such action items from the Parking Lot Item list and add in the company’s Risk Register.

High point vents and low point drains
Can we discuss requirements of high point vent and low point drain in a HAZOP meeting?

Comment: Generally, the best time to discuss about high point vents and low point drains is when isometric drawings are ready or 3D model is available. Therefore, this can be put on hold during the HAZOP meeting.
P&IDs Correction

Shall we discuss and record all corrections required on P&IDs?

Comment: Recording of the P&IDs corrections on the main HAZOP worksheet can be time consuming especially when the process design is still under development. Therefore, it is recommended that process design engineer take a clean copy of the P&IDs and mark in red colour all agreed changes in the HAZOP meeting. A copy of the P&IDs with corrections should be given to team leader at the end of the meeting to be attached with the main HAZOP report for record purpose.

Safety Issue falling outside the Design Contractor’s Scope of Work

Sometimes a situation comes in the HAZOP meeting when the identified issue and its solution lie outside the scope of work of the contractor; so how should the situation be handled?

Comment: It is especially true for modification or revamp projects when the contractor has a limited scope of work but during the HAZOP meeting a lot of safety issues related to the existing plant are raised. The contractor’s point of view is that he is responsible for the new scope and not the safety issues being identified in the existing plant.

The contractor’s concern is that if the recommendation is recorded in the HAZOP worksheet with the responsibility on the Company then the action would remain open in the contractor’s status document until the time when the action is closed out by the Company.

The solution to that problem is again recording of all such recommendations in the Parking Lot Item list for the future action by the Company.

HAZOP Meeting Administration

Preparation for the first session

The team leader should thoroughly review the project documents before the HAZOP meeting. It should include Project Design Basis, Process Description, Process Flow Diagrams, Plot Plans, Engineering line drawings or P&IDs, Cause & Effect Diagrams, Area Classification drawings, Material Safety Data Sheets, Piping Specifications and Philosophy documents (e.g. Operating & Control, Isolation, Active & Passive Fire Protection, Maintenance etc.).

For a greenfield project, the team leader can mark-up the nodes based on his experience but for the brownfield projects, it is recommended that the nodes are marked-up in consultation with the process design engineer assigned on the project.

It is a good idea to send the electronic copies of the marked-up nodes to the HAZOP team members before the start of the HAZOP meeting.

The team leader should also prepare the following short presentations for the opening session;

- Safety moment
- Meeting Agenda
- A short presentation on HAZOP methodology

The design contractor should be asked to prepare a small presentation covering the salient features of the project. The short presentation can be given by the Project Manager of the design team.

Next, the process design engineer from the design contractor should give a brief overview of the process design to be studied with the help of process flow diagrams.

The first HAZOP session is always a difficult one as new members from different departments and companies come together and they take some time to form a team and work together. Therefore, the team leader should try to be flexible and keep his calm during the first session and encourage the participants to speak and ask questions.

The team leader should present the P&IDs with marked-up nodes to the team preferably on process flow diagrams to get their buy-in. If the team feels that the nodes are very large then the team leader should consider splitting them into smaller nodes or vice versa.

The team leader should send a list of items needed for the HAZOP meeting to the organizer in advance. It can include requirement for the following;

- Overhead projector
- Printout of marked-up P&IDs in A3 size, HAZOP terms of reference, Cause & Effect diagrams, Plot plan etc.
- Tea/coffee arrangement

Sometimes, it is observed that in the first session there are issues related to set-up of the projector, electrical power connection or network computer accessibility. It is, therefore, recommended that the organizers and team leader meet before the meeting preferably one day in advance or at least one hour before the first session of the HAZOP meeting to sort out such issues.

The team members sometimes arrive late on the first day because of difficulty in finding the address or place for parking. It is recommended that a location map is sent to all participants with the information on parking areas well before the meeting.

Role of team leader

The role of a team leader is to follow a structured approach of the HAZOP methodology and prompt discussion among the team members with the help of guidewords e.g. can there be low flow in this line? What will be the cause?
The team leader should not involve himself in the technical discussions and become a party. He should try to remain neutral and endeavor to bring the consensus among the team members if there are different point of views on the matter under discussion.

It is the team leader’s job to give dictation to the scribe and discourage team members who are trying to dictate directly to the scribe. The scribe should be briefed on this rule before the start of the HAZOP meeting.

The other important task of the team leader is to control the team as they start cross-talk and the session becomes noisy. A simple tap on the table can do the trick but sometimes more commanding approach is needed.

There was a team leader who used cards to control the team. If he showed a yellow card it was a simple warning to an individual and if he showed the red one the member was asked to leave the meeting room for 10 to 15 minutes. The technique worked well for him.

The time management is another key task of the team leader. The team leader should always try to start and break the meeting as per the agreed agenda.

The team leader should try to remain, preferably, on the move in the meeting room most of the meeting time, if possible, rather than keep sitting in one corner. A U-shaped sitting arrangement is good for HAZOP meetings.

If the meeting is stuck because the problem is not clear in the team members mind then instead of talking in air for hours, the team leader should invite team member to come in the front and make a simple sketch so that everyone can understand the problem under discussion.

**Team composition**

The team composition for a HAZOP study should include Process Design Engineer, Project Engineer, Operations Engineer, Maintenance Engineer, Instrument Engineer & Safety Engineer on permanent basis and Machinery Specialist, Civil/Structural Engineers and Specialist Engineers (piping, electrical, corrosion, etc.) should be on available on call basis.

**Team Size**

The recommended HAZOP team size is 5 to 8 but this is rarely seen in most workshops. The team size that is witnessed on most big projects is between 20 to 30. The first session starts with the maximum participation. It’s a room full of people eager to participate but as the time progresses they lose interest and the number of team members dwindle down.

No matter how big the size of the team; there are only a few members who actively participate in the HAZOP meetings. Sometimes, companies send their young technical staff for the purpose of training to HAZOP meetings. This should not be encouraged by the team leader. In fact, anyone who is not participating in the HAZOP meeting should not be there.

**HAZOP Meeting Show Stoppers**

**Defining the Nodes**

A NODE is the selection of one or more items of equipment as a focal point of study. A node could be as small as a line, a pump, a vessel or a heat exchanger or as large as an entire process plant.

In the early method of assigning node, each of the lines entering and leaving the vessel was treated as a separate node. The vessel itself was not treated as a separate node because it was considered to be adequately addressed by applying deviations to the entry and exit lines.

The method of defining nodes at present day is to define compound nodes. For example, *Feed piping from a feed vessel, a centrifugal pump, a control valve set and a heat exchanger supplying a reactor vessel* would be considered as a single node.

Greater the familiarity and confidence are with the HAZOP methodology; the node size can be increased to include more equipment. Just as small node sizes are inefficient, very large node sizes may also be inefficient. In general, the optimum node size can include multiple items of equipment, provided, that they share a common function. There is usually a better overview of systems with large nodes. Important synergies and interactions are maintained, while repetition is minimized.

The way the nodes are defined on the P&IDs can determine the time required to complete the HAZOP study. Defining the smaller nodes would increase the total number of nodes and hence it would require more time and vice versa.

The method most commonly used at present day is to include the utility connections within the main node of an equipment. For example, if there is a column with nitrogen connection at the top and reboiler at the bottom with the hot oil supply. Then the node mark-up can be as given below.

1. Node 1A - Column C-101 (Node color: Blue)
2. Node 1B – Nitrogen supply (Node color: Orange)
3. Node 1C – Reboiler with Hotel Oil supply (Node color: Green)

The team can see on the P&ID with the help of different colors that node 1 is further divided into three separate sections with the different labelling (Node 1A, Node 1B and Node 1C), however, it is not difficult to study all the three sections under one main node. This approach minimizes repetitions and make available valuable time for more critical examination of the process design and identification of hazards.
Missing Information
A lot of time is wasted in the HAZOP meetings because the required information is not available. The team leader can send a list of information which would be required during the meeting in advance. Information such as design conditions, corrosion allowance, cathodic protection, vessel or tank internal coating should be readily available.

Discussing Design Options in the HAZOP Meeting
The key tasks are hazard identification, evaluation, and control. The HAZOP review team should not attempt to resolve issues unless they are obvious; otherwise the team will get "bogged-down" trying to redesign the facility. Simply list the concern for the follow-up people to resolve.

Generic Hazards
There are certain hazards which are generic in nature, therefore, they should be discussed in a ‘general’ node or only once e.g. corrosion, maintenance issues, requirement for positive isolation on equipment etc.

Describing hazardous situation in vague terms
It has been observed that some team members use a very vague language to describe a situation e.g. if there are many pumps and valves on the P&ID; they will just start by describing the scenario as “...if the pump tripped and the valve is open and the other valve is closed then there will be reverse flow and the vessel will be flooded...” This type of vague description leads to different understanding by different team members and causes a confusion and leads to wastage of time. The team members should be trained in the beginning to be specific in their statements by using tag number, equipment names, stating units with numbers etc.

A white board is a very useful tool and many team leaders invite team member to come and draw the sketch before stating a hazardous situation.

The HAZOP presentation by the team leader in the beginning session should include a bullet point advising team members how to describe a situation for analysis.

The Late Entry
A late entry of a member into a HAZOP meeting, when the team has already completed more than 50% of the study can prove to be disastrous and it should be avoided. The new team member won’t know the background, the discussion which took since the first session, the methodology being used. He may start asking basic questions about the project and HAZOP methodology being used especially if he is not very experienced in HAZOP studies.

The Random Shooter
It is easy for anyone in the team to lose focus on the issue being discussed and stray into some other issue which is not currently being discussed by the team. He may start asking questions from the designer and a cross talk would start disrupting the meeting. It should be avoided and the team leader should take control and stop the meeting within a meeting. The team should be asked to note down anything that comes to their mind for discussion at the appropriate time.

Assigning Responsibility to an Action
The most contentious thing in a HAZOP meeting is when a responsibility for an action is assigned to a contractor which carries a certain cost. It is especially true for large projects where the contractor has signed a lump sum agreement. The contractor would fight to the death to avoid taking on recommendations which he feels are not necessary or they are out of his scope of work. One way to avoid frequent disruptions can be to defer the assignment of responsibility till the end of the workshop.

Full Recording vs Recording by Exception
In some countries there is a law binding HAZOP teams to do full recording of all the deviations whether the consequence of the deviation is a hazardous or non-hazardous. The full recording takes much more time than recording by exception where the team records only those scenarios which are leading to hazardous outcome. This should be agreed before the workshop with the design contractor and company.

Process Units Interface Hazards
It has been observed that for big projects multiple HAZOP teams are sometimes commissioned by the design contractor so that the dedicated teams can work in parallel and complete the study in the shortest possible time. The problem with that approach is sometimes hazards related to the interface of one process unit with the next unit are missed out. Therefore, it is recommended that a separate Interface HAZOP session be arranged at the end of the study in which only interface issues are analyzed. To facilitate the interface HAZOP, it is recommended that all dedicated teams working on different units of the project record safety issues related to the interface and pass on to the interface HAZOP team.

HAZOP of multiple identical trains
It is an accepted practice that if there are multiple identical trains then HAZOP study will cover in detail only one train and the HAZOP report would say that recommendations would be applicable to the other trains. There are two approaches on this which are widely used.

In the first approach, the HAZOP is done for only one train using its own tag numbers and then the report would say that the recommendations are applicable to the other trains.
In the second approach, once the HAZOP is completed for one train then a copy is made and tag numbers are changed for the next train and the HAZOP worksheet is reviewed by the team.

One pitfall in this approach is missing out on hazards when multiple trains are in operation. It is suggested that a separate node is defined which should take into consideration the operation of multiple trains.

It will be a waste of time if the team decided to do HAZOP for all the identical trains one by one.

Different marked-up P&IDs for different operating modes

It has been observed that a lot of time is wasted when P&IDs are not correctly marked-up based on different operating scenarios. It is recommended that for a process where multiple operating modes are possible then P&IDs should be accordingly marked-up and discussed as separate nodes.

The Success of a HAZOP Study

The success of the HAZOP review depends on the combined team experience, the team's persistence, and its ability to conceptualize undefined possibilities. The HAZOP review is a team exercise. As such, the team leader should ensure that the quieter members get their say and that no one is put on the defensive. In the event of conflict, the team leader should consider postponing review of the controversial area, or consider changing team composition. It is important that the team leader be diplomatic.

Quality of the HAZOP Study

The quality of the HAZOP study depends upon number of factors. Some of them are discussed below.

Preparation by the Team Leader

If the team leader is not well prepared, it can slow down the workshop. The team leader should go through all relevant documents of the project including the project design basis, process description, process flow diagrams, P&IDs, Cause & Effect diagrams, philosophy documents and plot plans before the workshop. A meeting with the process design engineer could be useful to quickly understand the project scope.

Participation of the Team Members

It has been observed that there are only a few active members in any HAZOP meeting especially if it is a large group. The other team members act as observers. The team should be selected based on the expertise level as the quality of the HAZOP study directly depends upon the cumulative knowledge of the team when they contribute actively. The HAZOP meetings should not be used for the purpose of training.

Availability of Team Members

If the venue of the HAZOP meeting is at a design contractor’s office then the chances are that the team members of the contractor will sneak out from the meeting room every now and then to take care of their other tasks. It slows down the HAZOP meeting especially if an explanation is required from a discipline expert and he is found missing. The advantage of having a HAZOP meeting at contractor’s office is that any information required by the team is readily available and a discipline expert from the contractor’s team can be called for discussion in a very short time.

The Scribe

The job of a scribe is very important with respect to the quality of the recording and it also affects the meeting duration. The scribe should be familiar with the technical terms which are commonly used in a typical HAZOP meeting. Moreover, he should have good spellings and typing speed. Most importantly, he should only record what the team leader asks him to write rather than follow team members dictations.

I once took an office secretary as a scribe to an important HAZOP meeting as no one else was available. She was good in typing but she was not familiar with the technical terms. At one point, when I asked her to write 'butane’ she wrote ‘beauty’ and everyone in the meeting burst into laughter.

The Rush

The estimation of the time required to complete a HAZOP study for the given scope should be done by the team leader in consultation with the design contractor. As a rough rule, for a typical, oil and gas project no more than 4 to 5 P&IDs should be planned for HAZOP per day.

The rough rule given above takes into account that there will be identical equipment, some P&IDs will be simple and some complex.

It has been observed that no matter how fast the team leader goes there will always be someone from the design contractor’s team asking to speed up.

Recording

In recording, the wordings and details given in the causes, consequences, safeguards and recommendations is very important. There should be no vague statement. For example, if the cause is written as ‘inadvertent closure of a manual valve’ then the reader won’t know which manual valve the team was talking about. Use the tag numbers if assigned to manual valves and if not then simply say upstream of e.g. MOV-1208 or downstream of PCV-1105 so that the reader of the report can identify the manual valve on the piping & instrument diagram.

Similarly, the wording of a recommendation should be self-explanatory and there shouldn’t be a need to refer to the HAZOP worksheet in order to understand it. For example, a
good recommendation can be “Provide a low-pressure alarm on PT-403 located on 20-inch overhead line of Absorber C-101”
Lastly, the recording of the HAZOP proceedings should be done using a software, if possible, to minimize the recording and editing time.

References
3. HAZOP and HAZAN, 3rd edition, T. Kletz, IChemE.