HAZOP

Hazard & Operability Analysis

honour

1. Introduction:

Hazard and Operability Analysis (HAZOP) is a structured and systematic technique, for system examination and risk management, implemented by a distinct team of the engineering and operating intentions of a process to assess the hazard potential of mal-operation or mal-function of individual items of equipment and the consequential effects on the facility as a whole.

In particular, HAZOP is very often used as a technique to fulfill the following objectives:

- Identifying potential hazards in a system. The hazards involved may include both those essentially relevant only to the immediate area of the system and those with a much wider sphere of influence, e.g. some environmental hazards, and

- Identifying potential operability problems with the system, and in particular identifying causes of operational disturbances and production deviations likely to lead to nonconforming products.

HAZOP is considered as a risk assessment tool, and is frequently described as:

- A brainstorming technique
- A qualitative risk assessment tool
- An inductive risk assessment tool, meaning that it is a “bottom-up” risk identification approach, where success relies on the ability of subject matter experts (SMEs) to predict deviations based on past experiences and general subject matter expertise.

HAZOP is based on a theory that assumes risk events are caused by deviations from design or operating intentions. Identification of such deviations is facilitated by using sets of “guide words” as a systematic list of deviation perspectives. This approach is a unique feature of the HAZOP methodology that helps stimulates the imagination of team members when exploring potential deviations.

HAZOP is best suited for assessing and analyzing hazards of such deviations in facilities, equipment, and processes and it is capable of assessing and analyzing systems from multiple points of view such as:

- **Design**

Assessing system design capability to meet user specifications and safety standards identifying weaknesses in systems.

- **Physical and operational environments**

Assessing environment to ensure system is appropriately situated, supported, serviced, contained, etc.

- **Operational and procedural controls**

Assessing engineered controls (ex: automation), sequences of operations, procedural controls (ex: human interactions etc) and assessing different operational modes – start-up, standby, normal operation, steady & unsteady states, normal shutdown, emergency shutdown, etc.

Necessity of HAZOP:

In areas of major risk, a code of practice has usually been built up and accordingly the equipment may be designed safely.
However, relying on codes of practice only ensures that the particular piece of equipment is adequate, while the operation of the process (which is a dynamic running process) as a whole is not perfectly accounted; accordingly it is necessary to make a systematic examination of the system as a whole in order to reveal and detect any inadequacies in design.
This will need to be directed particularly at all the obscure and unexpected happenings which may occur during plant operation and which could give rise to hazards.

An additional issue in the process design field is that there is a tendency to focus attention on these aspects of the design for which individual departments are responsible, for example:-

- Suitability of materials of construction,
- Adequacy of blow down and relief facilities,
- Suitability of proposed instrumentation.

An additional need for HAZOP is due to the fact that economic pressures have led to larger and more complex plants. These contain correspondingly much larger inventories of hazardous materials and their more complicated nature can lead to interaction between the various units making up the whole. Any shutdown necessitated by plant failures will also be much more expensive.

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When is a HAZOP carried out?

The timing of a hazard and operability study is determined by the objectives of a study, and subsequently determines the benefits that may be gained.
The outline concept of a process may be examined to highlight any major omissions or significant features.
As further detailing is carried out, e.g. when the process design is complete, the full study procedure may best be applied. Operating procedures may be examined to ensure that all eventualities have been considered. Modifications including so-called “minor modifications” generally benefit from a rigorous & an accurate study. Often an apparently simple, uncomplicated modification can lead to a greater problem than it was planned to solve.

Therefore a project may be studied several times in its life-time.
Despite these comments there is quite a distinct benefit from carrying out a proper HAZOP Study in terms of the correct timing and to obtain the maximum cost benefit. Therefore, a hazop cannot be carried out before the line diagrams (or process instrumentation diagrams as they are often called) are complete. It should be carried out as soon as possible thereafter.

If an existing plant is being studied the first step is to bring the line diagrams up to date or check that they are up-to-date.
Meetings are usually restricted to 3 hours, twice per day, 2 or 3 or even 4 days per week, to give the team time to attend to their other duties and because the imagination ability feels exhausted after 3 hours at a time.

HOW carry out / perform HAZOPs?

Intention:

An intention is the expected behavior of a process and its associated hardware, under normal and abnormal conditions. It may be defined diagrammatically or descriptively; diagrammatically in terms of flow sheets, P&ID's. etc., or descriptively with operating instructions or design specifications.

A very important assumption is that no hazard can arise from an intention that behaves as expected, i.e. no one deliberately builds in a hazard.
Therefore, a hazard can arise only if there is a deviation from the expected behavior.
Hypothetical deviations are prompted by applying guide words, which will be explained later, to each intention. Consequently the design basis is not explicitly challenged and process alternatives may not be recognized.
For example, it is proposed that excess pressure may exist in a line. Firstly, it must be established if there is a realistic cause of this deviation. If there is, the consequences must be considered. They may be trivial or significant. If significant, they must be evaluated to see if they constitute a hazard. In the example of line over-pressure, the excess may be within the line rating. This consequence is trivial. If the rating is exceeded, however, rupture may result. This is obviously a hazardous occurrence.
The study procedure may be broken into several distinct steps (subsequently detailed). We must define the scope of the study, select a team to carry it out, and make the necessary preparations before the examination itself can be carried out.

A lot of follow up activities will result from that examination. Finally a detailed record of the study is also necessary; but now we will consider the "Application of the Guidewords" to a particular "Section" or "Study Node".

Guide words:

Guide words are simply words used as keys to suggest the various ways in which deviations from an intention can occur.
Firstly, the intention can fail completely and nothing at all happens. This is prompted by **NO** or **NOT**. For example, a "no flow" situation can exist if a pump fails to start.

If there is a quantitative variation, it may be described by **MORE** or **LESS**. This refers to quantities, physical properties and activities. For example, more of a charge of reactant, a high mole ratio in a reactor, less reaction, and so forth.

If the intention is changed, a qualitative deviation results. An additional activity may occur **AS WELL AS** the original intention. If a motor starts-up on auto start, a drop in the power supply may upset other equipment.

The intention may be incompletely achieved, that is to say, only **PART OF** what was originally intended may be completed. A diesel fire-pump may start-up, but fails to reach full speed.

The exact opposite of what was intended may occur, giving the **REVERSE of** the intention. Reverse flow is a common occurrence, very often in spite of the use of check valves. In a reaction kinetics situation, the reverse reaction may occur.

OTHER is a guide word used as a final catch all. It is used to identify something completely different. Following the reaction kinetics thought, a different reaction mechanism may be more important under certain conditions. OTHER is also used to call up requirements for maintenance, start-up, shut-down, catalyst change, etc.

The following some guide words with corresponding function

None	No forward flow when there should be, i.e. no flow or reverse flow.
More of	More of any relevant physical property than there should be, e.g. higher flow rate or quantity, higher pressure, higher temperature, higher viscosity, etc.
Less of	Less of any relevant physical property than there should be, e.g. lower flow rate or quantity, lower pressure, lower temperature, less viscosity, etc.
Part of	Composition of system different from what it should be, i.e. change in ratio of components &/or component missing, etc.
As well as or More than	More components present in the system than it should be, e.g. extra phase present (vapor, solid), impurities (air, water, acids, corrosion products), etc.
Reverse	A parameter occurs in opposite direction to that which it was intended, e.g. reverse flow.
Other than Equipment or word “Other”	Complete substitution e.g. sulphuric acid was added instead of water. What else can happen apart from normal operation, e.g. start up, shutdown, up-rating, low rate running, alternative operation mode, failure of plan services, maintenance, catalyst change, etc.

The GUIDE WORDS are applied to a range of process PARAMETERS. Usually only a limited number of combinations of guidewords and process parameters are used.

The most common process parameters:

- Flow
- Pressure
- Temperature
- Level
- Time
- Composition
- pH value
- Speed
- Frequency
- Viscosity
- Voltage
- Information
- Mixing
- Addition
- Separation
- Reaction

Each guide word is combined with relevant process parameters and applied at each part (study node, process section, or operating step) in the process that is being examined. The following is an example showing deviations created using guide words and process parameters:

Guide word	Parameter	Deviation
No	Flow	No flow
More	Pressure	Higher pressure
As well as	One phase	Two phases

HAZOP terminology:

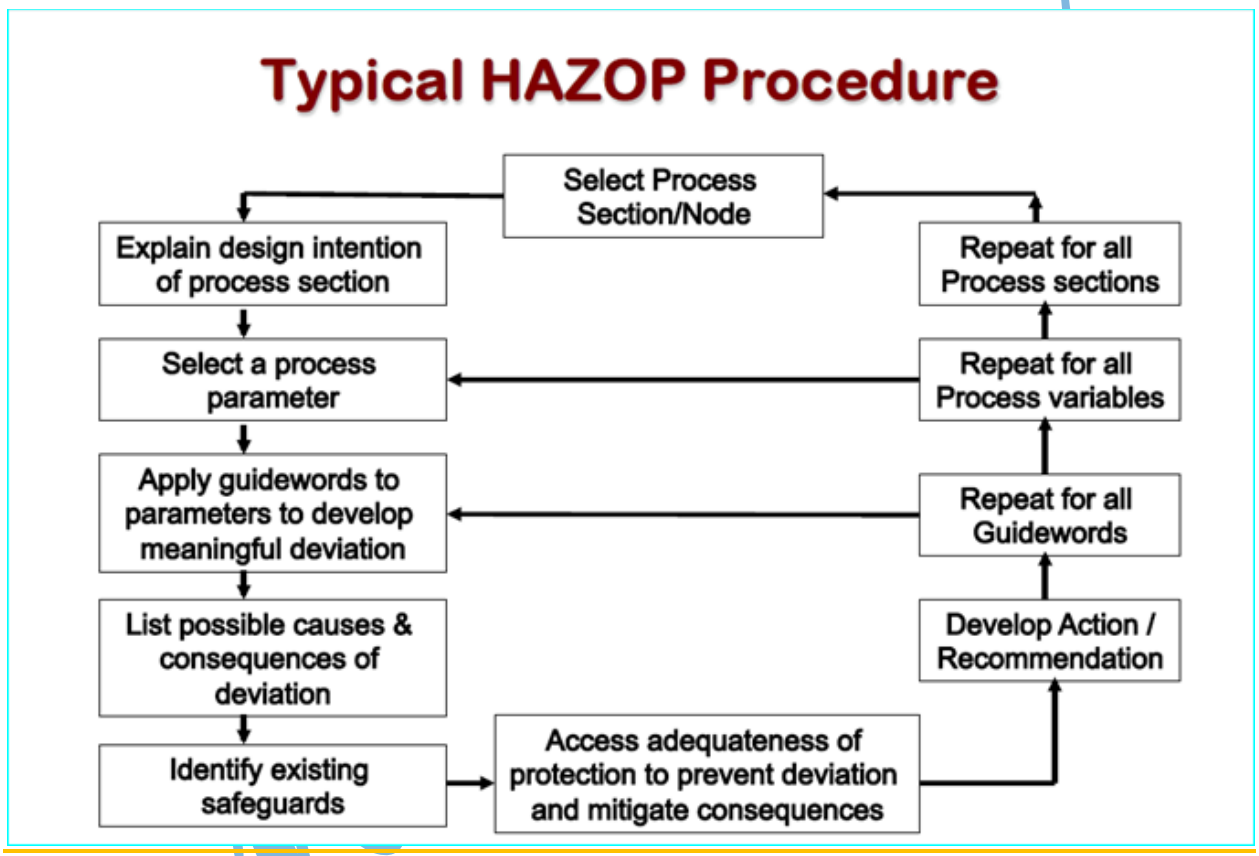
HAZOP terminology are some words frequently used along HAZOP study, such terminology

are defined in the following:

Term	Definition
Process Sections (or Study Nodes)	Sections of equipment with definite boundaries (e.g., a line between two vessels) within which process parameters are investigated for deviations. The locations on P&IDs at which the process parameters are investigated for deviations (e.g. reactor)
Operating Steps	Discrete actions in a batch process or a procedure analyzed by a HAZOP analysis team. May be manual, automatic, or software-implemented actions. The deviations applied to each step are somewhat different than the ones used for a continuous process
Intention	Definition of how the plant is expected to operate in the absence of deviation. Takes a number of forms and can be either descriptive or diagrammatic (e.g., process description, flowsheets, line diagrams, P&IDs)
Guide Words	Simple words that are used to qualify the design intention and to guide and stimulate the brainstorming process for identifying process hazards
Process Parameter	Physical or chemical property associated with the process. Includes general items such as reaction, mixing, concentration, pH, and specific items such as temperature, pressure, phase, and flow
Deviations	Departures from the design intention that are discovered by systematically applying the guide words to process parameters (flow, pressure, etc.) resulting in a list for the team to review (no flow, high pressure, etc.) for each process section. Teams often supplement their list of deviations with ad hoc items
Causes	Reasons why deviations might occur. Once a deviation has been shown to have a credible cause, it can be treated as a meaningful deviation. These causes can be hardware failures, human errors, unanticipated process states (e.g. change of composition), external disruptions (e.g. loss of power), etc.
Consequences	Results of deviations (e.g. release of toxic materials). Normally, the team assumes active protection systems fail to work. Minor consequences, unrelated to the study objective, are not considered
Safeguards	Engineered systems or administrative controls designed to prevent the causes or mitigate the consequences of deviations (e.g. process alarms, interlocks, procedures)
Actions (or Recommendation)	Suggestions for design changes, procedural changes, or areas for further study (e.g. adding a redundant pressure alarm or reversing the sequence of two operating steps)

TYPICAL HAZOP STUDY PROCEDURE:

1. Divide the system into sections (i.e., reactor, storage)
2. Choose a study node (i.e., line, vessel, pump, operating instruction)
3. Describe the design intent
4. Select a process parameter
5. Apply a guide-word
6. Determine cause(s)
7. Evaluate consequences/problems
8. Recommend action: What? When? Who?
9. Record information
10. Repeat procedure (from step 2)



HAZOP STUDY PROCEDURE

1. Introduction to the HAZOP Approach

The Hazard and Operability (HAZOP) Analysis technique is based on the principle that several experts with different backgrounds can interact in a creative, systematic fashion and identify more problems when working together than when working separately and combining their results.

The essential feature of the HAZOP Study approach is to review process drawings and/or procedures in a series of meetings

The primary advantage of the brainstorming associated with HAZOP Study is that it stimulates creativity and generates new ideas. This creativity results from the interaction of a team with diverse backgrounds.
HAZOP Analysis studies can be performed on new projects as well as on existing facilities. For new projects, it is best to conduct a HAZOP Analysis when the process design is fairly firm.

2. Structure of the HAZOP Study Procedure

The following elements of the HAZOP Study should be studied and each element should be reviewed in detail.

a) Company PHA/Safety/PSMP Team Meet
b) Identify the Project for the HAZOP Study
c) Identify the Lead Process Engineer
d) Select the HAZOP Team Leader
e) Define Purpose and Scope of HAZOP
f) Select the Team/Define Roles
g) Pre-HAZOP Meeting
    - Lead Process Engineer and HAZOP Study Leader
    - Identify and Obtain Required Information
    - Plan the Study Sequence
    - Plan the Schedule
h) Inform Everyone Concerned
i) HAZOP Study Review and Documenting the Results (Minutes)
j) Preparing and Submitting the HAZOP Study Report
k) Taking the Actions
l) Close-Out Meeting and Signing Off

3. Company PHA/Safety/PSMP Team Meeting

Each company will have (or should establish), as part of their Process Safety Management Program, an experienced team or responsible person who will decide which safety route should be followed and state which Process Hazard Analysis (PHA's) methods will be used to assess the process hazards.

4. Identify the Project for the HAZOP Study

The decision to HAZOP or not to HAZOP is primarily the responsibility of the Company Safety Team.

5. Identify the Lead Process Engineer

As the project has been assigned for a HAZOP study, the lead Process Engineer must be informed, where he has a very detailed understanding of the process being reviewed. In some cases he may act as a Technical Secretary

6. Select the HAZOP Team Leader

Selecting a HAZOP Study Leader or HAZOP Study Chairperson is a key issue, he is recommended to be an experienced engineer who has been trained in the discipline of conducting HAZOPs and who has a measure of independence

In the case of a new plant he should not have been involved in the design of the plant.

In the case of an existing plant he should not be responsible in any way for the operation or maintenance of the Plant; generally he must control, develop all members of the team and encourage their contributions. Usually an outside Consultant Engineer is brought in for that duty.

7. Define Purpose and Scope of HAZOP

The purpose, objectives, and scope of the study should be made as clear & explicit as possible. The objectives are normally set by the person who is responsible for the plant or project; this person is assisted by the HAZOP study leader. It is important that people work together to provide the proper direction and focus for the study. It is also important to define what specific consequences are to be considered.
For example, a HAZOP study might be conducted to determine where to build a plant to have the minimal impact on public safety. In this case, the HAZOP study should focus on deviations that result in off-site effects.

8. Selecting the HAZOP Team and Defining the Roles

The HAZOP team leader should ensure the availability of an adequately sized and skilled HAZOP team. A HAZOP team, at a minimum, should consist of a leader, a technical secretary, and two other individuals who have an understanding of the design and operation of the subject process. Ideally, the team consists of five to seven members, although a smaller team could be sufficient for a simpler, less hazardous plant. If the team is too large, the group approach will be difficult. On the other hand, if the group is too small, it may lack the breadth of knowledge needed to assure thoroughness.
It is important to have certain people present, others are optional extras. However it is counterproductive to have more than six or seven, people at a review and so the Study Leader must look at the P and ID in advance of the HAZOP, and decide which engineers should be present for the particular study.
The basic minimum HAZOP Study team consists of :

- The Study Leader (Chairman)
- Project Engineer (Secretary)
- Process Engineer (Technical Expert)
- Instrument Engineer
- Operations or Commissioning Engineer

In addition some of the following may be required:

- Design Safety Engineer
- Mechanical Engineer (specialist in rotating equipment)
- Electrical Engineer
- Vessel Engineer
- Client's representative
- Licensor's representative
- Equipment Supplier's representative

9. Pre-HAZOP Meeting

For an effective HAZOP study, a number of pre-HAZOP activities must be carried out. These activities include:

- Pre-HAZOP meeting (usually takes place between the HAZOP Study Chairperson, the Lead Process Engineer and often the Project Manager would be present).
- Identifying and Obtaining the Required Information
- Planning the Study Sequence
- Planning the Schedule

10. Inform Everybody Concerned

An official agenda should be sent out as far in advance of the HAZOP Study Meetings as possible. The Agenda will list topics, times of meetings and a list of required attendees. The Project Manager will usually take on the role of HAZOP coordinator, but it may not be the case, depending on how the roles have been defined.

11. HAZOP Study Meeting or HAZOP Review

The HAZOP Study technique requires that a process drawing or procedure be divided into study nodes, process sections, or operating steps and that the hazards of the process be addressed using the guide words.
As the team applies all of the relevant guide words to each process section or step, they record either the
(1) Deviation with its causes, consequences, safeguards, the actions, or
(2) Need for more complete information to evaluate the deviation.

As hazardous situations are detected, the team leader should make sure that everyone understands them. It is important for the HAZOP team leader to control the degree of problem solving that occurs during the team meetings. To control this aspect, the leader can:

- Complete the study of one process deviation and associated suggested actions before proceeding to the next deviation;
- Evaluate all hazards associated with a process section before considering suggested actions for improving safety.

In practice, HAZOP leaders should strike a compromise, allowing the team enough time to consider solutions that are easy to resolve, yet not allowing the team to spend too much time “designing solutions”.

It may not be appropriate, or even possible, for a team to find a solution during a meeting. On the other hand, if the solution is straightforward, a specific recommendation should be recorded immediately.

To ensure successful and effective meetings, the team leader should:
(1) Not compete with the members;
(2) Be a good listener and caring to listen to all of the members;
(3) Not permit anyone to be put on the defensive during meetings; and
(4) Save the energy level high by taking breaks as needed.

Whenever there is a shortage or a gap in the available plant operating information or in the knowledge of the team members, the team leader may be urged to calling a specialist for information on some aspect of plant operation, or deciding to postpone certain parts of the study to get more information.

12. Preparing the Actions Report

The key document that is produced from the HAZOP Study is a HAZOP Study Actions Report.
This report may conform to the following structure:

1. INTRODUCTION
2. SUMMARY
3. HAZOP DETAILS
   - 3.1 Format of HAZOP
   - 3.2 HAZOP Study Team
   - 3.3 HAZOP Keywords (Guidewords)
   - 3.4 System Descriptions
4. HAZOP STUDY MINUTES
   - 4.1 Minutes of Meeting
   - 4.2 HAZOP Actions
5. APPENDICES
   a. P&ID's
   b. Minutes of HAZOP Meeting
   c. HAZOP Action Report
   d. Information
   e. Equipment Manuals

13. Taking the HAZOP Actions

This is very straightforward if the action to be taken is obvious and involves the change of a small detail, which can be implemented by one of the study team.

It is more difficult if the action has to be taken by someone who has not been present at the study. In this case, it is clear that the action needs to be recorded in such a way that the action required is completely defined and self explanatory to the person who has to implement it.

The HAZOP Study Report needs to be a verifiable record of the study, and all the statements made, especially the requested actions, need to be written so that they are readily understood by people who were not at the meeting.
A great responsibility therefore devolves upon the Study Leader or the Project Engineer, or whoever has the responsibility for incorporating the changes proposed into the revised issue of the P&ID. If anything more than trivial changes are proposed, it is wise to re-assemble the HAZOP Study Team, to confirm that the changes proposed as a result of individual investigations do not over-ride the safeguards, which have been assumed to be present, when the rest of the study was done.

14. Final HAZOP Close-Out Meeting

At this survey the revised P&IDs, ready for issue are on the table and all team members have the HAZOP Report Sheets in their hands. The review consists of going one by one through the HAZOP action requests, making sure that the action has been taken, and that the new drawing takes into account any changes required.
Normally at the Final Design Safety Review a series of say 12 or 20 P&IDs will be reviewed against a long list of HAZOP Study actions required. The reviewing of all these P&IDs at one meeting gives an overall perspective on the level of safety on the unit concerned.

The team should go on to consider the overall objective of design safety for this unit, and consider whether the scope of the HAZOP Study was sufficient, or what safety reviews should be undertaken.
It may be desirable at the end of the Final Safety Review to require all the HAZOP Study Team to sign the new revised P&ID as a sign that they have jointly checked and approved the amended version of this drawing.
The usual procedure is for the HAZOP Actions Close-Out Sheets to be completed. The meeting is held and each action taken is read out and approved by the HAZOP team. The HAZOP Study Leader then signs, and dates the action. In this way all the actions are accounted for. Strictly according to HAZOP protocol the P&ID's may not be issued for construction/building until the HAZOP Actions have been closed out.

15. Design Safety Audits

HAZOP Study work, like other engineering design work, should always be verifiable, and it is desirable for management to have evidence that a HAZOP Study has been carried out in a satisfactory way.

One quick check which can be carried out either as a 10% Audit, or as a 100% Audit, is for an independent person to check the final P&ID against the HAZOP action list, and then to submit a report in the form :

P&ID No.	Action No.	Action Requested	Evidence of Action
372496 Rev. (0)	37.3	Remove the isolation valve No.472X	Valve No. 472X does not appear on P&ID 372496 Rev. (1)