PROCESS SAFETY MANAGEMENT

AND

RISK HAZARD ANALYSIS

BY

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9.11 HAZOP STUDY ANALYSIS COURSE

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1.0 INTRODUCING HAZARD AND OPERABILITY STUDIES - SUMMARY (HAZOPs)

1.1 WHAT is a HAZOP?

A hazard and operability study (or HAZOP) is a systematic, critical examination by a 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.

It is quite normal to carry out safety reviews. These may take different forms. Experts may be consulted in isolation, without reference to each other. They may instead be gathered in lengthy meetings to discuss the particular topic. Hazops are meetings with a distinct structure, the structure imposing a certain organization, to enhance effectiveness. They are a generalized study technique, equally applicable to microchip manufacture, pharmaceutical synthesis, effluent plant operation or any process.

They should not be seen, however, as a solution to all ills, the ultimate review. The procedure is only anther tool in the safety locker and should be seen as complementary to other techniques. Indeed it is best applied as one stage of a multi-stage procedure, applying different techniques as relevant to each stage. It does not replace, but rather supplements, existing Codes of Practice. Neither can it totally substitute for experience. But, both Codes of Practice and experience are evolved from existing situations. Innovative developments require a review which investigates the unknown. Hazops are a systematic, logical approach to determining problems.

1.2 WHY is a HAZOP carried out ?

The reasons for carrying out hazard and operability studies, are :

i. Primarily, **to identify hazards**, and
ii. To a lesser extent, **to resolve these hazards**.

In saying this, hazards are very generally defined. They are understood to be events, which :-

i. Lead to injury of people, either inside or outside the plant.
ii. Injure the environment.
iii. Insult the environment. Harmful effects may not occur, but disturbance itself is unacceptable.
iv. Damage the plant, an obvious hazard.
v. Result in loss of production quantity, quality or schedule.

In practice, some resolution of hazards is normally accepted. However a careful balance must be maintained to ensure that the primary purpose of hazard identification is not compromised.

1.3 WHEN is a HAZOP carried out ?

The timing of a hazard and operability study is determined by the objectives of a study, and in turn 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 study. Often an apparently simple, uncomplicated modification can give rise to a greater problem than it was intended to solve. Existing plant and new equipment are other examples of topics that may benefit from study.

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. Carrying out a hazop on an incorrect line diagram is the most useless occupation in the world. It is as effective as setting out on a journey with railway timetable ten years out of date.

A hazop takes 1.5-3 hours per main plant item (still, furnace, reactor, heater, etc.). If the plant is similar to an existing one it will take 1.5 hours per item but if the process is new it may take 3 hours per item.

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 tires after 3 hours at a stretch.

The hazop on a large project may take several months, even with 2 or 3 teams working in parallel on different sections of the plant. It is thus necessary to either :

a) Hold up detailed design and construction until the hazop is complete, or
b) Allow detailed design and construction to go ahead and risk having to modify the detailed design or even alter the plant when the results of the hazop are known.

Ideally, the design should be planned to allow time for (a) but if completion is urgent (b) may have to accepted - but this is not a widely accepted option due to the cost implications.

A preliminary hazop may be carried out on the flowsheet before detailed design starts. This will take much less time than the hazop of the line diagrams and will identify ‘area’ of the process of a particular hazardous nature. It provides a more “structured” and “systematic” approach than a preliminary design review - but NOT the detailed analytical data of a true P&ID HAZOP.

Overall Procedural Steps in a HAZOP Study

1. Company PHA/Safety/PSMP Team Meet

2. Identify the Project for the HAZOP Study

3. Identify the Lead Process Engineer

4. Select the HAZOP Team Leader

5. Define Purpose and Scope of HAZOP

6. Select the Team/Define Roles

7. Pre-HAZOP Meeting
   - Lead Process Engineer and HAZOP Study Leader
   - Identify and Obtain Required Information
   - Plan the Study Sequence
   - Plan the Schedule

8. Inform Everyone Concerned

9. HAZOP Study Review and Documenting the Results (Minutes)

10. Preparing and Submitting the HAZOP Study Report

11. Taking the Actions

12. Close-Out Meeting and Signing Off

1.4 Introduction to the HAZOP Study Procedure

The outline steps for the overall HAZOP Study methodology are shown in the table. A potential HAZOP Study Leader or HAZOP Study Chairperson must be aware of all of these.

However, many people - engineers, chemists, project managers, process operators, maintenance staff, services engineers, contractors, equipment suppliers, control systems staff etc. etc. - will be required to attend and participate in HAZOP Studies. Consequently, as part of introducing HAZOP it is worthwhile early on in this course for us to look at two aspects of the study method relating to Blocks 7 and 9 in the Table.

Two methods of importance in the "practical side" of performing a HAZOP Study are:

- Defining each Pipe section to be studied. This should have been agreed previous to the actual HAZOP Study Meeting between the HAZOP Study Chairman and the Lead Process Engineer
- Application of the Guide Words

- Process Section

The section to be studied is usually a section of pipeline between two main process items on a P&ID (piping and instrumentation diagram) - for continuous process operations. Usually the analysis is carried out on final P&ID's, that is, prior to "Issue for Construction".

Frequently the section of line undergoing a HAZOP Study may go through several other items of equipment which must be considered but providing there is no chemical change it is acceptable and normal to HAZOP in this way. Sometimes an additional chemical may even be added into the line (via a branch line, e.g. T junction on Y junction) and these "in-line" additions are usually included as part of the HAZOP of this particular section - but NOT always the branch line.

When the Pipe section has been followed through to the equipment item it is usual to assess the equipment item as part of the "same section" by applying a number of equipment guidewords. The same method, of course, applies to the equipment item at the beginning of the process.

The whole HAZOP process usually starts with the engineering drawing(s) at the BEGINNING of the process, the feeds being the raw materials. Often as many as 3 or 4 P&ID's may be tabled at one session to enable the HAZOP team to identify where streams are coming from on one or more P&ID's and where they are going to on the next one or two P&ID's.

1.5 HOW are HAZOPs done ?

Earlier, these studies were defined as examinations of engineering and operating intentions. An intention is the expected behaviour of a process and its associated hardware, under normal and abnormal conditions. It may be defined either diagrammatically or descriptively; diagrammatically in terms of flowsheets, 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 behaviour. Hypothetical deviations are prompted by applying guide words, which will be explained shortly, 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 and is shown in the Table. 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. Arising from the examination will be a number of follow-up activities. 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".

(The other steps will be elaborated in the detailed analysis later.)

- <u>Guide words</u>

Guide words are simply words used as keys to suggest the various ways in which deviations from an intention can occur. A list and their meaning is provided.

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 fail 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.

A list of Guidewords are shown in the Table.

TABLE GUIDE WORDS	
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 total quantity), higher temperature, higher pressure, higher viscosity, etc.
LESS OF	Less of any relevant physical property than there should be, e.g. lower flow (rate or total quantity), lower temperature, lower pressure, etc.
PART OF	Composition of system different from what it should be, e.g. change in ratio of components, component missing, etc.
AS WELL AS MORE THAN	More components present in the system than there should be, e.g. extra phase present (vapour, solid), impurities (air, water, acids, corrosion products), etc.
REVERSE	A parameter occurs in the opposite direction to that for which it was intended e.g. reverse flow.
OTHER THAN	Complete substitution e.g. sulphuric acid was added instead of water.
EQUIPMENT WORDS "OTHER"	What else can happen apart from normal operation, e.g. start-up, shutdown, uprating, low rate running, alternative operation mode, failure of plant services, maintenance, catalyst change, etc.

The GUIDEWORDS 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 are shown in the Table and the four in the first column are the ones most frequently used - FLOW, PRESSURE, TEMPERATURE and LEVEL, others will be tested and used on a case by case basis if required.

TABLE HAZOP Analysis Process Parameters

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

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

TABLE Creating Deviations

Guide Words		Parameter		Deviation
NO	+	FLOW	=	NO FLOW
MORE	+	PRESSURE	=	HIGH PRESSURE
AS WELL AS	+	ONE PHASE	=	TWO PHASE

Guide words are applied to both the more general parameters (e.g. react, mix) and the more specific parameters (e.g. pressure, temperature). With the general parameters, it is not unusual to have more than one deviation from the application of one guide word. For example, “more reaction” could mean either that a reaction takes place at a faster rate, or that a greater quantity of product results. On the other hand, some combinations of guide words and parameter will yield no sensible deviation (e.g. “as well as” with “pressure”).

With the specific parameters, some modification of the guide words may be necessary. In addition, we often find that some potential deviations are irrelevant because of a physical limitation. For example, if temperature parameters are being considered, the guide words “more” or “less” may be the only possibilities.

The following are other useful alternative interpretations of the original guide words :

- Sooner or later of “other than” when considering time
- Where else for “other than” when considering position, sources, or destination
- Higher and lower for “more” and “less” when considering levels, temperature, or pressure

When dealing with a design intention involving a complex set of interrelated plant parameters (e.g. temperature, reaction rate, composition, and pressure), it may be better to apply the whole sequence of guide words to each parameter individually than to apply each guide word across all of the parameters as a group.

For example : NO FLOW
MORE FLOW
LESS FLOW
REVERSE FLOW

It is more confusing to jump from NO FLOW to NO PRESSURE to NO TEMPERATURE etc. than to deal will all the FLOW scenarios in the particular section under study.

Deciding on which group of GUIDEWORDS and PARAMETERS is often difficult. In Section 4, concerned with the detailed study method, the Chemical Industries Association (CIA) list will be used. But you will need to be flexible as different sets exist - always leading to the same conclusions and recommendations.

1.6 HAZOP Terminology

Words frequently arising in HAZOP Studies are defined in this section.
Table HAZOP Terminology

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 Recommendations)	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)

1.7 The History of the HAZOP Study

In 1963 the Heavy Organic Chemicals (HOC, later Petrochemicals) Division of ICI was designing a plant for the production of phenol and acetone from cumene. It was a time when the cry was for 'minimum capital cost' (rather than minimum lifetime cost or maximum profit) and the design had been cut back of all but essential features. Some people felt that it had been cut back too far. It was also a time when method study and, in particular, 'critical examination' were in vogue. Critical examination is a formal technique for examining an activity and generating alternatives by asking, 'What is achieved?', 'What else could be achieved?' and so on.

The production manager had recently spent a year in ICI's Central Work Study Department. He decided to see if critical examination could be applied to the design of the phenol plant in order to bring out into the open any deficiencies in design and find the best way of spending any extra money that might be available. A team was set up including the commissioning manager, the plant manager and an expert in method study and critical examination. During 1964 they met for three full days per week for four months, examining the phenol plant line diagrams and covering acres of paper with all the questions and answers. They discovered many potential hazards and operating problems that had not been forseen, modifying the technique as they did so. Mr. H. later wrote, "We concocted an approach for trial.. and to cut a long story short this approach did not work. Not because it did not do the job but because it was too detailed, penetrated into too many corners, all good stuff but life was just too short. After a good many tries we came up with an approach which has much of the principle of critical examination but was somewhat bent in style". The essence of the new approach was that a technique designed to identify alternatives was modified so that it identified deviations. It was recognizably hazop as we know it today though it was further modified during later studies to the form described in this Training Course.

TABLE
Critical examination

METHOD STUDY : CRITICAL EXAMINATION SHEET			
Description of element..............................Reference...........Page..........Date.......			
The present facts		**Alternatives**	**Selection for development**
WHAT is achieved ?	WHY ?	What ELSE could be achieved ?	What SHOULD be achieved ?
HOW is it achieved ?	WHY THAT WAY?	How ELSE could it be achieved ?	How SHOULD it be achieved ?
WHEN is it achieved ?	WHY THEN ?	When ELSE could it be achieved ?	When SHOULD it be achieved ?
WHERE is it achieved ?	WHY THERE ?	Where ELSE could it be achieved ?	Where SHOULD it be achieved ?
WHO achieved it ?	WHY THAT PERSON ?	Who ELSE could achieve it ?	Who SHOULD achieve it ?

The following are a few of the safety points that came out of this early hazop (though that term was not used then; the exercise was described as a method study or hazard investigation). Some of the points are now included in design specifications but were not included at the time.

- By-passes around control valves which are connected to safety trips should be deleted. Use of a by-pass renders the safety trip useless.
- Nitrogen should be used for vacuum breaking to prevent the ingress of air into a hot system.
- Break tanks should be fitted in town water supply to prevent contamination by reverse flow.
- The relief valve system should be checked for places in which liquid could collect.
- A slip-plate should be fitted in the feed line to [vessel X] to prevent liquid leaking in before conditions are correct.
- Vent valves should be fitted to all blowing points so that the pressure can be blown off before hoses are disconnected.
- A vent valve should be fitted to a high pressure filter so that the pressure can be blown off before the filter is opened for cleaning.
- Extended spindles should be fitted to the valves on acid tanks to reduce the risk that operators may be splashed by leaks.
- Special equipment should be designed for charging and discharging catalysts and other auxiliary materials, to remove the dangers that go with improvisation.

Note that all these points are written as recommendations. Today most hazop teams would not say ‘should’ but simply ‘Delete by-passes... etc.’.

More operating points than safety ones came out of the study. This was expected. The remit of the team was ‘To devote themselves full-time to obtaining and studying information from all sources and to take any necessary decisions on broad plant design aimed at ensuring that the phenol plant would start up quickly and satisfactorily; that it will produce its design output and quality of products; that it will operate safely and its effluents will be satisfactorily treated’. Today many, perhaps most, hazops produce more operating points than safety ones.

A few months before the phenol study was undertaken in ICI HOC Division at Billingham the Mond Division at Runcorn carried out a similar but very much shorter study (it occupied a team of four for 21 hours) on a semi-technical plant. The remit for this study was ‘To evaluate the process for hazards which may arise during operation of the semi-technical plant. Particular attention to be paid to the effect of impurities in raw materials, build-up of products in recycle systems, maloperation and equipment failures’.

In 1968 D.M. Elliott and J.M. Owen of Mond Division described the use of critical examination for generating alternatives in the early stages of design. Even earlier, in 1960, D.S. Binsted described a similar application in ICI Organics Division. However, these applications of critical examination never became as popular as hazop, perhaps because they were before their time but more probably because, compared with hazop, they were too cumbersome and time-consuming.

ICI in London played a part in integrating the Mond and HOC forms of the developing hazop technique and spreading knowledge of it throughout the company. A report in ICI dated November 1964 clearly highlighted the difference between hazop and critical examination :

‘Suppose one significant word in the description of a process is “Stirred”, and take the guide-word Eliminate, i.e. No Stirring. In a normal [critical] examination of the process one would be looking at the necessity to stir, and recording possible advantages and disadvantages of not doing so. In Hazard Investigation [that is, what we now call hazop], on the other hand, one is seeking possible causes of such a situation (e.g. motor not switched on; motor burnt out; paddle blades broken; etc.), and what hazards to personnel, plant, or product might happen as a result of it (e.g. intense local heating with off-spec. product and loss of batch; possible risk of explosion; if product coagulates plant may have to be stripped down; etc.).’

Later, the report said :

‘A Hazard Investigation affords a means of producing on paper in a systematic and thorough fashion, and in advance of plant start-up, potential hazards to the plant, process and personnel, and of making recommendations to eliminate the hazards. Where the Company policy demands that plants be built with minimum capital expenditure and with minimum sparage [number of spares], and yet with immediate high outputs on start-up, the the need for Hazard Investigation becomes obvious.’

Reading this report over 25 years later, the need for a better Company policy seems equally obvious.

ICI Pharmaceutical Division adopted hazop enthusiastically and the first use of the technique outside ICI occurred in 1967 when R.E. Knowlton (then in ICI) led a study for Ilford Ltd. The first published paper on hazop was by H.G. Lawley in 1974. It was presented at the American Institute of Chemical Engineers Loss Prevention Symposium in Philadelphia the previous year.

2.0 DETAILS OF THE HAZOP STUDY PROCEDURE

2.1 Introduction to the HAZOP Approach

2.2 Structure of the HAZOP Study Procedure

2.3 Company PHA/Safety/PSMP Team Meeting

2.4 Identify the Project for the HAZOP Study

2.5 Identify the Lead Process Engineer

2.6 Select the HAZOP Team Leader (Chairperson)

2.7 Define Purpose and Scope of HAZOP

2.8 Selecting the HAZOP Team and Defining the Roles

2.9 Pre-HAZOP Meeting

2.10 Inform Everybody Concerned

2.11 HAZOP Study Meeting (HAZOP Review)

2.12 Preparing the Actions Report

2.13 Taking the HAZOP Actions

2.14 HAZOP Close-Out Meeting

2.15 Design Safety Audits

2.0 DETAILS OF THE HAZOP STUDY PROCEDURE

2.1 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. Although the HAZOP Study technique was originally developed for evaluation of a new design or technology, it is applicable to almost all phases of a process's lifetime.

The essential feature of the HAZOP Study approach is to review process drawings and/or procedures in a series of meetings, during which a multidisciplinary team uses a defined protocol to methodically evaluate the significance of deviations from the normal design intention.

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. Consequently, the success of the study requires that all participants freely express their views and good supportive teamwork practices are adopted. Participants should refrain from criticizing each other to avoid smothering the creative process. This creative approach combined with the use of a systematic protocol for examining hazardous situations helps improve the thoroughness of the study.

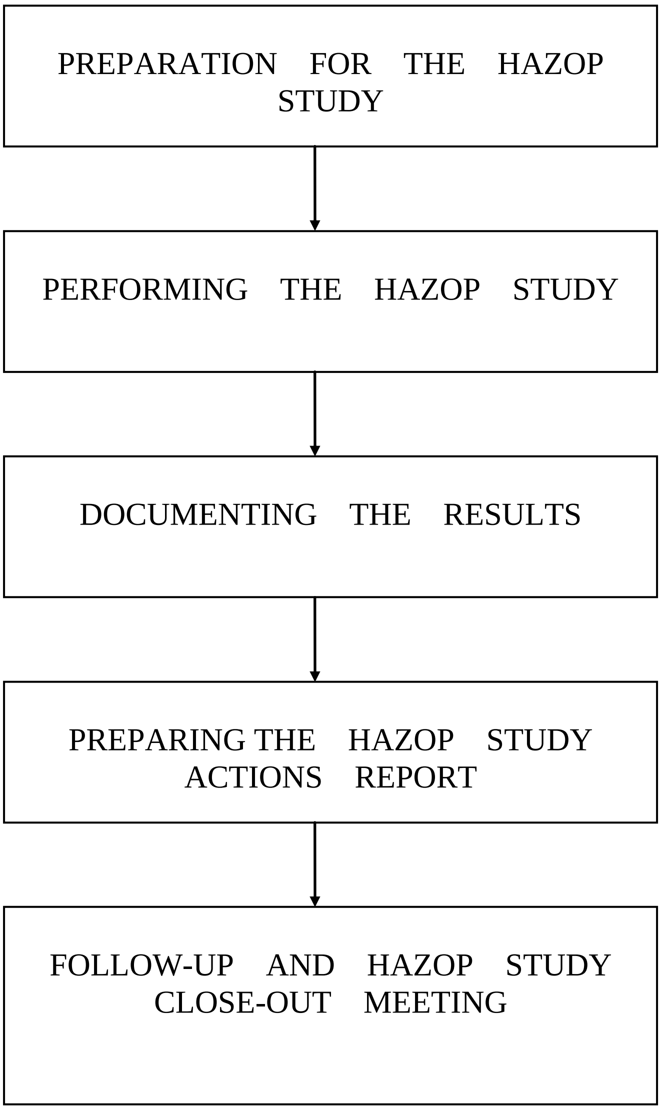
The HAZOP study focuses on specific points of the process or operation called "study nodes," process sections, or operating steps. One at a time, the HAZOP team examines each section or step for potentially hazardous process deviations that are derived from a set of established guide words. One purpose of the guide words is to ensure that all relevant deviations of process parameters are evaluated. Sometimes, teams consider a fairly large number of deviations (i.e. up to 10 to 20) for each section or step and identify their potential causes and consequences. Normally, all of the deviations for a given section or step are analyzed by the team before it proceeds further.

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. Normally, the system P&IDs are available so the team can formulate meaningful answers to the questions raised in the HAZOP Analysis process. Also, it is still possible to change the design without incurring major costs. However, HAZOP Analysis studies can also be performed at earlier stages of a process lifetime as long as the team members have adequate process documentation and knowledge upon which to base their analysis. But a HAZOP analysis performed at this early stage should not be a substitute for a thorough design review.

Although the basic HAZOP Analysis approach is well established, the way that it is employed may vary from organization to organization.

The basic elements of the HAZOP procedure are shown.

TABLE BASIC CONCEPTS



2.2 <u>Structure of the HAZOP Study Procedure</u>

The Table shows the key elements in the HAZOP Study Procedure. Each element will be reviewed in detail.

TABLE

<u>Overall Procedural Steps in a HAZOP Study</u>

1. Company PHA/Safety/PSMP Team Meet
2. Identify the Project for the HAZOP Study
3. Identify the Lead Process Engineer
4. Select the HAZOP Team Leader
5. Define Purpose and Scope of HAZOP
6. Select the Team/Define Roles
7. Pre-HAZOP Meeting
   - Lead Process Engineer and HAZOP Study Leader
   - Identify and Obtain Required Information
   - Plan the Study Sequence
   - Plan the Schedule
8. Inform Everyone Concerned
9. HAZOP Study Review and Documenting the Results (Minutes)
10. Preparing and Submitting the HAZOP Study Report
11. Taking the Actions
12. Close-Out Meeting and Signing Off

2.3 Company PHA/Safety/PSMP Team Meeting

1. Each company will have (or should establish), as part of their Process Safety Management Programme, an experienced team or responsible person who will decide which safety route a new project/an existing process/a process modification/a revamp/or a retrofit should follow. By deciding which route, then this should automatically state which Process Hazard Analysis (PHA's) methods will be used to assess the process hazards.

2.4 Identify the Project for the HAZOP Study

2. Based on the Safety Team meeting in Section 4.3 then the Safety Process route selected will specify whether the project/process will undergo a HAZOP study. If a project is selected there will be some indication of the time scheduling of the HAZOP because of the timing of the Project Planning Programme.

   The decision to HAZOP or not to HAZOP is primarily the responsibility of this team and will be based on several contributing factors :

   - legislation - does local SHE legislation require a HAZOP
   - tradition - has the company a tradition of using HAZOP techniques
   - process conditions - hazardous chemicals, high/low temperatures, high/low pressures, chemical reactions etc., etc.
   - experience - has the company wide HAZOP experience ?
     - does the company want it ?
   - cost - the project value may be low, in which case a small projects hazop group may handle it (3/4 people).

2.5 Identify the Lead Process Engineer

3. If a project has been assigned for a HAZOP then the Lead Process Engineer must be informed in order that he can plan for it.

   Duties of the Lead Process Engineer

   The Process Engineer should have a very detailed understanding of the process being reviewed. Apart from voicing questions of his own he should act as consultant to the team, providing the process descriptions and answering the bulk of the questions which will be raised by the team.

   He sometimes will also act as Technical Secretary although the assignment of this important position decision depends on company policy and the nature of the project.

2.6 Select the HAZOP Team Leader

4. Selecting a HAZOP Study Leader or HAZOP Study Chairperson is a key issue.

It is important that the Study Leader 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. Usually an outside Consultant Engineer is brought in for the duty.

The technical duties of the HAZOP Study Leader are reviewed in the next three sections and take place throughout the various stages of the whole HAZOP process.

Duties of the Study Leader

i. Before the HAZOP Study

Ask for two copies of the P and ID to be HAZOPed at least a week ahead of the study. Check the P and ID to ensure that ;

a The right members of the team have been requested to attend the HAZOP Study. (See who is listed on the HAZOP Schedule).

b. The Process is a continuous process rather than a batch process. If it is a batch process there are additional documents to be obtained, and additional work for the Study Leader to do before the study begins. (See section 7 for details)

c. P and ID is developed to the point where it is ready to be HAZOPed (New Design). For an existing plant make sure the P and ID is up to date and is an accurate representation of the plant as built, rather than an indication of what the designers intended to have built.

d. The drawing is readily understandable and that by looking at it the Study Leader gets a good overall grasp of the overall process.

e. If there are non-standard symbols used on the P and ID, a key to the symbols used is available for reference.

ii. Pre-HAZOP Meeting

It is wise for the Study Leader to meet with the Process Engineer in advance of the actual study to assure himself that he has a good grasp of what the process is all about, and to agree a mutually acceptable basis for dividing up the P and ID into short sections suitable for individual study.

At the pre-HAZOP meeting it is good to make up one copy of the P and ID with the division into short sections, and to record any other comments or explanations the Study Leader might wish to record as an aid memoir.

The second copy of the P and ID will be put on the table at the HAZOP Study as a clean drawing, and any markings put onto it will be done in the presence of the HAZOP team. This second copy is then called the "HAZOP Master".

While the Study Leader should be independent of those who are associated with the project or plant, he should take time before the HAZOP Study to brief himself with details of the project or plant, so that he does not waste the time of the HAZOP team asking unnecessary questions.

iii. <u>During the HAZOP Study</u>

The Study Leader acts as Chairman and is responsible for starting the meeting on time and terminating the session once it has run for three hours.

He begins by calling on the Process Engineer to give the overall process description and the design intent for each P and ID. This should be a final revision as far as the Study Leader is concerned, but it ensures that others present, who may not have done any preparation in advance, have the background information against which to carry out the study.

The Study Leader then defines the first section to be studied in detail and he may put a dotted yellow line onto the HAZOP Master to ensure that everyone is looking at the same section of the plant. He then calls on the Process Engineer to give the design intent and detailed information about the contents of the line, the design and operating temperature and pressure, etc.

The Study Leader begins the review of this section by reading out the first guide word "NO FLOW". When possible reasons for NO FLOW are established by the team he writes them down on his pad, and then ticks them off as they are studied in detail and at the same time, transferred onto the formal record of the HAZOP Study.

When an action is agreed the Study Leader writes onto the HAZOP Master the number of the action in red, next to the item to be changed. If the change is agreed by the meeting he also marks up the HAZOP Master in red with the change to be made.

When all the guide words have been used and the study of a sub-section is complete, the Study leader should yellow-off all the section completed.

The Study Leader then defines the second section to be studied in detail and calls on the Process Engineer to give a detailed process description before starting again with the first guide word, 'NO FLOW".

iv. <u>After the HAZOP Study</u>

At the Study the Report Form is filled in by the Technical Secretary. However before this Report Form is typed up for distribution it is helpful for the HAZOP Study Leader to check that the actions are stated clearly - so that they can be understood by persons not at the meeting - and that the scope of each action is completely defined. It may be helpful for the HAZOP Report to be signed by the Project Engineer and approved by the Study Leader.

While checking the report the Study Leader should also check the HAZOP Master P and ID to ensure that all the modifications agreed at the study are shown clearly, and that the locations of all the actions are shown by the number drawn-on in red.

Sometimes the HAZOP Study Leader (Chairperson) may also act as Technical Secretary.

v. <u>Team Building/Development Role of HAZOP Study Chairperson</u>

The HAZOP Study Leader must control, develop, encourage contributions from all members of the team. Only some of the these valuable characteristics are listed in the Table.

TABLE Responsibilities of HAZOP Chairperson	
• Ensure that the proper hazard evaluation is selected and correctly applied • Organize an analysis and negotiate for resources • Communicate with personnel at all levels in the organization • Motivate a group to achieve a common goal • Work with a wide range of personalities (possibly including highly defensive and argumentative individuals, quick and direct individuals, and rambling and talkative individuals) • Interpret engineering drawings and understand process operations • Ask questions and probe for further explanations without making team members defensive • Maintain objectivity, honesty, and ethical conduct, reporting all significant findings regardless of the potential discomfort to the leader, team, or management	• Encourage, direct, and focus group discussions • Judge the relative importance of issues and help the team drop those not worth pursuing • Summarize issues, negotiate a compromise, and forge a consensus • Appreciate different points of view and empathize with team members • Remain impartial and maintain the respect of the team • Manage the pace of team discussions and tactfully maintain the meeting schedule • Sense team fatigue, boredom, unsuitability, etc., and implement corrective action • Keep the team working together • Suspend discussion of issues that cannot be resolved by the team • Fulfill team members' psychological needs without letting any one ego, including the leader's , dominate the team

2.7 Define Purpose and Scope of HAZOP

5. The purpose, objectives, and scope of the study should be made as 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.

2.8 Selecting the HAZOP Team and Defining the Roles

6. 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 and 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.

TABLE <u>The basic minimum HAZOP Study team consists of</u> :

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

In addition <u>some</u> 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

For a modification to an existing plant the composition would be a little different.

The Process Engineer and the Operations or Commissioning Engineer, on the other hand, should be very familiar with all details of the plant under review so that they can answer the questions which will be raised by the HAZOP team. In this case the core team format will comprise :

TABLE <u>HAZOP TEAM for an Existing Plant</u>

HAZOP Chairperson (Independent)
Plant Manager
Plant Maintenance Engineer
Instrument Engineer

The roles of the HAZOP Study Chairperson (Team Leader) and the Lead Process Engineer on the project have already been discussed. Other roles which may need defining are the duties of the Project Engineer (Project Manager) and the Technical Secretary.

TABLE Duties of the Project Engineer/Project Manager
The Project Engineer should undertake the following duties : a) Draw up and issue the HAZOP Schedule with the times and dates and location of all the meetings. b) Book the conference room for the days required. c) Make sure all the required reference documents are available at the HAZOP Study. d) Act as a secretary to the team and fill in the official record on the HAZOP Report Forms. e) Issue the HAZOP Report after the meeting. f) Follow-up to make sure all the actions are taken. g) Re-issue the P and ID with all the modifications as required. h) Set up the Final Safety Review meeting.

The role of the Technical Secretary is to take the "Minutes" of the meeting. This is a key responsibility as the HAZOP Minutes form the core of the HAZOP Study Actions Report. The person usually takes directions from the HAZOP Chairperson. The role needs a technical background and knowledge of HAZOP procedures; the duty is carried out in a variety of ways depending on the size and complexity of the project. Often a Team Member may take on the role of Technical Secretary, for example :

- Project Manager/Project Engineer
- HAZOP Study Chairperson
- Lead Process Engineer
- Independent Technical Secretary (usually someone used to working with the Chairperson).

Other team members may be drawn from a wide range of disciplines as shown in the next table. In addition, many companies now use the HAZOP Study as a training exercise for their process operators, shift superintendents, engineers - who are going to work on and operate the plant.

TABLE Potential Members of a HAZOP Study Team	
Chemist Civil engineer Construction representative Corporate safety manager Electrical engineer Environmental engineer Expert from another plant Fire protection engineer Hazard evaluation expert/leader Human factors specialist Industrial hygienist Inspection engineer/technician Instrument engineer/technician Interpreter Maintenance supervisor Maintenance planner Mechanic/pipefitter/electrician	Mechanical engineer Medical doctor/nurse Metallurgist Operations supervisor Operator/technician Outside consultant Process engineer Process control programmer Project engineer Recorder/secretary/scribe R&D engineer Safety engineer Shift foreman Toxicologist Transportation specialist Vendor representative

2.9 <u>Pre-HAZOP Meeting</u>

7. In order to make the HAZOP run effectively a number of pre-HAZOP activities must be carried out. The pre-HAZOP meeting is an essential component of these activities and normally involves the following :

– Identifying and Obtaining the Required Information
– Planning the Study Sequence
– Planning the Schedule

The pre-HAZOP meeting usually takes place between the HAZOP Study Chairperson, the Lead Process Engineer and often the Project Manager would be present.

• Identifying the Obtaining the Required Information

A HAZOP Study is review of Process and Instrument Diagrams (P&IDs) otherwise known as Engineering Flow Diagrams. To make the study useful, it is essential to have full details of the following :

a) All pipeline size, numbers and design parameters.
b) Extent of insulation and electrical tracing.
c) Dimensions of vessels with the rough location of branches.
d) Design and operating pressures and temperatures of these vessels.
e) Definition of all instrumentation, both controllers and trip systems.
f) Delivery characteristics of the pumps.

Some of this information may be on the P&IDs, but some of it may not. Therefore P&IDs need to be supplemented with line tables, vessel specifications, pump specifications, etc. However it should be noted that it is only the P&IDs which are being reviewed, the other documents are simply available for reference. If the other documents need to be reviewed, they should be subject to a different kind of safety review.

Using the general considerations outlined in the previous list, the following documents are needed for reference during a HAZOP Study :

The P&ID under review
All P&IDs from the which lines come and to which lines go
Processes Data Sheets for all Equipment on the P&ID, including Dimensions
Process Flow Diagrams, Flowsheets
Material Balance
Design Pressure and Temperature Diagrams
Details of Hazardous Materials
Plot Plans, Layout Drawings
Line Classification Lists
RV Philosophy and Schedules
Instrument Logic Diagrams
Cause and Effect Charts
Control Charts
Computer Programs
Plant Manuals
Equipment Manufacturers Manuals
Operating Instructions

Not all the above information may be required but the pre-HAZOP meeting should be used to decide what information should be available for the HAZOP Study Meeting and what information should be circulated to the HAZOP Study Team prior to the HAZOP Study Meeting.

Additional documents are needed for the HAZOP of a batch system, see Section 7.2.

- Planning the Study Sequence

The amount of work required in this stage depends on the type of process. With continuous processes, preparation can be minimal as the order usually starts with P&IDs and raw material inputs at the beginning of the process and proceeds in a logical progression to the end of the processes with P&ID's showing product outputs. Process sections may be identified before the meetings using <u>up-to-date</u> flowsheets and P&IDs. Sufficient copies of each drawing should be available for team members to see during the meeting(s).

Sometimes, team leaders may also develop a preliminary list of deviations to be considered in the meeting and prepare a worksheet on which to record the team's responses. However, the leader should avoid using a previously assembled list as the "only" deviations to be considered. This could stifle the creative synergism of the team when identifying process hazards and could result in missing some hazardous deviations due to complacency. It is to be expected that, due to the learning process that accompanies the study, some changes will be made as the study progresses.

The leader will usually prepare a plan before the study begins to make sure that the team approaches the plant and its operation methodically. This means the team leader must spend some time before the meetings to determine the "best" study sequence, based on how the specific plant is operated.

- Planning the Schedule

Because of the importance of having all the right people present for a HAZOP Study, and the composition of the team may be required to change as the team moves from one P and ID to another, it is important to have a Schedule issued well in advance, to warn personnel when they will be required, and to advise them where the HAZOP Studies will take place.

Due to the importance assigned to HAZOP studies, failure to attend a HAZOP session by one of the nominated team members is regarded as a severe breach of the plant safety management procedures. In addition, several other attendees may have wasted time waiting for inputs from the absentee team member.

Once the data and drawings have been assembled, the team leader is in a position to plan the review meetings. The first requirement is to estimate the meeting time needed for the study. As a general rule, each process section will take an average of 20-30 minutes. For example, a vessel with two inlets, two exits, and a vent should take about three hours. Thus, a leader can estimate the HAZOP meeting time required by considering the number of process sections. Another way to make a rough estimate is to allow about two to three hours for each major piece of equipment. Fifteen minutes should also be allowed for each simple verbal statement in operating procedures, such as "switch on pump", "motor starts", or "pump starts". After estimating the meeting time required, the team leader can arrange the review meetings.

It is undesirable for the HAZOP Team to carry on too long at one sitting, or for too many hours per day, or for too many days per week. An individual meeting should not continue for more than three hours at a time. Two sessions per day - one in the morning and one in the afternoon may be acceptable. If six hours per day are being used for the HAZOP Studies, it is wise not to do this for more than three or four days each week. If the team try to do more than this they are likely to become inefficient, and less thorough, in the way they carry out the study.

With large projects, one team may not be able to analyze all of the subject processes within the allotted time; it may be necessary to use several teams and team leaders (one of the team leaders should act as coordinator). The coordinator will divide the processes into logical sets, allocate portions of the process to different teams, and prepare schedules for the study as a whole.

2.10 Inform Everybody Concerned

8. 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.

2.11 HAZOP Study Meeting or HAZOP Review

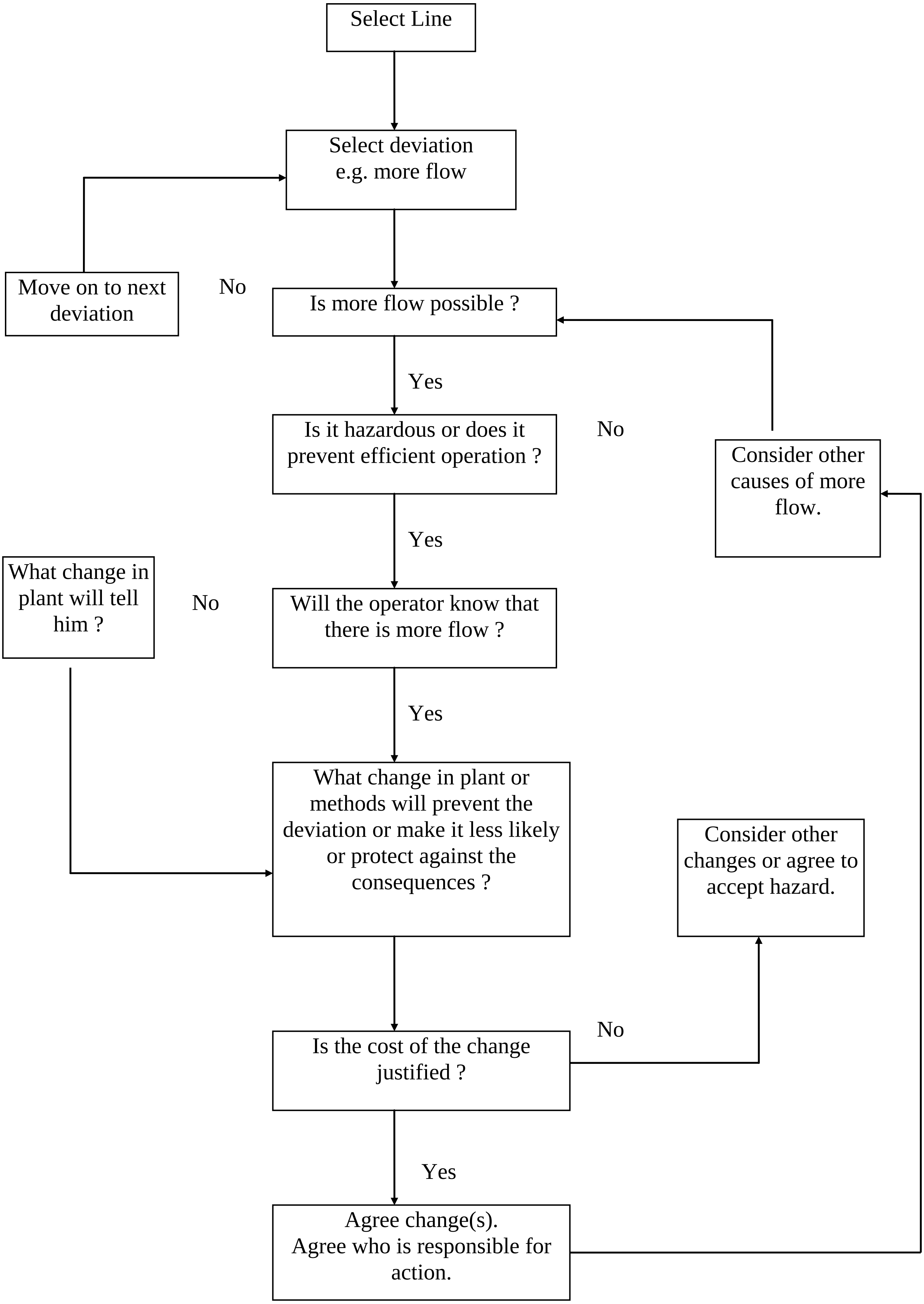
9. The HAZOP Study technique requires that a process drawing or procedure be divided into study nodes, process sections, or operating steps and that the hazards of the process be addressed using the guide words, The Figure illustrates the typical flow of activities in a HAZOP meeting. As the team applies all of the relevant guide words to each process section or step, they record either (1) the deviation with its causes, consequences, safeguards, the actions, or (2) the 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 effective meetings, the team leader must keep several factors in mind : (1) do not compete with the members; (2) take care to listen to all of the members; (3) during meetings, do not permit anyone to be put on the defensive; and (4) keep the energy level high by taking breaks as needed.

Although the team leader will have prepared for the study, the HAZOP technique may expose gaps in the available plant operating information or in the knowledge of the team members. Sometimes calling a specialist for information on some aspect of plant operation or deciding to postpone certain parts of the study to obtain more information may be necessary.

Figure Flow Chart of the Study Method



HAZOP MINUTES

System No. :		System Name :			Page of
Report of HAZOP Study		Client :	Project :		Content No. :
Date :		Present :			Report by:
SYSTEM NUMBER :		SYSTEM :			

No	Guide Word	Deviation	Possible Causes	Possible Consequences	Action Required

Procedure for the HAZOP Review Meeting

The practical aspects of the procedure during the HAZOP Study Meeting will follow a path, something like this :

a) Study Leader opens the meeting. If people are present who have not taken part in a HAZOP Study, he gives an outline of the method for carrying out a HAZOP Study.
b) The Process Engineer gives an overall process description and the design intent for the P&ID to be reviewed.
c) The Study Leader defines the first section to be studied in detail.
d) The Process Engineer gives detailed information and the design intent for this first section.
e) The Study Leader starts the study with the first guide work : NO FLOW.
f) The team examine whether there are ways of achieving NO FLOW in the section under review.
g) The Study Leader makes a list of the ways in which NO FLOW can be achieved.
h) The team then consider the consequences of NO FLOW against each of the ways in which NO FLOW can be achieved. (At this stage, these are filled-in on the report sheet) with the details found.
i) If any of these consequences result in a dangerous or undesirable situation then an action is agreed, and put into the action column.
j) If no action can be agreed by the team, an appropriate engineer will be asked to investigate what action could, or should, be taken.
k) At this point, the team move on to the second guide work REVERSE FLOW and the review is repeated from item e) above.
l) All the guidewords and parameters are applied to the first process section.
m) Study Leader defines the second section for study.
n) Process Engineer gives the design intent for this section.
o) Second section studied in detail using the Guide Words.

The general strategy is to start with the streams flowing into a vessel or major item of equipment, and then to study the streams leaving this vessel or major item of equipment. Finally the vessel or major item of equipment, is itself studied, using the OTHER THAN Guide Words.

Once the final section has been studied, then all the drawing will have been yellowed-off and notes will have been made on the drawing. The Study Leader reads each note made on the drawing out in full, and if there are no comments he yellows the note, and then reads the next one. Any changes that may be required are recorded as HAZOP Actions.

- Complete List of Guidewords

As discussed earlier, various formats and lists of guidewords exist, nearly always, leading to the same conclusions and actions. The guidewords presented here are those of the Chemical Industries Association developed in conjunction with ICI, the originators of the HAZOP technique.

The Guide Words

PARAMETER	ROOT	APPLICATION	EXAMPLE
FLOW	NONE	No Flow	Wrong routing, complete blockage, slip plate, incorrectly fitted non return valves, burst pipe, large leak, equipment failure (control valve or isolation valve, or pump, vessel etc.)
	REVERSE	Reverse Flow	As above
	MORE OF	More Flow	More than one pump, reduced delivery head, increased suction pressure, static generation under high velocity, pump gland leaks.
	LESS OF	Less Flow	Line blockage, filter blockage, fouling in vessels, valves, etc. and restriction of orifice plates.
PRESSURE	MORE OF	More Pressure	Surge problems (line and flange sized) (leakage from any connected higher pressure system, thermal relief.
	LESS OF	Less Pressure	Generation of vacuum condition
TEMPERATURE	MORE OF	More Temperature	Higher than normal temperature, fouled cooler tubes, cooling water temp wrong, cooling water failure.
	LESS OF	Less Temperature	Line freezing.
VISCOSITY	MORE OF	More viscosity	Incorrect material specification, temperature, etc.
	LESS OF	Less viscosity	As above
COMPOSITION	PART OF	Composition Change	Passing isolation valves, double isolations.
	MORE THAN	Composition Change	More A added, More B added.
	OTHER THAN	(Contamination)	Wrong material, wrong operation, ingress of air, shutdown and start-up conditions.
OTHERS		Relief	Sizing for two phase
		Instrumentation	Control, flow measurement, pressure relief, instruments, pump overheating due to closed control valves, location of alarms, etc., temp. indicators, flow recorders, etc.
		Sampling	
		Corrosion	
		Service Failure	Cooling water, instrument air, steam, nitrogen, power, etc.
		Maintenance	System drainage, isolation of equipment, preparation for maintenance, shutdown and start-up.
		Static	Plastic lines, solvent velocities, earthing
		Spare Equipment	Critical equipment
		Safety	Lagging, fire fighting, toxic gas, safety showers, security etc.

- Documenting the Results

The recording process is an important part of the HAZOP study. The secretary assigned to write the minutes must be able to abstract the pertinent results from the myriad of conversations that occur during the meetings. It is impossible to manually record all that is said during the meetings, yet it is very important that all important ideas are preserved. Some analysts may decide to minimize their documentation effort by not pursuing (and not documenting) the causes of deviations for which there are no significant safety consequences. It may be helpful to have the team members review the final report and reconvene for a report review meeting. Reviewing key issues will often fine-tune the findings and uncover other problems. Normally, the results of HAZOP meetings are recorded in a tabular format.

A typical table for documenting the Minutes of the HAZOP Study Meeting is shown. Various formats exist but they all are all readily recognizable.

2.12 Preparing the Actions Report

10. The key document that is produced from the HAZOP Study is a HAZOP Study Actions Report. A typical structure for such a report is shown in the Table:

TABLE

Title : Sulphuric Acid Recovery System HAZOP STUDY

TABLE OF CONTENTS

There are several formats for producing a HAZOP Study Actions Report, varying in the level of details reported. Two types will be reviewed here. A full record of all components discussed and reviewed at the meeting may be recorded in the HAZOP Minutes section. This implies ALL Guidewords applied to ALL Process Parameters resulting in ALL the deviations.

Reports in full contain many pages and take a lot of time to prepare, however, they are comprehensive and represent a FULL record of the HAZOP meeting. From a legal stand point this may be the way HAZOPs will have to be reported in the future, so that there is a full record available in case an Accident Investigation is required.

The more realistic and favoured approach to HAZOP Study reporting contains records of only those items where the outcome is an Action. This does reduce the volume of the Minutes section of the HAZOP Report quite significantly. Therefore the HAZOP Study Report containing the Minutes or Record of the Recommendations is prepared and submitted to the Client Company with 3 to 7 days of completing the HAZOP Study.

The HAZOP Study Minutes are completed according to the format described earlier using the standard sheet, as shown on the next page.

In addition to the HAZOP Study Minutes another standard set of sheets are generated. There are the HAZOP Actions Close-Out Sheets and these will form the basis of the HAZOP Close-Out Report shown on the attached sheet. The first four columns are taken directly from the HAZOP Minutes sheets and the fifth column is completed by assigning the initials of the person responsible for that action. But the last three columns are left blank and are to be completed at the Close-Out Meeting described in Section 4.16.

HAZOP MINUTES

<table>
<tr><td colspan="3">System No. :</td><td colspan="2">System Name :</td><td>Page of</td></tr>
<tr><td colspan="3">Report of HAZOP Study</td><td>Client :</td><td>Project :</td><td>Content No. :</td></tr>
<tr><td colspan="3">Date :</td><td colspan="2">Present :</td><td>Report by:</td></tr>
<tr><td colspan="3">SYSTEM NUMBER :</td><td colspan="3">SYSTEM :</td></tr>
<tr><th>No</th><th>Guide Word</th><th>Deviation</th><th>Possible Causes</th><th>Possible Consequences</th><th>Action Required</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

HAZOP ACTIONS CLOSE-OUT

System No. :			System Name :			Page of	
Report of HAZOP Study			Client :	Project :		Report by :	
No	Guide Word	Deviation	Action Required	Action By	Action Taken	Checked By	Date

2.13 Taking the HAZOP Actions

11. 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.

    In fact, a HAZOP Study Report needs to be a verifiable record of the study, and all the statements made, especially the actions requested, need to be written so that they are readily understood by people who were not at the meeting.

    There is a difficulty when someone is asked to investigate a particular problem raised, but might also change the rest of the design in such a way that a new potential hazard is now possible.

    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 check that the changes proposed as a result of individual investigations do not over-ride the safeguards, which have been assumed to have been present, when the rest of the study was done.

2.14 Final HAZOP Close-Out Meeting

12. In order to make sure that the actions requested at the HAZOP Study have been taken, and at the same time that the actions requested as a result of the subsequent investigations have not invalidated the original study, it is desirable to hold a HAZOP Actions Close-Out Meeting.

    At this review 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, in the first instance, 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.

2.15 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**
372496A	37.3	Remove the isolation valve No.472X	Valve No. 472X does not appear on P&ID 372496B

Some of the actions may call for changes in operating instructions and in documents other than the P&ID. As revisions to operating instruction may take longer to achieve than merely updating a drawing, it is good for the auditor to also check what has happened as a result of this kind of action.

See further information on Design Safety Audits in Section 8.9.

3.0 HAZOP VARIATIONS

3.1 Concerns to Guard Against in a HAZOP

3.2 Computer HAZOP's

3.3 HAZOP Variations in Identifying Deviations

3.4 HAZOP Variations in Documenting the Study Report

3.5 Ranking (Prioritizing) HAZOP Actions

5.0 <u>HAZOP VARIATIONS</u>

3.1 <u>Concerns to Guard Against in a HAZOP</u>

3.1.1 DON'T GET CARRIED AWAY

It may be possible for a HAZOP team to get over enthusiastic and propose the installation of expensive equipment to guard against unlikely hazards. The team leader can counter this tendency by asking how often the hazard will occur and how serious the consequences will be. Sometimes he may suggest a full hazard analysis, but more often he can bring a problem into perspective by just quoting a few figures or asking a team member to do so. How often have similar pumps leaked in the past ?

3.1.2 DIFFERENT SORTS OF ACTIONS

The HAZOP team is mainly engineers. They like hardware solutions, but a hardware solution is sometimes impossible or too expensive and it is necessary to make a change in methods or improve the training of the operators - that is, a software solution. We cannot spend our way out of every problem.

Contractors, in particular, should select solutions suitable to the sophistication and experience of their client. It is no use installing elaborate trips if a client has neither the skill nor the will to use them.

The actions agreed should normally be changes (in equipment or procedures) to prevent deviations occurring (or to give protection against the consequences or to provide opportunities for recovery), not actions to deal with the results of the deviation (such as handling a leak or fighting a fire). Hazop teams may merely decide what they would do if a leak occurred, not how to <u>prevent</u> it.

3.1.3 MODIFICATIONS

Many people believe that hazop is unsuitable for small modifications because it is difficult to assemble a team every time we wish to install a new valve or sample point or raise the operating temperature. However, many accidents have occurred because modifications had unforeseen and unpleasant side-effects. If proposals are not 'hazoped', therefore, they should still be thoroughly probed before they are authorized. Try to answer the question "What is the worst thing that can go wrong".

All modifications should be 'hazoped' or considered in a similar way; sometimes a small specialist HAZOP group may be used.

3.1.4 'WE DON'T NEED A HAZOP, WE EMPLOY GOOD PEOPLE'

A hazop is no substitute for knowledge and experience. A HAZOP harnesses the knowledge and experience of a team in a systematic, planned way. However, many designs are so complicated the team cannot apply their knowledge and experience without this structured HAZOP approach for their thinking. If the HAZOP team does not have knowledge and experience the hazop will produce nothing worthwhile.

HAZOP ensures that hazards and operating problems are considered systematically by people from different functions working together. Experience shows that start-up, shut down and other abnormal conditions are often overlooked by functional groups working in isolation.

3.1.5 'DO IT FOR US'

Companies have been known to say to a design contractor, 'We are understaffed and you are the experts, so why don't you do the hazop for us ?'

The client should be involved as well as the contractor because the client will have to operate the plant. The hazop will give the client's staff an understanding of the reasons for various design features and help them write the operating instructions. The actions agreed at a hazop include changes in procedures as well as changes to equipment and while the contractor is responsible for the latter, the client is responsible for the former.

Hazops are used by many leading companies to train their operations staff and engineers.

3.1.6 KNOCK-ON EFFECTS

When a change in design (or operating conditions) is made during a hazop, it may have effects elsewhere in the plant, including the sections already studied.

For example, during a hazop, the team decided to connect an alternative cooling water supply to a heat exchanger. The original water supply was clean but the alternative was contaminated, and so the team had to change the grade of steel used for the heat exchanger and connecting lines. They also had to consider the effects of reverse flow in the original lines.

3.1.7 'LEAVE IT UNTIL THE HAZOP'

Design engineers have been known to say, when a change in design is suggested, 'I'm too busy now. We'll be having a hazop later on. Let's tackle it then'.

This is the wrong approach. A hazop is a final check on a basically sound design to make sure that no unforeseen effects have been overlooked. It should not replace the normal consultations and discussions that take place while a design is being developed. A hazop meeting is not the right place for redesigning the plant.

3.2 <u>Computer HAZOP's</u>

Computers are certainly be used as an aid to a hazop study. Several programs are available for recording the results of studies, and such programs may also act to remind teams of the possible causes various deviations and possible remedies so that they are less likely to overlook them. For example, if the team is considering 'no flow' in a pipeline, the computer can remind them that possible causes are an empty suction vessel, a pump failure (which in turn could be due to failure of the power supply, the motor, the coupling or the pump itself), a blockage, a closed valve, a slip-plate, a broken pipe or high pressure in the delivery vessel.

However, when considering if a computer could examine the line diagram, say what deviations can occur, and why, and suggest changes to the design or method of operation, perhaps using an expert system; the general opinion is NO or, at least, not within the forseeable future, for two reasons.

The first reason is that hazop is a creative exercise and those who are best at it are people who can let their minds go free and think of all the possible ways in which deviations might occur and possible methods of prevention and control.

The second reason is that the knowledge used in a hazop is ‘broad and deep’ while expert systems are suitable only for ‘narrow and deep’ knowledge.

Kletz “HAZOP and HAZAN” divides the knowledge used in a HAZOP into four types and gives the following four examples in the context of computer applications to HAZOPS.

- PLANT SPECIFIC KNOWLEDGE

For example, the monomer may polymerize if it is kept too long at reaction temperature. It should be possible to put this knowledge into an expert system but it would not be worth the effort as the information would be useful only for one study (and perhaps for later studies of plant extensions or modifications).

- GENERAL PROCESS ENGINEERING KNOWLEDGE

For example, a pump pumping against a dead head will overheat and this may lead to gland failure, a leak and a fire; if the residence time in a settling tank falls,

(i) Plant specific	The easiest to put into an expert system but not worth the effort as it would be used so little.
(ii) General process engineering	↓
(iii) General scientific	Difficulty of putting into an expert system increases.
(iv) Everyday (commonsense)	↓

Figure Types of knowledge.

settling may be incomplete. It should be possible in theory to put this knowledge into an expert system but the task would be enormous - a vast amount of knowledge would have to be incorporated, much of it ‘good engineering practice’ which is not usually written down. Expert systems are most suitable for restricted subject areas (knowledge domains). Furthermore, engineers ‘know what they don’t know” - know (or should know) the limitations of their knowledge and when they ought to call in an expert. It would be difficult to incorporate this ‘negative knowledge’ into an expert system. An expert system could be used during hazop to answer questions on, say, corrosion to avoid calling in a corrosion expert, but only the team can tell that they are getting out of their depth and that it is time to call in the expert (human or otherwise).

- GENERAL SCIENTIFIC KNOWLEDGE

  For example, water may freeze if the temperature falls below 0^{o}C; if a closed system full of liquid is heated, the pressure will rise. The difficulty of putting the knowledge into an expert system is even greater that in Case 2.

- COMPUTER SOFTWARE AIDS

  The following represent a number of commercially available software programs specifically designed to perform HAZOP Analysis studies; primarily in the manner already described,

  CAHAZOP
  (NUS Corporation, San Diego, California)

  HAZOP-PC
  (Primatech, Inc, Columbus, Ohio)

  HAZOPtimizer
  (A.D. Little, Cambridge, Massachusetts)

  HAZSEC
  (Technica, Inc., Columbus, Ohio)

  HAZTEK
  (Westinghouse Electric Corp., Pittsburgh, Pennsylvania)

  LEADER
  (JBF Associates, Inc., Knoxville, Tennessee)

  SAFEPLAN
  (Du Pont, Westlake Village, California)

  Standard word processing and spreadsheet software programs can also aid analysts in documenting the results of HAZOP Analysis studies.

3.3 HAZOP Variations in Identifying Deviations

The original guide word based HAZOP approach presented in this course is that developed by ICI.

One of the strengths of the guide-world approach is its ability to exhaustively identify process deviations for each study node, process section, or operating step. Systematically applying the complete list of various guide words of process parameters can lead to an overwhelming list of deviations for the team to evaluate. The advantage of this approach is that an inexperienced HAZOP leader and team can be fairly confident that they have considered all of the ways that a process can malfunction. The disadvantage is that an experienced team may be burdened by this rigorous, yet ponderous, approach if many of the guide-word-based deviations lead to "dead ends" from a hazard significance standpoint.

Two alternatives have emerged through practice as efficient ways for relatively experienced leaders and teams to generate the list of deviations : the ***library-based approach*** and the ***knowledge-based approach***. Both variations seek to increase the efficiency of the team meetings by minimizing the time spent in identifying the causes, effects, and safeguards of deviations that would obviously not result in an effect of interest.

The ***library-based approach*** is the most closely related alternative to the original guide-word approach. Before the HAZOP team meeting, the HAZOP leader surveys a standard library of potential deviations to determine which ones are relevant for each section. Depending upon the type of equipment involved (e.g. reactor, column, pump, tank, piping, heat exchanger), some potential deviations will not be relevant. For example, high level in a normally liquid-filled vessel would not be expected to create any significant hazard.

In addition, some hazardous deviations may be omitted from consideration if the analyst believes that evaluating upstream or downstream sections will identify these effects. For example, consider three process sections involving a feed line, a set of redundant centrifugal pumps, and a discharge line leading to a reactor. There is nothing gained by a team considering "High Flow", or other such deviations in the pump section if this same deviation and its effects have been considered elsewhere. The location of the effect of "High Flow" would normally be at the reactor. Since there are no credibly different causes and effects of "High flow" in the pump section itself, time can be saved if the team, does not have to reconsider the causes and effects of deviations in sections that are otherwise identified in upstream or downstream sections.

An example of a library that HAZOP leaders may use to select relevant deviations of concern before the HAZOP meetings is shown. Using this approach can save upto 20% to 50% in meeting time, depending upon the specific process, hazards of interest, and types of equipment involved. However, there is a possibility to inadvertently miss some deviations because the team did not participate in creating the library.

Table Example Library of Relevant Deviations

Deviation	Process Section Type[a]				
	Column	Tank/Vessel	Line	Heat Exchanger[b]	Pump[b]
High flow			X		
Low/no flow			X		
High level	X	X			
Low level	X	X			
High interface		X			
Low interface		X			
High pressure	X	X	X		
Low pressure	X	X	X		
High temperature	X	X	X		
Low temperature	X	X	X		
High concentration	X	X	X		
Low concentration	X	X	X		
Reverse/misdirected flow			X		
Tube leak				X	
Tube rupture				X	
Leak	X	X	X	X	X
Rupture	X	X	X	X	X

(from Guidelines for Hazard Evaluation Procedures)

[a]This library was developed for a specific strategy for defining a process section. Readers are cautioned not to blindly use this typical library or any other library without carefully reviewing it for relevance and completeness.

[b]This library assumes that other deviations (e.g. low flow, high temperature) are considered when examining the line downstream of these equipment items.

The ***knowledge-based approach*** is a variation of the guide-word HAZOP Analysis in which the guide words are supplemented or partially replaced by both the team's knowledge and specific checklists. This knowledge base is used to compare the design to well-established basic design practices that have been developed and documented from previous plant experience. The basic concept of this version of the HAZOP Analysis techniques is that the organization has extensive design method and that the lessons learned over many years of experience are incorporated into the company's practices and are available for use at all stages in the plant's design and construction. Therefore, the knowledge-based HAZOP Analysis study can help ensure that company's practices, and therefore its experience, have certainly been incorporated in the design.

Comparing a process design to codes and practices will generate additional questions that are different from the guide-world HAZOP Analysis deviations.

As a more specific example, consider the discharge from a centrifugal pump. The guide-word HAZOP approach would apply the guide word "Reverse" to identify the need for a check valve. The knowledge-based HAZOP approach might also identify the need for a check valve because an actual problem was experienced with reverse flow, and the use of check valves on a centrifugal pump discharge has been adopted as a standard practice.

It is also important to note that the experience-based checklists used in this variation of HAZOP may be of little value compared to the guide-word approach when portions of the process involve major changes in equipment technology or involve new chemistry.

3.4 HAZOP Variations in Documenting the Study Report

3.4.1 General

An outline of the methodology was given in an earlier section, basically giving a generally classification into two types of report. In one method ALL the deviations and causes were documented to provide a very full and comprehensive report for record purposes. The second method of reporting, we discussed, was the more popular reporting by exception approach of documenting the minutes of the HAZOP study in terms of the Actions to be taken items, only. However, many companies have developed their own ways of documenting their HAZOP results. Some of the more common ones are presented.

3.4.2 Deviation-by-deviation HAZOP table

In the deviation-by-deviation (DBD) approach, all causes, consequences, safeguards, and actions are related to a particular deviation. However, no correlation between individual causes, consequences, and safeguards for that deviation is expressed. Thus, all causes listed for a deviation do not necessarily result in all of the listed consequences, and specific cause/consequence/safeguard/action relationships are not explicitly identified. For example, high steam flow and external fire may both cause high temperature, but a sprinkler system is only an effective safeguard against the fire. Documenting a table using the DBD approach assumes that the correlation(s) among causes, consequences, safeguards, and actions can be understood by anyone reading the HAZOP TABLE. The DBD documentation approach is widely used because the table construction requires less time.

3.4.3 Cause-by-cause HAZOP table

In the cause-by-cause (CBC) approach, the HAZOP table correlates the consequences, safeguards, and actions to each particular cause of a deviation. A team may identify as many causes of a deviation as are appropriate, and every cause will have an independent set of consequences and safeguards related to it. For example, consider the deviation “pump leak”. If the first cause of that deviation is seal failure, the table would list all consequences, safeguards, and actions related to seal failures. The team would then proceed to the next cause, which might be pump casing flange failure. Therefore, by its very nature, CBC is more precise in the treatment of data than DBD. And CBC may reduce ambiguity in some instance. For example, a malfunctioning level controller may cause high level, but that same level controller may be a safeguard against high feed flow causing high level. Displaying the same item as both a cause and a safeguard, as in DBD, may be confusing. So if data for a particular table are potentially confusing, or if personal or company needs require that explicit safeguards be clearly defined for each cause, an HE team should consider using CBC for its documentation approach.

3.4.4 Exception-only HAZOP table

In this approach, the table includes only those deviations for which the team believes there are credible causes and significant effects. The advantage of this approach is that the resulting HAZOP meeting time and table length are greatly reduced. A major disadvantage is that it is almost impossible to audit such an analysis for completeness. This is especially important if the report could be subject to the scrutiny of a regulatory agency. The exception-only approach can be used with either the DBD or CBC format.

3.4.5 Action item-only HAZOP table

This variation is considered to be the minimal documentation acceptable from a HAZOP study. In this case, only the suggestions that a team makes for safety improvements are recorded. These action items can then be passed on for risk management decision making purposes. The advantage of this variation is that it can save meeting time and documentation time outside the meeting since no detailed table is prepared as a result of the team meetings. The disadvantage is that there is no documentation to audit the analysis for quality assurance or other purposes.

3.5 Ranking (Prioritizing) HAZOP Actions

Companies should consider the following activities to help them make the most effective use of the products of a study: (1) prioritize the analysis results, (2) document the hazard evaluation study, (3) develop a management response to the study, and (4) resolve the actions resulting from the risk management decision making process in a timely manner. Items (2), (3) and (4) are integral to a proper HAZOP Study, item (1) is optional.

It is sometimes difficult to rank the safety improvement suggestions from Hazard Analysis studies because the techniques generally do not provide definitive, quantitative characteristics useful for ranking purposes. This section describes a strategy for prioritizing HAZOP study recommendations should this option be required.

A frequent problem facing the users of the HAZOP study results is that the study team creates a long list of items for management to consider implementing in order to improve safety. In cases where this occurs, decision makers can rightfully wonder whether these results are of any practical use to them. They may ask, "Where do we start?" or "Which are the most important suggestions?"

To help management make these decisions, an efficient HAZOP team should give them as much information as possible. One way to do this is to rank the results of the HAZOP study. Ranking the safety improvement recommendations from the study allows management to prioritize the immediate efforts for resolution and follow-up.

The two most common criteria for ranking the safety improvement recommendations of HAZOP study are :

- The analysts' understanding of the *risk posed*
- The analysts' perception of the *risk reduction*

The first criterion ranks items based on their associated level of risk - it makes sense to resolve the most important problems first. The second criterion ranks proposed improvements by how much they will benefit the facility, not necessarily on how serious the problem is.

The table shows the techniques as they are normally applied, along with some extensions of the techniques that can easily be used to rank HE study results. For example, hazard analysts sometimes assign a "criticality" attribute to the severity associated with a component failure in an FMEA. This extension of the FMEA techniques is formally known as the Failure Modes, Effects, and Criticality Analysis (FMECA) method. Table 7.6 is an example of a FMECA table. Similar extensions can be made to any technique that provides information about the accident causes and effects (e.g. HAZOP Analysis).

Frequently, qualitative or semi-quantitative scales will be used - the Tables are examples of such scales. Typically, teams discuss the potential causes and effects of particular accident scenarios and assign them to frequency and consequence categories.

After Hazard analysts have assigned each accident scenario to frequency and consequence categories, a risk matrix (Figure) can be used to prioritize the action items associated with each potential accident. The size of the matrix and category definitions should be defined to meet the needs of the organization.

The Risk Ranking Categories Table lists descriptions of how some companies use a risk matrix to prioritize their response to safety improvement recommendations. The numbers in each risk matrix cell in the Figure correspond to the category numbers in the RRC Table. For example, accidents that are closer to the upper right corner of the risk matrix (Category I) are individually considered to be higher risk events (i.e. they have higher frequencies and/or higher consequences) than events below and to their left (Category II, III, or IV). If the frequency and consequence categories are selected consistently (i.e. if the same ratio between adjacent categories is used for both the frequency and consequence categories), event on a diagonal from the upper left to lower right are of equivalent risk. This is because risk is the combination of frequency and consequence (e.g. often expressed as a simple mathematical product); therefore, the apparent decrease in risk from being a frequency category lower (i.e. one horizontal row down) is offset by being a consequence category higher (i.e. one vertical row to the right). In this example, a HAZOP team would rank accident scenarios in the upper right region as presenting greater risk than ones toward the lower left. Likewise, any recommendation the team makes for reducing the risk of these scenarios would be ranked accordingly.

If a hazard evaluation study provides information about specific accident scenarios as well as recommendations for improving safety, the recommendations can be ranked by the scenarios they address and the extent to which the team believes the recommendation will reduce the risk. These risk-based ranking methods represent the most balanced view possible in that the team considers both frequency and consequence in determining the importance of their suggestions. The RRC Table lists examples of how a HAZOP team might categorize recommendations from a HAZOP study using the risk matrix in the Figure.

Table **Consequence Categories**

Public Safety		Employee Safety	
Category	Description	Category	Description
1	No injury or health effects	1	No injury or occupational safety impact
2	Minor injury or minor health effects	2	Minor injury or minor occupational illness
3	Injury or moderate health effects	3	Injury or moderate occupational illness
4	Death or severe health effects	4	Death or severe occupational illness

Production Loss		Facility/Equipment Damage (Millions of Dollars)	
Category	Description	Category	Description
1	Less than one week	1	Less than 0.1
2	Between one week and one month	2	Between 0.1 and 1
3	Between one and six months	3	Between 1 and 10
4	More than six months	4	Above 10

Source : JBF Associates, Inc.

Table Frequency Categories

Category	Description
1	Not expected occur during the facility lifetime
2	Expected to occur no more than once during the facility lifetime
3	Expected to occur several times during the facility lifetime
4	Expected to occur more than once in a year

Source : JBF Associates, Inc.,

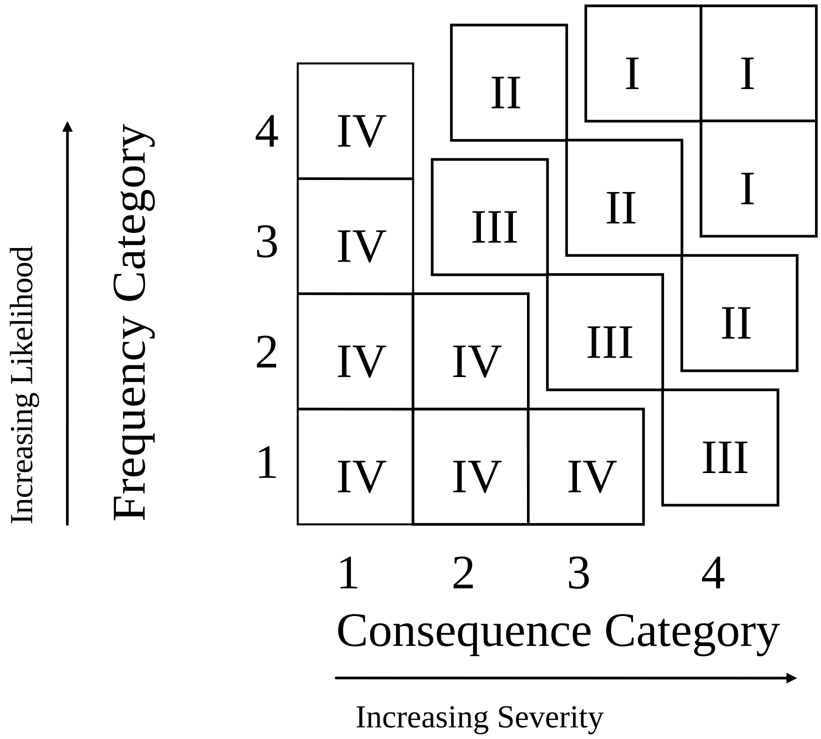


Figure Risk matrix

Table Risk Ranking Categories

Number	Category	Description
I	Unacceptable	Should be mitigated with engineering and/or administrative controls to a risk ranking of III or less within a specified time period such as six months
II	Undesirable	Should be mitigated with engineering and/or administrative controls to a risk ranking of III or less within a specified time period such as 12 months
III	Acceptable with controls	Should be verified that procedures or controls are in place
IV	Acceptable as is	No mitigation required

Source : Stone and Webster Engineering Corporation

4.0 HAZOP LIMITATIONS

- STRENGTHS AND WEAKNESSES

4.1 Strengths of the HAZOP Study

4.2 Weaknesses of the HAZOP Study

4.0 HAZOP LIMITATIONS - STRENGTHS AND WEAKNESSES

4.1 Strengths of the HAZOP Study

- HAZOP's Work

  Firstly, it must be emphasized that the technique does work. It is very methodical and systematic. It identifies the chain of cause to consequence of the hazard. This facilitates risk assessment and the design of preventative and mitigating measures. Subsequent designs are improved by a more systematic approach.

- Benefits of Synergy

  Team synergy is promoted. Operating problems are identified and communicated to the design team. In turn, participation by operating personnel promotes training and design acceptance. The meetings are potentially efficient in distributing information, actions and reviewing actions.

- HAZOPs are Good Economics

  Despite the costs of keeping a team together for several days there are many detailed studies which show HAZOP's save a lot of money from the costs of accidents and more effective plant operability. Reports on several major accidents have shown a well-done HAZOP would have identified the potential hazards that initiated the major disasters.

- Time Saving

  Engineers and designers have to allocate valuable working time to attend HAZOP meetings. However, experience has shown that the time spent in carrying out a HAZOP, though it may delay completion of a design, earns more than its payback time in a smoother start-up, earlier production level attainment and trouble free operation.

- Legislation

  Auditors from the Health and Safety Authorities and from the Environmental Protection Agency look for how PHA is dealt with in a company. Correctly performed HAZOP's satisfy this criteria completely. OSHA specify certain plants must HAZOP

  – any time there is a modification or process change;
  – every two years on hazardous process plant;
  – every five years on standard process plants.

4.2 Weaknesses of the HAZOP Study

- Too Early/Too Late?

However, hazops should not be seen as the answer to all our problems. Process hazards are identified but hazards due to layout or the failure of components in detail are often missed. They are only as good as the information that is used and the people who use it. If the hazop is carried out on an early version of the design, it will be necessary to re-hazop. Deviations from the proposal are considered rather than alternatives.

The conventional HAZOP is normally carried out late in design. It brings hazards and operating problems to light at a time when they can be put right with a drawing change rather than a mechanical engineering operation, but at a time when it is too late to make fundamental changes in design.

- Team Selection

Team selection is important. The study team must be committed and determined and encouraged to do a good job. The procedure suffers from the usual weaknesses of group discussion, which must be controlled. Fatigue leads to poor application and lack of concentration, and familiarity with the process can lead to boredom.

There is a tendency to solve problems - immediately! Follow-up can be weak, especially when there is no budget for changes.

- Costs

HAZOP's are based on teams of people and the systematic approach does require time, consequently costs are high. However, it is widely accepted by HAZOP users that the end justifies the means (Seveso, Bhopal etc. etc.). Small specialist teams are often used to HAZOP small projects.

The Perfect Solution

HAZOPs are only as good as the knowledge and experience of the people present. If they do not understand or know what is taking place then the HAZOP study will not identify the hazards.

Consider the following example to highlight this point.

An account of an incident not foreseen during the hazop study will illustrate a limitation of the technique.

A plant was fitted with blowdown valves which were operated by high-pressure gas. On a cold day, a leak on the plant caught fire. The operators isolated the feed and tried to blow off the pressure in the plant. The blowdown valves failed to open as there was some water in the impulse lines and it had frozen. As a result the fire continued for longer and caused more damage than it would otherwise have done.

How the water got into the impulse lines was at first a mystery. At a hazop two years earlier, when the plant was modified, the team were asked if water could get into the impulse lines and they said ‘No’.

Occasionally the valves had to be operated during a shutdown, when no high-pressure gas was available. The maintenance team were asked to operate the valves but not told how to do so. They used water and a hydraulic pump. None of the hazop team, which included the operator shop steward, knew that the valves had been operated in this way.

“Hazops are only as good as the knowledge and experience of the people present. If they do not know what goes on, the hazop cannot bring out the hazards.”