Risk Assessment
9. HAZOP

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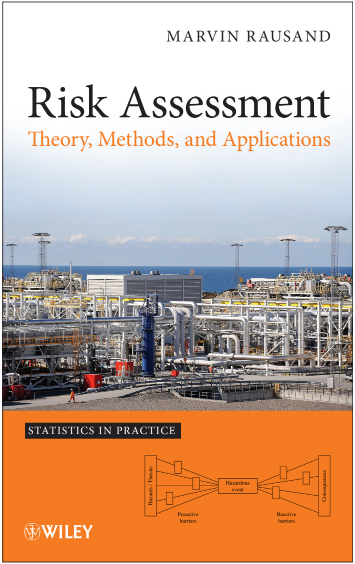
Slides related to the book

Risk Assessment
Theory, Methods, and Applications

Wiley, 2011

Homepage of the book:
http://www.ntnu.edu/ross/books/risk



What is HAZOP?

A Hazard and Operability (HAZOP) study is a structured and systematic examination of a planned or existing *process* or *operation* in order to identify and evaluate problems that may represent risks to personnel or equipment, or prevent efficient operation.

The HAZOP technique was initially developed to analyze *chemical process* systems, but has later been extended to other types of systems and also to complex operations and to software systems.

A HAZOP is a qualitative technique based on *guide-words* and is carried out by a multi-disciplinary team (*HAZOP team*) during a set of meetings.

HAZOP objectives

- Identify all deviations from the way a system is intended to function: their causes, and all the hazards and operability problems associated with these deviations.
- Decide whether actions are required to control the hazards and/or the operability problems, and if so, identify the ways in which the problems can be solved.
- Identify cases where a decision cannot be made immediately, and decide on what information or actions are required.
- Ensure that actions decided are followed up.
- Make operator aware of hazards and operability problems.

When to perform a HAZOP? - 1

The HAZOP study should preferably be carried out as early in the design phase as possible – to have influence on the design. On the other hand; to carry out a HAZOP we need a rather complete design. As a compromise, the HAZOP is usually carried out as a final check when the detailed design has been completed.

A HAZOP study may also be conducted on an existing facility to identify modifications that should be implemented to reduce risk and operability problems.

When to perform a HAZOP? - 2

HAZOP studies may also be used more extensively, including:

- At the initial concept stage when design drawings are available
- When the final piping and instrumentation diagrams (P&ID) are available
- During construction and installation to ensure that recommendations are implemented
- During commissioning
- During operation to ensure that plant emergency and operating procedures are regularly reviewed and updated as required

– From Kyriakdis (2003)

HAZOP history

- The basis for HAZOP was laid by ICI in 1963 and was based on so-called “critical examination” techniques
- First guide: “A Guide to Hazard and Operability Studies”, ICI and Chemical Industries Associations Ltd. 1977.
- First main textbook: Kletz, T. A.: *“Hazop and Hazan – Identifying and Assessing Process Industry Hazards”*, Institution of Chemical Engineers.
- See also: Kletz, T. A.: “Hazop – past and future”. *Reliability Engineering and System Safety*, 55:263-266, 1997.

Standards and guidelines

- IEC 61882. *"Hazard and operability studies (HAZOP studies) – Application guide"*. International Electrotechnical Commission, Geneva.
- Crawley, F., M. Preston, and B. Tyler: *"HAZOP: Guide to best practice. Guidelines to best practice for the process and chemical industries"*. European Process Safety Centre and Institution of Chemical Engineers, 2000
- Kyriakdis, I.: *"HAZOP – Comprehensive Guide to HAZOP in CSIRO"*, CSIRO Minerals, National Safety Council of Australia, 2003

Types of HAZOP

- Process HAZOP
  - The HAZOP technique was originally developed to assess plants and process systems
- Human HAZOP
  - A “family” of specialized HAZOPs. More focused on human errors than technical failures
- Procedure HAZOP
  - Review of procedures or operational sequences Sometimes denoted SAFOP – SAFe Operation Study
- Software HAZOP
  - Identification of possible errors in the development of software

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Only Process HAZOP and Procedure HAZOP are covered in this presentation.

Team member responsibilities

- HAZOP team leader
  Responsibilities:
  - Define the scope for the analysis
  - Select HAZOP team members
  - Plan and prepare the study
  - Chair the HAZOP meetings
    - Trigger the discussion using guide-words and parameters
    - Follow up progress according to schedule/agenda
    - Ensure completeness of the analysis

The team leader should be independent (i.e., no responsibility for the process and/or the performance of operations)

Team member responsibilities

- HAZOP secretary
  Responsibilities:
  - Prepare HAZOP work-sheets
  - Record the discussion in the HAZOP meetings
  - Prepare draft report(s)

Team members

- HAZOP team members

  The basic team for a process plant may be:

  - Project engineer
  - Commissioning manager
  - Process engineer
  - Instrument/electrical engineer
  - Safety engineer

  Depending on the actual process the team may be enhanced by:

  - Operating team leader
  - Maintenance engineer
  - Suppliers representative
  - Other specialists as appropriate

How to be a good HAZOP participant

- Be active! Everybody's contribution is important
- Be to the point. Avoid endless discussion of details
- Be critical in a positive way – not negative, but constructive
- Be responsible. Shee who knows should let the others know

HAZOP meeting - 1

Proposed agenda:

1. Introduction and presentation of participants
2. Overall presentation of the system/operation to be analyzed
3. Description of the HAZOP approach
4. Presentation of the first node or logical part of the operation
5. Analyze the first node/part using the guide-words and parameters
6. Continue presentation and analysis (steps 4 and 5)
7. Coarse summary of findings

HAZOP meeting - 2

Focus should be on potential hazards as well as potential operational problems

Each session of the HAZOP meeting should not exceed two hours.

HAZOP recording

The findings are recorded during the meeting(s) using a *HAZOP work-sheet*, either by filling in paper copies, or by using a computer connected to a projector (recommended).

HAZOP work-sheet

The HAZOP work-sheets may be different depending on the scope of the study – generally the following entries (columns) are included:

1. Ref. no.
2. Guide-word
3. Deviation
4. Possible causes
5. Consequences
6. Safeguards
7. Actions required (or, recommendations)
8. Actions allocated to (follow-up responsibility)

Prerequisites

As a basis for the HAZOP study the following information should be available:

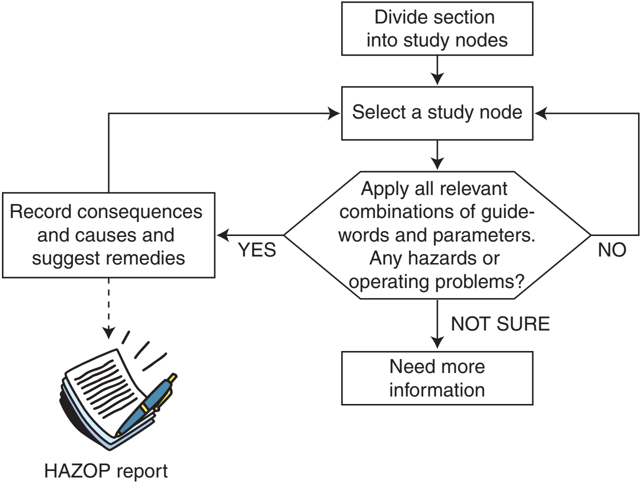
- Process flow diagrams
- Piping and instrumentation diagrams (P&IDs)
- Layout diagrams
- Material safety data sheets
- Provisional operating instructions
- Heat and material balances
- Equipment data sheets Start-up and emergency shut-down procedures

HAZOP procedure

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

HAZOP procedure

The HAZOP procedure may be illustrated as follows:



Modes of operation

The following modes of plant operation should be considered for each node:

- Normal operation
- Reduced throughput operation
- Routine start-up
- Routine shutdown
- Emergency shutdown
- Commissioning
- Special operating modes

– Based on Kyriakdis (2003)

Process HAZOP work-sheet

<table>
<tr><td colspan="7">Study title:</td><td colspan="3">Page: of</td></tr>
<tr><td colspan="3">Drawing no.:</td><td colspan="4">Rev no.:</td><td colspan="3">Date:</td></tr>
<tr><td colspan="7">HAZOP team:</td><td colspan="3">Meeting date:</td></tr>
<tr><td colspan="10">Part considered:</td></tr>
<tr><td colspan="3">Design intent:</td><td colspan="2">Material:
Source:</td><td colspan="5">Activity:
Destination:</td></tr>
<tr><td>No.</td><td>Guide-word</td><td>Element</td><td>Deviation</td><td>Possible causes</td><td>Conse-quences</td><td>Safeguards</td><td>Comments</td><td>Actions required</td><td>Action allocated to</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

– Source: IEC 61882

Work-sheet entries - 1

- Node
  A node is a specific location in the process in which (the deviations of) the design/process intent are evaluated. Examples might be: separators, heat exchangers, scrubbers, pumps, compressors, and interconnecting pipes with equipment.
- Design intent
  The design intent is a description of how the process is expected to behave at the node; this is qualitatively described as an activity (e.g., feed, reaction, sedimentation) and/or quantitatively in the process parameters, like temperature, flow rate, pressure, composition, etc.

Work-sheet entries - 2

- Deviation
  A deviation is a way in which the process conditions may depart from their design/process intent.
- Parameter
  The relevant parameter for the condition(s) of the process (e.g. pressure, temperature, composition).

Work-sheet entries - 3

- Guideword
  A short word to create the imagination of a *deviation* of the design/process intent. The most commonly used *guide-words* are: no, more, less, as well as, part of, other than, and reverse.

  In addition, guidewords such as too early, too late, instead of, are used; the latter mainly for batch-like processes. The *guidewords* are applied, in turn, to all the *parameters*, in order to identify unexpected and yet credible *deviations* from the design/process intent.

Guide-word + Parameter → Deviation

Work-sheet entries - 4

- Cause
  The reason(s) why the *deviation* could occur. Several *causes* may be identified for one *deviation*. It is often recommended to start with the causes that may result in the worst possible consequence.
- Consequence
  The results of the *deviation*, in case it occurs. *Consequences* may both comprise process hazards and operability problems, like plant shut-down or reduced quality of the product. Several *consequences* may follow from one cause and, in turn, one *consequence* can have several *causes*

Work-sheet entries - 5

- Safeguard
  Facilities that help to reduce the occurrence frequency of the *deviation* or to mitigate its *consequences*.

Safeguard types

1. Identify the deviation (e.g., detectors and alarms, and human operator detection)
2. Compensate for the deviation (e.g., an automatic control system that reduces the feed to a vessel in case of overfilling it. These are usually an integrated part of the process control)
3. Prevent the deviation from occurring (e.g., an inert gas blanket in storages of flammable substances)
4. Prevent further escalation of the *deviation* (e.g., by (total) trip of the activity. These facilities are often interlocked with several units in the process, often controlled by computers)
5. Relieve the process from the hazardous deviation (e.g., pressure safety valves (PSV) and vent systems)

Process parameters - 1

Process parameters may generally be classified into the following groups:

- Physical parameters related to input medium properties
- Physical parameters related to input medium conditions
- Physical parameters related to system dynamics
- Non-physical tangible parameters related to batch type processes
- Parameters related to system operations

– From Statoil Guideline HMS-T/99142

Process parameters - 2

The parameters related to system operations are not necessarily used in conjunction with guide-words:

- Instrumentation
- Relief
- Start-up / shutdown
- Maintenance
- Safety / contingency
- Sampling

Examples of process parameters

Flow	Composition	pH
Pressure	Addition	Sequence
Temperature	Separation	Signal
Mixing	Time	Start/stop
Stirring	Phase	Operate
Transfer	Speed	Maintain
Level	Particle size	Services
Viscosity	Measure	Communication
Reaction	Control	

Guidewords

The basic HAZOP guide-words are:

Guide-word	Meaning	Example
No (not, none)	None of the design intent is achieved	No flow when production is expected
More (more of, higher)	Quantitative increase in a parameter	Higher temperature than designed
Less (lessof, lower)	Quantitative decrease in a parameter	Lower pressure than normal
As well as (more than)	An additional activity occurs	Other valves closed at the same time (logic fault or human error)
Part of	Only some of the design intention is achieved	Only part of the system is shut down
Reverse	Logical opposite of the design intention occurs	Back-flow when the system shuts down
Other than (other)	Complete substitution - another activity takes place	Liquids in the gas piping

Additional guidewords

Guide-word	Meaning
Early / late	The timing is different from the intention
Before / after	The step (or part of it) is effected out of sequence
Faster / slower	The step is done/not done with the right timing
Where else	Applicable for flows, transfer, sources and destinations

Guideword & parameter - 1

Some examples of combinations of guide-words and parameters:

- NO FLOW
  Wrong flow path – blockage – incorrect slip plate – incorrectly fitted return valve – burst pipe – large leak – equipment failure – incorrect pressure differential – isolation in error
- MORE FLOW
  Increase pumping capacity – increased suction pressure – reduced delivery head – greater fluid density - exchanger tube leaks – cross connection of systems – control faults

Guideword & parameter - 2

- MORE TEMPERATURE
  Ambient conditions – failed exchanger tubes – fire situation – cooling water failure – defective control – internal fires

– Many more examples in Kyriakdis (2003)

What is a procedure HAZOP?

A procedure HAZOP is an examination of an existing or planned operation (work) procedure to identify hazards and causes for operational problems, quality problems, and delays.

- Can be applied to all sequences of operations
- Focus on both human errors and failures of technical systems
- Best suited for detailed assessments, but can also be used for coarse preliminary assessments
- Flexible approach with respect to use of guide-words

Procedure

- Breakdown of operation (work) procedure to suitable steps
- Define intention of each step
- Establish boundary conditions

else as
conventional Process HAZOP

- Apply guide-words to intention and boundary conditions for each step.

Guidewords

Guide-word	Meaning
No (not, none)	None of the design intent is achieved
More (more of, higher)	Quantitative increase in a parameter
Less (lessof, lower)	Quantitative decrease in a parameter
As well as (more than)	An additional activity occurs
Part of	Only some of the design intention is achieved
Reverse	Logical opposite of the design intention occurs
Other than (other)	Complete substitution - another activity takes place

Alternative guidewords - 1

Guide-word	Meaning
Unclear	Procedure written in confusing and ambiguous fashion
Step in wrong place	Procedure will lead to actions out of correct sequence or recovery failure
Wrong action	Procedure action specified is incorrect
Incorrect information	Information being checked prior to action is incorrectly specified
Step omitted	Missin step, or steps too large, requiring too much of the operator
Step unsuccessful	Step likely to be unsuccessful due to demands on operator
Interference effects from others	Procedure-following performance likely to be affected by other personnel carrying out simultaneous tasks (usually when co-located)

– Adapted from B. Kirwan

Alternative guidewords - 2

Parameter	Guide-word / deviation
Time	Too early, too late
Sequence	Wrong sequence, omissions, wrong action
Procedure	Not available, not applicable, not followed
Measurement	Instrument failure, observation error
Organization	Unclear responsibilities, not fitted for purpose
Communication	Failed equipment, insufficient/incorrect information
Personnel	Lack of competence, too few, too many
Position	Wrong position, movement exceeding tolerences
Power	Complete loss, partly lost
Weather	Above limitations - causing delayed operation

Report contents

Summary

1. Introduction
2. System definition and delimitation
3. Documents (on which the analysis is based)
4. Methodology
5. Team members
6. HAZOP results
   - Reporting principles
   - Classification of recordings
   - Main results

Appendix 1: HAZOP work-sheets

Appendix 2: P&IDs (marked)

Review meetings

Review meetings should be arranged to monitor completion of agreed actions that have been recorded. The review meeting should involve the whole HAZOP team. A summary of actions should be noted and classified as:

- Action is complete
- Action is in progress
- Action is incomplete, awaiting further information

– Based on Kyriakdis (2003)

HAZOP Results

- Improvement of system or operations
  - Reduced risk and better contingency
  - More efficient operations
- Improvement of procedures
  - Logical order
  - Completeness
- General awareness among involved parties
- Team building

Advantages

- Systematic examination
- Multidisciplinary study
- Utilizes operational experience
- Covers safety as well as operational aspects
- Solutions to the problems identified may be indicated
- Considers operational procedures
- Covers human errors
- Study led by independent person
- Results are recorded

Success factors

- Accuracy of drawings and data used as a basis for the study
- Experience and skills of the HAZOP team leader
- Technical skills and insights of the team
- Ability of the team to use the HAZOP approach as an *aid* to identify deviations, causes, and consequences
- Ability of the team to maintain a sense of proportion, especially when assessing the severity of the potential consequences.

Pitfalls and objections

- Time consuming
- Focusing too much on solutions
- Team members allowed to divert into endless discussions of details
- A few of the team members dominate the discussion
- "This is my design/procedure"
  - Defending a design/procedure
  - HAZOP is not an audit
- "No problem"
- "Wasted time"