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.
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.
Standards and guidelines


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

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)
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
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
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).
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
9. Record information
10. Repeat procedure (from step 2)
The HAZOP procedure may be illustrated as follows:

1. Select a study node
2. Apply all relevant combinations of guide-words and parameters. Any hazards or operating problems?
   - Yes: Record consequences and causes and suggest remedies
   - No: Need more information
   - Not sure: Divide section into study nodes
3. HAZOP report

S. Haugen & M. Rausand (RAMS Group)
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>
<thead>
<tr>
<th>Study title:</th>
<th>Page:</th>
<th>of</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawing no.:</td>
<td>Rev no.:</td>
<td>Date:</td>
</tr>
<tr>
<td>HAZOP team:</td>
<td>Meeting date:</td>
<td></td>
</tr>
<tr>
<td>Part considered:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design intent:</td>
<td>Material:</td>
<td>Activity:</td>
</tr>
<tr>
<td>Source:</td>
<td>Destination:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No.</th>
<th>Guide-word</th>
<th>Element</th>
<th>Deviation</th>
<th>Possible causes</th>
<th>Consequences</th>
<th>Safeguards</th>
<th>Comments</th>
<th>Actions required</th>
<th>Action allocated to</th>
</tr>
</thead>
</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).
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*.
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

<table>
<thead>
<tr>
<th>Process Parameter</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>Composition</td>
</tr>
<tr>
<td>Pressure</td>
<td>Addition</td>
</tr>
<tr>
<td>Temperature</td>
<td>Separation</td>
</tr>
<tr>
<td>Mixing</td>
<td>Time</td>
</tr>
<tr>
<td>Stirring</td>
<td>Phase</td>
</tr>
<tr>
<td>Transfer</td>
<td>Speed</td>
</tr>
<tr>
<td>Level</td>
<td>Particle size</td>
</tr>
<tr>
<td>Viscosity</td>
<td>Measure</td>
</tr>
<tr>
<td>Reaction</td>
<td>Control</td>
</tr>
<tr>
<td>pH</td>
<td>Sequence</td>
</tr>
<tr>
<td></td>
<td>Signal</td>
</tr>
<tr>
<td></td>
<td>Start/stop</td>
</tr>
<tr>
<td></td>
<td>Operate</td>
</tr>
<tr>
<td></td>
<td>Maintain</td>
</tr>
<tr>
<td></td>
<td>Services</td>
</tr>
<tr>
<td></td>
<td>Communication</td>
</tr>
</tbody>
</table>
### Guidewords

The basic HAZOP guide-words are:

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

<table>
<thead>
<tr>
<th>Guide-word</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early / late</td>
<td>The timing is different from the intention</td>
</tr>
<tr>
<td>Before / after</td>
<td>The step (or part of it) is effected out of sequence</td>
</tr>
<tr>
<td>Faster / slower</td>
<td>The step is done/not done with the right timing</td>
</tr>
<tr>
<td>Where else</td>
<td>Applicable for flows, transfer, sources and destinations</td>
</tr>
</tbody>
</table>
Some examples of combinations of guide-words and parameters:

- **NO FLOW**

- **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.
<table>
<thead>
<tr>
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<tr>
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<td>Quantitative increase in a parameter</td>
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</tbody>
</table>
## Alternative guidewords - 1

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

– Adapted from B. Kirwan
## Alternative guidewords - 2

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