

# Practical HAZOPS For Engineers and Technicians

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**Presents**

**Practical HAZOPS  
For Engineers and Technicians**

*Revision 4*

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First published 2007.

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ISBN: 978-1-921007-064

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### **Acknowledgements**

IDC Technologies expresses its sincere thanks to all those engineers and technicians on our training workshops who freely made available their expertise in preparing this manual.

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# Glossary

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## Abbreviations and terminologies used in this manual or relevant to hazard studies and safety instrumented systems

### **AECI**

South African Chemicals manufacturing company. Originally part of the ICI Chemicals Group the company produced a wide-ranging manual on HAZOP procedures based on many years of practical experience within the ICI group.

### **ALARP**

As Low As Reasonably Practicable. The UK Health and Safety Executive (HSE) adopted this expression to describe the principle that can be applied to determine if an acceptably low risk of harm has been achieved when safety measures are applied to potentially hazardous situation. See Chapter 6.

### **Architectural constraints**

Refers to the need for fault tolerant structures to be provided in SIS sub systems where safe failure cannot always be assured. In practice this means 2 or more redundant devices are needed to achieve high SIL ratings unless very safe failure fractions can be shown. See IEC 61511-1 clause 11.4

### **Availability**

The probability that an item of equipment or a control system will perform its intended task. It is often expressed as a percentage of the time per year of use

### **BPCS: Basic Process Control System**

Generic term used to describe any control system equipment provided for the normal operation of a plant or machine. A BPCS may or may not include safety functions.

**Cause and effect diagram**

A matrix drawing showing the functional logic between inputs and outputs of a safety control system. (See also “FLD”).

**Common-cause failure**

Failure of a plant item or safeguarding system as a result of one or more events, originating from the same external or internal conditions, causing coincident failures of two or more separate channels in a multiple channel system.

**De-energized safe condition**

In this context: the electrical or pneumatic valves, which can shutdown the guarded process, are energized during the normal (safe) process situation. If an unsafe condition arises, the (spring-loaded) valve will close, because the energy is cut off.

**Demand mode**

Applies to a safety-instrumented system when the frequency of demands for operation is no greater than once per year. (Refer IEC 61511 –1). The safety performance in this mode is measured by the probability of failure on demand. See PFD. See high demand mode

**ELD**

Engineering Line Diagram. Often used as an alternative term for P&ID, especially mechanical plant applications. Can be used as a basis for plant definition in HAZOP.

**Emergency Shutdown or ESD**

Commonly used terminology to refer to the safeguarding systems intended to shutdown a plant in case of a process parameter limit-excess.

**E/E/PES (Electrical/electronic/programmable electronic system)**

System for control, protection or monitoring based on one or more electrical/electronic programmable electronic (E/E/PE) devices, including all elements of the system such as power supplies, sensors and other input devices, data highways and other communication paths, and actuators and other output devices.

**EPSC**

European Process Safety Centre.

This is an international industry-funded organisation that provides an independent technical focus for process safety in Europe. Based in Rugby, UK at the offices of the Institute of Chemical Engineers it is supported by many large chemical companies. The EPSC guide “HAZOP Guide to best practice” has been consulted extensively in the preparation of this manual. See Appendix 1 for reference details.

**ESD**

See Emergency shutdown system

**EUC (Equipment Under Control)**

Equipment, machinery, apparatus or plant used for manufacturing, process, transportation, medical or other activities. Scope includes the control system and its operators. (See in Chapter 2)

**EUC control system**

System that responds to input signals from the process and/or from an operator and generates output signals causing the EUC to operate in the desired manner. Basically those controls needed for normal operation of the plant excluding safety controls.

*Note* - The EUC control system includes input devices and final elements. See also BPCS.

**Fail-safe**

A control system response that, after one or multiple failures, lapses into a predictable safe condition.

**Failure modes**

In safety-instrumented systems, 4 types of failure mode are recognized:

Detected safe failure, (revealed fault).

Undetected safe failure. (An unrevealed fault that leads to a dangerous state)

Detected dangerous failure. A fault that is potentially dangerous but is detected by the system diagnostics, see revealed fault).

Undetected dangerous failure (A fault that prevents the system from providing its safety function and remains hidden within the system permanently or until found by periodic functional testing.)

**Fault**

IEC definition: *“abnormal condition that may cause a reduction in, or loss of, the capability of a functional unit to perform a required function”*.

**Fault tolerance**

IEC definition: *“ability of a functional unit to perform a required function in presence of faults or errors”*. Hence Fault tolerance level of 1 tolerates 1 dangerous failure without loss of safety function.

**F L D**

Functional Logic Diagram. A graphical representation of control system functions, showing the logic-gates and timers as well as the logic signal interconnections.

**FMEA**

Failure Mode and Effect Analysis. A numerical technique for assisting hazard analysis of mechanical or electronic equipment. Systematic component level analysis of the failures resulting from each component or subsystem within an electronic system (typically a process instrument). Also: FMECA: Criticality Analysis. Applies when FMEA is extended to identify dangerous or critical failure modes.

**Functional safety**

Safety that depends on the correct functioning of the SIS and other active protection layers. Hence a functional safety system provides safety by the way it functions. This distinguishes it from safety due to its presence such as a fire door or blast proof wall or a hard hat.

**HAZAN**

Generic abbreviation for Hazard analysis.

**Hazard analysis**

Describes the procedures for examining the possible causes of a hazard to decide the likelihood or hazardous event frequency. Hazard analysis methods therefore quantify the hazard. Sometimes confused with Hazard Identification. When the hazard analysis is extended to quantify the consequences of a hazardous event it becomes a risk assessment. See Chapter 8.

**Hazard study**

Generic term for any systematic method of identifying hazards and evaluating how they can be avoided.

**HAZID**

Hazard identification technique. Generic term, widely used, to describe any method of identifying hazards. These will include checklist methods, and guideword tables. Corresponds to preliminary process hazard analysis (PHA) or Hazard study level 2. See Appendix 4.

**High demand mode**

Where the frequency of demands for operation made on a safety-related system is greater than one per year (IEC 61511). High demand or continuous mode covers those safety-related systems that implement continuous control to maintain functional safety.

**HAZOP**

Term applied to the structured and systematic examination of a process or system in functional parts to find possible hazards and operability problems. HAZOP is one of a number of recognized hazard study methods.

**Logic Solver**

E/E/PES components or subsystems that execute the application logic. A relay system, solid-state logic, pneumatic logic or a PLC can perform this role.

**HIPPS**

High Integrity Pressure Protection System. Also called “Over Pressure Protection System”.

**HMI**

Human to Machine Interface or “operator interface”, usually a computer screen to present the actual process and system status.

**I ChemE**

UK Institution of Chemical Engineers.

**ICI**

ICI Ltd. Originally an abbreviation for Imperial Chemical Industries Ltd, major UK and international producer of chemicals, explosives, agri-chemicals, plastics and pharmaceuticals etc. ICI chemical plant design teams pioneered the development of HAZOP study method in the 1960s and many publications are based on the guidelines and experience arising from this organisation. (See AECI)

**IEC**

International Electrotechnical Commission. Based in Geneva. Develops a vast range of internationally supported standards. IEC 61882 is an established standard for HAZOP method.

**Inherently fail-safe**

A characteristic property of a device or a control system that causes it to revert to a non hazardous state if a failure occurs in the device. The fail-safe property derives from the principle itself and not from additional components or test circuits.

**ISA: Instrument Society of America**

Based in Research Triangle Park, North Carolina. Develops standards, technical reports and training material for the complete range of instrumentation with strong emphasis on process industries. See website list.

**Logic solver**

E/E/PES components or subsystems that execute the application logic. Electronic and programmable electronics include input/output modules. Some SIS functions do not require a logic solver.

**MTBF**

Mean time between failures. ( Statistical). This term is normally applied to serviceable equipment, typically instrument sensors, valves or PLCs. Hence normally used in SIS reliability calculations.

**MTTF**

Mean time to fail. This term is normally applied to disposable single life components such as relays or resistors, which are replaced when they fail. Numerically the same as MTBF when calculating reliability of a SIS.

**MTTR**

Mean Time To Repair. The mean time between the occurrence of a failure and the return to normal failure-free operation after a corrective action. This time also includes the time required for failure search and re-starting the system. Alternative: Mean Time To Restore.

**Nuisance failure**

See “Spurious Trip”

**Overt faults**

Faults that are classified as announced, detected, revealed, etc. Opposite of “covert fault”.

**PES**

Programmable Electronic System. Refers particularly to process control systems and safety control systems using digital electronics in the form of PLCs and DCS. Identifies devices that depend on software as well as hardware for their correct functioning.

**PFD (of a process)**

Process flow diagram. Line diagram showing the key features of process with material types and process conditions.

**PFD (of a safety device)**

Probability of Failure on Demand (PFD): The probability of a safety system failing to respond to a demand for action arising from a potentially hazardous condition.

**P&ID**

Piping and Instruments Diagram. Alternatively: Process and Instruments Diagram. Single or multiple set of drawings defining all process plant equipment and piping interconnections with all valves and line devices and includes details of controls and instrumentation.

**PID Controller**

Automatic control function employing proportional, integral and derivative functions of the deviation from set point to drive a corrective action in the process.

**PLC**

Programmable Logic Controller. Refers to industrial grade PLCs usually seen in BPCS duties. See safety PLC.

**Proof test**

A 100% functional test used to prove the availability of a safeguarding system.

**Redundancy (Identical and diverse):**

Identical redundancy involves the use of elements identical in design, construction and in function with the objective to make the system more robust for self-revealing failures. “Diverse redundancy” uses non-identical elements and provides a greater degree of protection against the potential for common cause faults. It can apply to hardware as well as to software.

**Reliability**

The probability that no functional failure has occurred in a system during a given period of time.

**Safety availability**

Probability that a SIS is able to perform its designated safety service when the process is operating. The average Probability of Failure on Demand (PFD<sub>avg</sub>) is the preferred term. (PFD equals 1 minus Safety Availability).

**Safety Instrumented Systems (SIS)**

System composed of sensors, logic solvers, and final control elements for the purpose of taking the process to a safe state when predetermined conditions are violated. Other terms commonly used include Emergency Shutdown System (ESD, ESS), Safety Shutdown System (SSD), and Safety Interlock System.

**Safety lifecycle**

Necessary activities involved in the implementation of safety-related systems, occurring during a period of time that starts at the concept phase of a project and finishes when all of the E/E/PE safety-related systems, other technology safety-related systems and external risk reduction facilities are no longer available for use.



**Safety PLC**

PLC or controller specially designed and configured for safety duties. The safety PLC is characterized by specialized software design to reduce the chances of systematic errors being introduced into its operating system and in its application software. The hardware system is provided with comprehensive internal diagnostic routines and techniques designed to check for the presence of known types of electronic faults. All diagnostics are designed to result in safe failure states of the safety functions.

**SCADA**

Supervisory Control and Data Acquisition. This term is most commonly applied to PC based equipment interfaced to plant via PLCs or input output devices.

**SIL**

Safety Integrity Level defining a PFD by order of magnitude, which is related to the risk involved in various types of processes. The SIL range is from 1 to 4 as defined in IEC 61508. Process plants are normally restricted to using SILs 1 to 3. See IEC 61511 part 1 clauses 9.2.3 and 9.2.4.

**Spurious trip**

A plant trip arising out of an overt or detected equipment failure in the SIS or an erroneous assessment of the situation. (E.g. error in the logic functions). A shutdown is initiated, though no demand for safety function response exists. Also referred to as a “false trip” or a “nuisance failure”. Spurious trips can contribute to the hazard rate of the plant through the disturbances so caused.

**Systematic failures**

Failures occurring in identical parts of a (redundant) system due to similar circumstances. History shows that also errors in specification, engineering, software and environmental factors, such as electrical interference or maintenance errors must be considered. Such faults can only be eliminated by a modification of the design or of the manufacturing process, operational procedures, documentation or other relevant factors.

**Trip**

A shutdown of the process or machinery by a safety system. The plant cannot start operating again until there is a manually initiated restart procedure.

**T Ü V: Technische Überwachungs Verein**

A testing laboratory in Germany that certifies safety of equipment in terms of compliance with international standards or German national standards. International representation in most industrial countries. TUV America offers wide-ranging services in SIS testing and evaluation. Best known in SIS for the TUV certification of components and logic solvers in conformity to IEC 61508.



## Introduction

### 1.1 General information

The HAZOP technique is widely recognized as the most effective method currently available for satisfying two basic requirements. The first is checking a new design for safety and operability problems whilst the piping and instrumentation diagram (P&ID) is being developed and finalized. The second is the identification of latent safety and operability problems in existing plant, which have yet to be revealed during operations.

The HAZOP technique is very powerful in terms of its ability to identify the potential for incidents. It is, however, a significant consumer of resources and needs to be an integral part of a project development activity. For this reason our training course begins by outlining the context of HAZOP studies within the legal and project frameworks that it serves.

HAZOP has developed over a number of years and there are a number of ways in which it is applied. This manual describes a typical approach to the technique, which is generally supported by well-established guide manuals and by an IEC standard. It has been prepared for two purposes:

- To be support material for a HAZOP training programme, which provides an insight into the technique for engineers new to HAZOP and gives more experienced people the opportunity for practice at an advanced level.
- To be a handbook for HAZOP facilitators when they carry out workshop studies and need to promote in their team an awareness of how the technique will be applied.

The successful practice of the technique is very dependent on the skills of the facilitator or HAZOP team leader. This manual identifies the leader's tasks and provides a first level of training in those duties. HAZOP leadership skills are largely based on the subsequent experience to be gained by the leader whilst making good use of the best available advice and guidance.

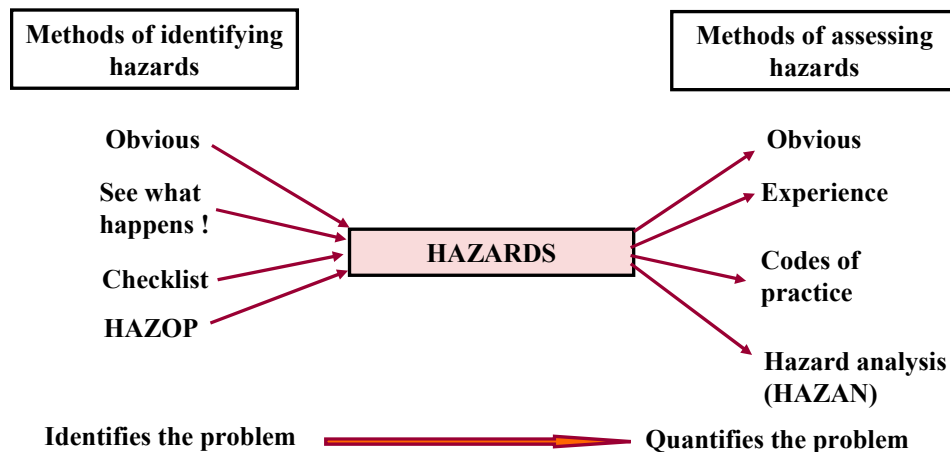
Both those who will participate in workshops, either as facilitator or team member, and those who will be recipients of workshop reports are encouraged to participate in this training to learn the behaviors necessary to contribute and respond optimally in the performance of a HAZOP workshop.

## 1.2 Workshop outline

The general plan of the workshop is to first build up an understanding of why HAZOP studies are done and how to conduct HAZOP studies. The workshop then highlights the tasks of the team leader and offers guidance on how these tasks can be performed. The workshop also outlines the principles of risk assessment and risk reduction and closes with a special section on safety instrumentation and the principles of SIL determination.

The best way to achieve competency in HAZOP is to practice the techniques in small study groups. The workshop provides practical exercises using simplified examples and these are intended for small groups of 3 or 4. Specimen answers are provided but the study groups may find additional items to note based on their own ideas or experiences. The key point here is that a HAZOP study must promote freethinking by the team members around each issue so that most possible problems can be identified. At the same time, the team leader must impose enough discipline to keep the study moving along without wasting time on issues that are of no consequence.

This workshop includes some outline training in methods of assessing hazards in terms of their likelihood and consequences. Such methods are broadly called Hazard Analysis or “HAZAN”. The long-established writer on chemical industry hazards, Trevor Kletz, advises that we must be careful to distinguish between HAZOP and HAZID methods, which search for possible hazards, and HAZAN, which evaluates known hazards for risk levels. Kletz uses the following diagram to explain the differences and we include it here as Figure 1.1 with acknowledgements.



**Figure 1.1**  
*Differences between HAZOP and HAZAN*

Please note that there is a glossary of abbreviations and terms placed at the beginning of the manual for help with the jargon and acronyms that inevitably arise from a technical subject.

Here is brief review of the path of study for the workshop:

Chapter 2 briefly describes what HAZOP is and why it is done so that we can get started with the concepts in mind.

Chapter 3 describes the background of plant safety and project needs that influence the timing and conduct of a HAZOP study. It also shows how HAZOP is part of a family of hazard studies that are used for a typical project from concept to final delivery and throughout its continuing life.

Chapter 4 provides an introduction to the overall HAZOP study method to allow you to become familiar with the general techniques as simply and as quickly as possible. It may be that you have already experienced this level of participation in HAZOPs but it should be helpful to refresh your understanding of the whole procedure in one package of notes.

Chapter 5 describes the HAZOP examination phase in more detail to build up competency in the techniques of structuring the study into nodes and in the application of guidewords and deviations to the operations being studied. This chapter also expands training in procedural HAZOPS, which are applied to a sequence of operations or procedures.

Chapter 6 then considers the role of the HAZOP team leader or facilitator and provides guidance on those duties including the reporting phase and on the problems of managing the study sessions. The leader's tasks can be most clearly seen once you have experienced some typical HAZOP study sessions and even when trying out the practical exercises.

Chapter 7 introduces the concepts of risk assessment and risk reduction and shows how these are related to the provision of safeguards, particularly using safety-instrumented systems. HAZOP study teams often call for instrumented trip and alarm solutions to unacceptable risk and therefore an understanding of risk reduction methods and Safety Integrity Levels (SILs) is helpful, particularly for the HAZOP team leader.

Chapter 8 introduces some methods of hazard analysis including failure mode and effects analysis (FMEA) and fault tree analysis (FTA). These are supporting tools that help with the understanding of the logic of failure modes and are used for the quantification of hazard rates once the possibility of hazard has been detected by the HAZOP stage.

Appendices are provided after Chapter 8. These contain useful references, guidewords and tables supporting HAZOP workshops.

Practical exercises are described at the back of the manual followed by some specimen answers.

### 1.3 Reference sources

The HAZOP techniques described in this manual are based on the recommendations, terminologies and procedures described in 3 widely accepted sources. These are:

1. **HAZOP and HAZAN:** Notes on the identification and assessment of hazards. By Trevor Kletz, published by I ChemE.
2. **HAZOP Guide to Best Practice** published jointly by The Chemical Industries Association (UK), I ChemE and the European Process Safety Centre (EPSC). References in our text to "The EPSC Guide" are references to this book.
3. **IEC 61882: HAZOP Guidance:** This IEC engineering standard provides a well defined set of procedures and terminologies for HAZOP and our training manual closely follows these as a definitive version.

Material for this course have also been sourced from previous and existing IDC Training Manuals, in particular:

- Training notes from earlier IDC HAZOP workshops have been integrated into this edition and IDC Technologies acknowledges with thanks the contribution of Max Barrie for much of the core material on HAZOP workshop techniques.
- **Practical HAZOPS, Trips and Alarms:** IDC Technologies' training manual that combines training in hazard studies with training in safety instrumented systems. Substantial material from this source has been adopted for this manual where we have more focus on the core training in HAZOP methods.

Further details on obtaining the above publications are to be found in Appendix 1.