PRIMATECH WHITE PAPER

HAZOP FUNDAMENTALS

- DESIGN INTENT, PARAMETERS, GUIDEWORDS, AND DEVIATIONS

Introduction

The hazard and operability (HAZOP) study is the most commonly used process hazard analysis (PHA) method in the world today. It is one of the techniques commonly accepted by regulators. The HAZOP method identifies deviations from design intent by applying guide words, such as No, More and Less, to aspects of the design intent (such as flow, temperature, pressure, addition, reaction, etc.) within parts of the process, called nodes, such as lines and vessels. A team of people then brainstorms causes of each deviation within each node and identifies the sequence of events that results, including safeguards that protect against them, and the consequences. Each sequence of events represents a scenario. Also, the team may identify improvements to reduce risk.

Design Intent

Design intent is the set of required or desired process behaviors, as intended by the process designers. The different aspects of design intent for a node are represented by parameters such as flow and pressure. Generally, numerous parameters are important for each node. The HAZOP method focuses on deviations from design intent because they represent potential problems, for example, lack of flow in a transfer line or overpressuring a vessel, that may result in hazard and operability scenarios.

There is no universal standard for what should be specified as part of the design intent for a process. Conceptually, the definition of design intent for a process may appear to be straightforward but practically it is challenging. Usually, the design intent for a process is complex with some aspects that are subtle. Of course, not all aspects of design intent need to be addressed in a HAZOP study but a determination needs to be made as to which aspects should be included. It is essential that HAZOP studies identify and consider all aspects of design intent for which deviations may result in scenarios within the scope and objectives of the study. Scenarios will be missed if the design intent is not defined fully and a complete set of deviations is not considered.

Unfortunately, HAZOP Study teams often define design intent simply by selecting process parameters from a checklist without full consideration of all key aspects of design intent. This practice likely results in missed scenarios. It is essential that study teams understand the meaning of design intent and consider all important aspects in studies to ensure that scenarios are identified as completely as possible. A preferred approach is to define the design intent for each process node as it is considered and extract parameters from it. This approach encourages a more complete treatment of design intent.

Parameters

Parameters describes a process:

- Physically, e.g. flow
- Chemically, e.g. composition
- In terms of what is happening, e.g. addition
- In other ways, e.g. specifications

Parameters are not always shown explicitly on design representations such as piping and instrumentation diagrams. HAZOP study teams must identify *relevant* parameters, i.e. those for which deviations could result in hazard scenarios within the study purpose, scope and objectives. This entails a systematic review of the process design.

Some parameters usually are obvious. For example, flow, temperature, pressure and composition are almost always potentially important. The importance of other common process parameters such as level, viscosity, and phase depends on the process and type of node considered. Other parameters depend on the situation being addressed. The HAZOP study team needs to brainstorm possible parameters to identify potentially important parameters such as:

- Materials
- Actions or operations being performed, e.g. addition
- Sources and destinations
- Functions, e.g. relief
- Specifications, e.g. for piping
- Environment, e.g. heated building
- Location, e.g. bermed area
- Time or timing, e.g. after catalyst addition
- Sequence or order, e.g. add acid to water

In considering parameters to address, the HAZOP study team should consider:

- Process parameters controlled
- Critical operating parameters listed in procedures
- Equipment present, e.g. stirrer
- Unit operations performed, e.g. separation
- Actions required by procedures
- Heat and material balances
- Parameters used in previous studies
- Knowledge / experience of PHA team members

Guidewords

Guidewords are simple words or phrases used to qualify or quantify the design intention. Deviations from design intent are generated by applying guide words to process parameters for each node:

Guideword + Parameter = Deviation

Usually, a standard set of guidewords is used (see table). For example, for an inlet line to a vessel, No + Flow = No Flow, or for a vessel, High + Pressure = High Pressure.

GUIDE WORD	MEANING	COMMENTS
NO (NOT, NONE)	Negation of design intent	No part of the intention is achieved *but nothing else happens.*
MORE (MORE OF)	Quantitative increase	The intention occurs in a way that is quantitatively greater. Usually applies to quantities, properties and activities.
LESS (LESS OF)	Quantitative decrease	The intention occurs in a way that is quantitatively lesser.
AS WELL AS (ALSO)	Qualitative increase	All of the intention is achieved *together with something else.*
PART OF	Qualitative decrease	Some of the intention is achieved *but some is not.*
REVERSE	Logical opposite	The opposite of the intention happens. Often applies to activities.
OTHER THAN	Complete substitution	No part of the intention is achieved *and something quite different happens.*

Guidewords should be used creatively to facilitate the process of identifying hazard scenarios, not constrain it. Common interpretations of guide word / parameter combinations are used but HAZOP study teams should be allowed to use their imagination in identifying deviations. There is no “correct” set of interpretations. The purpose of guide words is to facilitate creative exploration of deviations from design intent.

HAZOP study teams should not devise additional guide words unnecessarily. The standard set of guide words usually is sufficient. The use of additional guide words can result in confusion.

HAZOP study teams should avoid using guide words that are too specific or too general. Specific guide words, for example, “Maximum”, may limit the identification of deviations while general guide words, for example, “Vary”, may not focus the study sufficiently.

Deviations

The generation of deviations is the key aspect of HAZOP studies yet mistakes are commonly made by practitioners. The correct generation of deviations begins with an understanding of what is meant by each guideword (see table). Deviations should not just be selected from a standard set in a rote manner because important deviations likely will be missed. The generation of deviations should be part of the creative process of HAZOP studies. The purpose of using guide words is to facilitate creative exploration of deviations from design intent which helps to increase the chances of study completeness.

It is important to understand that any conceivable deviation from design intent can be generated by applying one of the standard guidewords to a process parameter, which is the power of the HAZOP study method. The challenge is to ensure that all important deviations are considered for each node by fully defining the design intent and generating a complete set of deviations from it.

In generating deviations, most practitioners do not have a problem in applying the guidewords No, More, and Less to common parameters such as Flow and Pressure. They generate deviations that are obvious. However, the combination of some guidewords and parameters may not produce an obvious deviation. For example, while No Flow is an obvious deviation, As Well As Flow is not meaningful as it stands. Here, practitioners must ask “What else can happen as flow is occurring?” One answer is a chemical reaction (e.g. polymerization, a chemical reaction, is a concern for flowing monomers as it may cause pipe blockages). Thus, “As Well As Flow” can rephrased as the more meaningful “Chemical Reaction”.

Similarly, “As Well As Composition” can be rephrased to produce the more meaningful “Contamination”. The logic in this case is that in addition to whatever materials are intended to be present in a node, additional, unintended materials are present, i.e. contaminants, hence the deviation, “Contamination”. It is also possible to combine Other Than with Flow to generate “Chemical Reaction”. In this case, a chemical reaction occurs instead of flow rather than in addition to it.

By way of counterexample, More Flow would not be an appropriate way to generate Chemical Reaction because the guideword “More” implies a quantitative increase, not a qualitative change. Note that Flow and some other parameters have multiple characteristics which can be important. Thus, Flow may be Flow Rate or Flow Quantity depending on the circumstances in the process.

Some practitioners confuse deviations with causes. For example, in a procedural PHA study, a maintenance step may involve replacing a check valve. Consider the application of the guideword “Reverse” to this action. What deviation might be generated by applying Reverse to Replace Check Valve. A clear contender would be “Backwards Installation of the Check Valve”. Novice practitioners may suggest “Improper Maintenance” as an appropriate deviation in this situation but that is the cause of the backwards installation of the check valve, not a deviation.

Some practitioners confuse deviations with consequences. For example, in a procedural PHA study, a maintenance step may involve replacing a gasket. Consider the application of the guideword “Other Than” to this action. What deviation might be generated by applying “Other Than” to “Replace Gasket”? One important characteristic of a gasket is its specification. Thus, Incorrect Gasket Specification would be a meaningful deviation in this case. Novice practitioners may suggest “Leak” as an appropriate deviation in this situation is but that would be a consequence of an incorrect gasket being installed, not a deviation.

Some practitioners confuse deviations with other deviations. For example, in the case of the check valve replacement, the practitioner may be thinking in terms of the consequences of reverse installation and believe that the result would be to obstruct flow. They then theorize that the appropriate deviation is No Flow. As we have seen, this is incorrect. Deviations are departures from the aspect of design intent expressed by the parameter, not the consequences of a deviation. The correct treatment of this situation in a HAZOP study would be to identify reverse installation of a check valve in a line as a cause of No Flow in the node containing the check valve.

Another example of the incorrect application of Reverse to Replace Check Valve would be to assign the deviation “Backflow” to this combination. However, backflow is a deviation in its own right, typically generated by applying Reverse to Flow.

A key test in deciding which combination of guideword and parameter makes sense for a deviation is to identify the attribute or aspect of the process that is addressed by the deviation. The parameter should then be clear and the appropriate guide word can be confirmed by reviewing their meanings. For example, if Missing Component is being considered as a deviation, on reflection, it should be obvious that the attribute of the process that is involved is composition. If a component is missing, some of the intention is achieved but some is not. Thus, Part Of is the clear choice as the most appropriate guideword.

Similarly, in considering the application of “Part Of” to “Composition”, a practitioner may suggest “Incorrect ratio of materials” as the deviation. Certainly, composition is related to the ratio of materials. However, the actual parameter in this case is the ratio of materials, not composition. Thus, it should be clear that this deviation is best viewed as resulting from the combination of “Other Than” with “Ratio of Materials”. It is also possible that “More” or “Less” could be applied if the concern is with adjusting the ratio of materials upwards or downwards, and even “Reverse” if the concern is with reversing the ratio of two materials.

In generating deviations, it is important to understand that not all guidewords generate meaningful deviations for all parameters, for example, No Temperature is not meaningful. Also, the same deviation can be generated by applying different guidewords to different parameters, for example, As Well As Flow and Other Than Flow to generate Chemical Reaction. Furthermore, multiple deviations may exist for the same guide word / parameter combination, for example, As Well As Flow can generate both Chemical Reaction and Foaming.

Deviations should be generated logically and consistently in HAZOP studies to alleviate confusion and they should be generated completely to reduce the chances of missing scenarios and producing an incomplete study.

Further Reading

Analytical Methods in Process Safety Management and System Safety Engineering – Process Hazards Analysis, in Handbook of Loss Prevention Engineering, Wiley-VCH, 2013.

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Guidelines for addressing limitations in the performance of HAZOP studies, Loss Prevention Bulletin, Issue 250, pages 21 - 24, August, 2016.

Design intent for hazard and operability (HAZOP) studies, Process Safety Progress, Volume 35, Issue 1, pages 36–40, March 2016.

Chemical Reactivity and Hazard and Operability (HAZOP) Studies, Loss Prevention Bulletin, Issue 244, August, 2015.

A critique of the hazard and operability (HAZOP) study, Journal of Loss Prevention in the Process Industries, Volume 33, Pages 52-58, January 2015

Requirements for improved process hazard analysis (PHA) methods, Journal of Loss Prevention in the Process Industries, Volume 32, Pages 182–191, November 2014.

