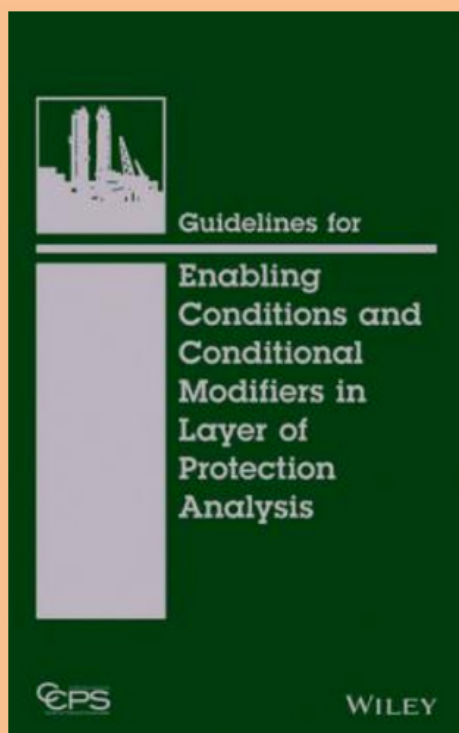


Guidelines for Enabling Conditions and Conditional Modifiers in Layers of Protection Analysis

A summary of the content of Guidelines for
Enabling Conditions and Conditional Modifiers
for Layer of Protection Analysis



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Abbreviations and Acronyms

AEGL Acute Exposure Guideline Level
AIChE American Institute of Chemical Engineers
AIHA American Industrial Hygiene Association
API American Petroleum Institute
BPCS Basic process control system
CCPS AIChE Center for Chemical Process Safety
CPI Chemical process industry
CPQRA Chemical Process Quantitative Risk Analysis
DDT Deflagration-to-detonation transition
DTL Dangerous Toxic Load
EPA U.S. Environmental Protection Agency
ERPG Emergency Response Planning Guideline
ETA Event Tree Analysis
FMEA Failure Modes and Effects Analysis
FMECA Failure Modes, Effects, and Criticality Analysis
FTA Fault Tree Analysis
HAZOP Hazard and Operability [Study]
IDLH Immediately Dangerous to Life and Health
IPL Independent protection layer
LCLO Lethal Concentration Low
LC50 Lethal Concentration, 50% mortality
LOPA Layer of Protection Analysis
LOPC Loss of primary containment
MAWP Maximum allowable working pressure
NFPA National Fire Protection Association
P Probability (dimensionless)
PFD Probability of failure on demand
PSV Pressure safety valve
QRA Quantitative risk analysis
RV Relief valve
SIF Safety instrumented function
SIS Safety instrumented system
SLOD Significant Likelihood of Death
SLOT Specified Level of Toxicity
U.K. United Kingdom
U.S. United States

1 Context

The Guidelines in this book characterize when and how to apply enabling conditions and conditional modifiers to Layer of Protection Analyses (LOPAs). A LOPA may have consequences and risk criteria expressed in final endpoint (impact) terms such as fatalities or environmental damage, and include conditional modifiers such as probability of fatality associated with a material or energy release. It may also take into account probabilities called enabling conditions that sometimes apply to scenario initiating events. One way to differentiate these two factors is that enabling conditions are associated with the part of an incident sequence leading up to a release of hazardous material or energy, whereas conditional modifiers are probabilities generally associated with the post-release part of an incident sequence.

1.1 LOPA Overview

Layer of Protection Analysis (LOPA) is a tool for analyzing and assessing scenario risk. LOPA has grown in popularity in the time since the publication of the CCPS Concept Book, *Layer of Protection Analysis: Simplified Process Risk Assessment*, in 2001. LOPA uses estimates of cause frequency, independent protection layer failure probabilities and consequence severity, employing conservative rules for making and combining these estimates. A brief summary of the methodology for conducting Layer of Protection Analyses as described in the LOPA book, with minor updates, is provided.

Interested in learning more about LOPA? See ***Layer of Protection Analysis: Simplified Process Risk Assessment***

<http://www.aiche.org/ccps/publications/books/layer-protection-analysis-simplified-process-risk-assessment>

A LOPA may have consequences and risk criteria expressed in final endpoint (impact) terms such as fatalities or environmental damage, and include *conditional modifiers* such as probability of fatality associated with a material or energy release. It may also take into account probabilities called *enabling conditions* that sometimes apply to scenario initiating events. The *Guidelines* in this book characterize when and how to apply enabling conditions and conditional modifiers to Layer of Protection Analyses (LOPAs).

One way to differentiate these two factors is that enabling conditions are associated with the part of an incident sequence leading up to a release of hazardous material or energy, whereas conditional modifiers are probabilities generally associated with the post-release part of an incident sequence.

1.2 Pertinent LOPA Variations

Users have developed many variations on the basic LOPA methodology. The variations that are pertinent to the use of enabling conditions and conditional modifiers are discussed in this section. These particular variations are a function of three main factors:

1. The resolution of the numerical values used in the LOPA calculations,
2. The means by which these values are determined, and
3. The extent to which loss event consequences are evaluated.

1.3 When to Use Enabling Conditions and Conditional Modifiers

Enabling conditions and conditional modifiers are not used in every LOPA. They only warrant being used when they support the objectives of the LOPA and are consistent with the risk criteria employed. This section provides guidance on when to use and when NOT to use enabling conditions and conditional modifiers.

1.4 Risk Criteria Endpoints

The consequence categories and risk criteria used in evaluating the adequacy of risk control measures must match the methodology used for estimating scenario risk. The basic difference between the categories and risk criteria used is the selection of *endpoints* for the determination of consequences. These endpoints can range from release magnitude to injury/fatality, environmental damage and/or business impacts or impact categories. This section will further discuss and illustrate different possible endpoints for various types of loss events (fires, explosions, toxic releases).

For more information about risk criteria see ***Guidelines for Developing Safety Risk Criteria*** <http://www.aiche.org/ccps/publications/books/guidelines-developing-quantitative-safety-risk-criteria>

2 LOPA Enabling Conditions

This chapter defines and illustrates *enabling conditions* as they may be used in Layer of Protection Analysis. It gives information and examples so the user can clearly recognize and properly employ enabling conditions where they are warranted.

2.1 Definition and Defining Characteristics

An *enabling condition* is a condition that makes the initiating event of a scenario possible. An enabling condition is neither a failure nor a protection layer. It consists of an operation or condition that does not directly cause the scenario, but that must be present or active in order for the scenario to proceed to a loss event. Note that mitigating factors, such as the probability of personnel presence or of emergency evacuation, are *conditional modifiers* (Chapter 3) and not enabling conditions. The term *enabling event* is sometimes used for *enabling condition*. The term *enabling condition* is preferred, since enabling conditions are not generally events but rather conditional states.

2.2 Interrelationship with Initiating Event

An enabling condition is expressed as a probability. The combination of the enabling condition probability with the initiating event frequency must always be a frequency that represents the times per year an abnormal situation would be encountered that could lead to a loss event. Note that most LOPA scenarios will not have enabling conditions.

2.3 Time-At-Risk Enabling Conditions

One general type of enabling conditions involves the concept of ***time at risk***. Time at risk is when an incident sequence may only be realized a certain fraction of the time when conditions are right for the

event sequence to progress to a loss event. An underlying assumption for time-at-risk enabling conditions is that only *revealed failures* can act as initiating events during time-at-risk conditions. A *revealed failure* is one that may be immediately or almost immediately apparent through an alarm or indicator system. For example, a primary feed pump failing off during continuous operation of a process would be rapidly apparent by its effects on process parameters when the feed flow is lost.

By contrast, *unrevealed (latent) failures*, such as a bypass line plugging or freezing up or a shutoff valve failing stuck in the open position, could occur at any time and remain dormant while still being able to run the process. If an unrevealed failure occurred before the beginning of the time at risk, and was then made evident when the time at risk began, it could then serve as an initiating event for an incident scenario. In this case, time at risk should not be taken into account as a LOPA enabling condition. Time-at-risk considerations can only be applied as enabling conditions when systems have been put in place to reliably ensure that potential unrevealed failures that could lead to incident scenarios are detected and corrected before the beginning of the time-at-risk state, or when the failures are naturally revealed due to the design of the process.

2.4 Campaign Enabling Conditions

Campaign enabling conditions are associated with processes that may differ from time to time or from batch to batch with respect to raw materials (chemicals, concentrations, rates, quantities), catalysts, final products, operating conditions and/or process configuration (e.g., recycle vs. non-recycle mode of operation), and these differences result in non-uniform risks during the different campaigns. The use of enabling conditions is one means of addressing the non-uniform risks in such facilities.

2.5 Other Possible Enabling Conditions

Other enabling conditions are possible that are not specifically time-at-risk or campaign situations as discussed above, but still involve a probability of a certain non-failure condition existing for the incident sequence to proceed to a loss event.

2.6 Documenting and Validating Enabling Conditions

Examples are shown in the book to illustrate a way of documenting enabling conditions in LOPAs. These examples are only one way of documenting enabling conditions. Some companies may require more than the enabling condition description and probability in the LOPA documentation, such as source references or calculations to back up enabling condition probabilities. The same is true if a range of possible values are associated with a given LOPA factor.

3 LOPA Conditional Modifiers

This chapter defines and illustrates *conditional modifiers* as they may be used in Layer of Protection Analysis. It is not intended to include an exhaustive set of possible conditional modifiers, but rather give sufficient information and examples that the user can clearly recognize and properly employ conditional modifiers where they are warranted. Following a general discussion of the characteristics of conditional modifier, the sections in this chapter cover five specific types of conditional modifiers.

3.1 Definition and Defining Characteristics

A *conditional modifier* is one of several possible probabilities included in scenario risk calculations when risk criteria endpoints are expressed in impact terms (e.g., fatalities) instead of in primary loss event terms (e.g., release, vessel rupture). Conditional modifiers include, but are not necessarily limited to:

1. Probability of a hazardous atmosphere
2. Probability of ignition or initiation
3. Probability of explosion
4. Probability of personnel presence
5. Probability of consequences
 - a. Probability of injury or fatality
 - b. Probability of equipment damage or other financial impact.

“Probability of environmental impact” would also be a possible conditional modifier. If used, it could follow the same general approaches as probability of injury or fatality and/or probability of equipment damage or other financial impact.

3.2 Probability of a Hazardous Atmosphere

This term is used for conditional modifiers involving loss of primary containment (LOPC) events or operational upsets that may or may not result in a hazardous atmosphere being formed, depending on the actual conditions. “Hazardous atmosphere” can refer to a toxic, oxygen-deficient or oxygen enriched atmosphere to which personnel could be exposed, or to a flammable vapor or explosible dust atmosphere.

For example, consider a small process building containing analytical instrumentation that relies on nitrogen for normal operation. This structure is not continuously occupied; however, it is entered several times per shift by operating personnel to record process measurements. An asphyxiation hazard exists due to the use of nitrogen inside the building. The enclosure is equipped with a continuously operated ventilation system designed for temperature control purposes only. Nitrogen is supplied to the analytical instruments via small-bore tubing, with the primary source of nitrogen being external to the building. If a nitrogen line or connection fails inside the building, an oxygen-deficient atmosphere may or may not be created, depending on such factors as the type of component that has failed, the hole size associated with the LOPC event, and the operating pressure of the nitrogen. If this scenario was evaluated using LOPA and used “Nitrogen primary containment failure inside the enclosure” as the initiating event, then the initiating event frequency should be a total frequency of all nitrogen LOPC events inside the enclosure. However, as previously stated, not all such nitrogen leaks will create an oxygen-deficient atmosphere, so a “probability of hazardous atmosphere” conditional modifier in the LOPA could be used to represent a best estimate of the fraction of leaks that would be expected to create a hazardous atmosphere. Without this conditional modifier, every nitrogen leak included in the initiating event frequency would be assumed to create an oxygen-deficient atmosphere. (For a constant pressure nitrogen source, an alternative would be to determine a minimum leak size that could create an oxygen-deficient atmosphere, then only include in the initiating event frequency those LOPC events greater than or equal to this minimum leak size.)

See *Estimating the Flammable Mass of a Vapor Cloud* to realistically estimate the flammable mass in a vapor cloud

<http://www.aiche.org/ccps/publications/books/estimating-flammable-mass-vapor-cloud>

and **Guidelines for Consequence Analysis of Chemical Releases** for how to conduct consequence analysis

<http://www.aiche.org/ccps/publications/books/guidelines-consequence-analysis-chemical-releases>

3.3 Probability of Ignition or Initiation

The LOPA conditional probability of a flammable vapor, explosible dust cloud or combustible mist igniting or an uncontrolled reaction (such as an explosive decomposition) initiating is treated in various ways by different companies. The easiest way of treating this factor is to always assume an ignition or initiation probability of 100%, and have risk criteria that are appropriate to compare with this conservative approach. However, this can significantly overstate the risk in some cases, and it does not differentiate between scenarios where the probability of ignition is high versus those where it is likely to be quite low.

Get a copy of **Guidelines for Determining the Probability of Ignition of a Released Flammable Mass** for tools to estimate the probability of ignition:

<http://www.aiche.org/ccps/resources/publications/books/guidelines-determining-probability-ignition-released-flammable-mass>

3.4 Probability of Explosion

This term is used for conditional modifiers where some type of explosion is possible, but would not be always expected to result. Since there are many explosion mechanisms, “probability of explosion” could take on any of several different meanings. Some common explosion mechanisms are discussed in this section.

To learn more about fires and explosions, get **Guidelines for Vapor Cloud Explosion, Pressure vessel Burst and Flash Fire Hazards**, 2nd Edition

<http://www.aiche.org/ccps/publications/books/guidelines-vapor-cloud-explosion-pressure-vessel-burst-bleve-and-flash-fire>

3.5 Probability of Personnel Presence

Probability of personnel presence is a conditional modifier that relates to the fraction of time people are likely to be within the affected area (sometimes termed *effect area* or *impact zone*) when a loss event occurs. Examples of conditional modifiers for the probability of personnel presence were given in Section 3.1 when defining and characterizing conditional modifiers.

3.6 Probability of Injury or Fatality

A *probability of injury or fatality* conditional modifier relates to the probability that, given a person is within the effect area (impact zone) as determined in the preceding section, a serious injury or fatality

would actually result. This conditional modifier cannot be determined independently of the probability of personnel presence, since it will be affected by the endpoint chosen for calculating the effect area.

See *Guidelines for Evaluating Process Plant Buildings for External Explosions, Fires and Toxic Releases, 2nd Edition* for more information on this topic
<http://www.aiche.org/ccps/resources/publications/books/guidelines-evaluating-process-plant-buildings-external-explosions-fires-and-toxic-releases-2nd>

3.7 Probability of Equipment Damage or Other Financial Impact

Discussed in this section is a conditional modifier that may be appropriate for some scenarios when evaluating economic impacts such as property damage and business interruption costs. This factor represents the probability that a significant economic impact would result, regardless of whether any independent protection layers are present.

3.8 Documenting, Managing and Validating Conditional Modifiers

As was the case for enabling conditions, the examples shown in this chapter illustrate only one way of documenting conditional modifiers in LOPAs. Some companies require more than the conditional modifier description and probability in the LOPA documentation, such as source references or calculations to back up conditional modifier probabilities.

4 Application to Other Methods

Enabling conditions and conditional modifiers are used not only in Layer of Protection Analyses, but also in other hazard evaluation methodologies. These include methods that are both more detailed and quantitative than the typical LOPA and less detailed than the typical LOPA. The application of conditional modifiers to more qualitative methods using barrier analysis and diagrams is discussed.

4.1 Quantitative Risk Analysis

Enabling conditions and conditional modifiers were employed in quantitative risk analyses (QRAs) for many years before LOPA was developed. Their function has generally been to take into account factors that are not related to system failures, in order to have an improved risk estimate and eliminate unnecessary conservatism from the analysis. This section illustrates how enabling conditions and conditional modifiers might be used in the context of three QRA approaches: Fault Tree Analysis (FTA), Event Tree Analysis (ETA) and consequence analysis.

For more information about these techniques, see *Guidelines for Chemical Process Quantitative Risk Analysis, 2nd Edition*
<http://www.aiche.org/ccps/publications/books/guidelines-chemical-process-quantitative-risk-analysis-2nd-edition>

4.2 Use of Enabling Conditions and Conditional Modifiers with Scenario Identification Methods

Any scenario-based hazard evaluation technique can be used to identify potential incident scenarios that can serve as the starting point for a Layer of Protection Analysis (LOPA). Several of these methodologies can also be extended to include aspects of a LOPA such as are discussed in these *Guidelines*, either in the same team-based review or in a follow-up review. These aspects include:

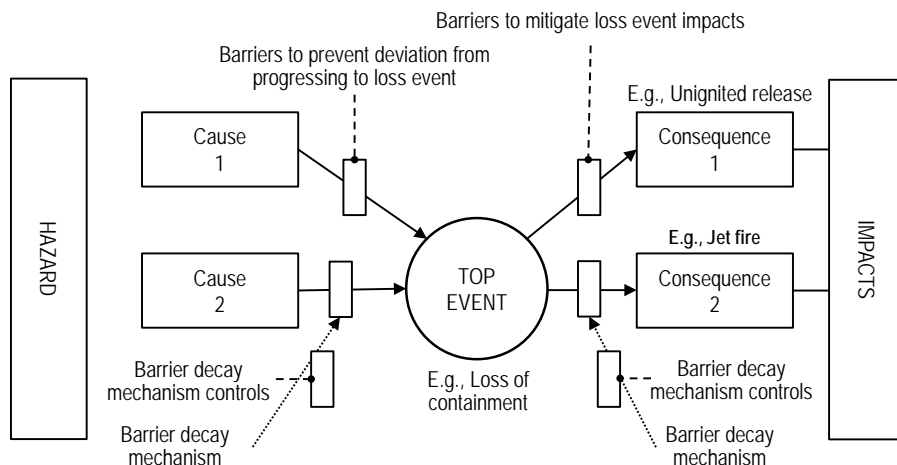
- Estimating the scenario risk for scenarios exceeding a threshold consequence of concern or meeting other screening criteria.
- For each such scenario, evaluating the initiating cause (initiating event) frequency, consequence severity and effectiveness of IPLs on an order-of-magnitude basis using best-estimate and/or rule-based values.
- Including conditional modifiers and/or enabling conditions to estimate the likelihood of harm posed by the scenario, if their use is consistent with how the facility's risk criteria are established.
- Comparing the calculated scenario risk to a risk goal to determine the adequacy of existing risk control measures.

***Guidelines for Hazard Evaluation Procedures*, 3rd Edition, gives a comprehensive overview of this topic area.**

<http://www.aiche.org/ccps/publications/books/guidelines-hazard-evaluation-procedures-3rd-edition>

4.3 Barrier Analysis and Diagrams

Conditional modifiers may also find their way into more qualitative methods such as barrier analysis techniques. One such technique uses “bow-tie” diagrams to graphically depict the preventive and mitigative “safety barriers” that are in place to protect against a specific loss event such as a major loss of containment event. These safety barriers might include the hardware and/or administrative controls associated with some conditional modifiers such as ignition source control and the presence of personnel in the potential effect area of a loss event.



Appendices

A – Simultaneous Failures and “Double Jeopardy”

Appendix A is a discussion of when it is and when it is not appropriate to consider simultaneous failures in the risk analysis of potential incident sequences. This issue sometimes arises when considering enabling conditions and conditional modifiers, since LOPAs that include them have multiple factors to combine when calculating scenario risk. Considering simultaneous failures is often characterized as “double jeopardy” and thereby disallowed. However, in a limited number of situations, it is valid and even necessary to analyze the possible occurrence of two or more concurrent failures, as explained in the following paragraphs.

B – Peak Risk Concepts

Appendix B discusses why the use of time-at-risk enabling conditions may be inappropriate in when evaluating LOPA scenarios that involve infrequent, short-duration operating modes involving risks with high potential severity, in the context of understanding the nature of “peak risk.” *Peak risk* can be defined as the level of risk associated with an activity while that activity is occurring. Risks may end up not being adequately controlled if annualized risks are calculated using time at risk as a factor in the risk equation.

C – Example Rule Set for LOPA Enabling Conditions

Layer of Protection Analysis (LOPA) is a simplified, rule-based approach for assessing scenario risk. An organization employing LOPA will need to establish its own set of rules to be used for conducting LOPAs for its facilities. Such rules can include how enabling conditions and/or conditional modifiers are to be treated. Appendix C presents examples of what those rules might comprise, although a full rule set might also include default values to be used for specific enabling conditions or conditional modifiers, as well as limits on how much risk reduction credit can be taken.

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<http://www.aiche.org/ccps/resources/publications/books/guidelines-enabling-conditions-and-conditional-modifiers-layers-protection-analysis>