Journal of Loss Prevention in the Process Industries 38 (2015) 163–168

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: www.elsevier.com/locate/jlp

Calibration of risk matrices for process safety

Paul Baybutt

Primatech Inc., Columbus, OH, USA

ARTICLE INFO

Article history:
Received 31 May 2015
Received in revised form
3 August 2015
Accepted 16 September 2015
Available online 21 September 2015

Keywords:
Risk matrix
Risk rating
Risk ranking
Process hazard analysis
Risk analysis
Process safety
Risk tolerance criteria
Process safety target levels

ABSTRACT

Risk matrices are used to rate and rank risks of hazardous events for processes. They provide for the lookup of the risk level for an event using its severity and likelihood levels which are estimated subjectively. Risk levels are associated with requirements for risk reduction to achieve tolerable risk. Often, risk matrices are defined using numerical values for event severity and likelihood levels. Therefore, the resulting risk levels denote numerical values of risk. Consequently, such risk matrices must be calibrated with reference to appropriate numerical risk tolerance criteria, or process safety target levels, to define appropriate risk reduction requirements. Calibration poses several pitfalls for the unwary. Many practitioners are unaware of these pitfalls and use risk matrices that are calibrated improperly producing incorrect risk reduction requirements. This paper describes how these pitfalls can be avoided and provides calibration procedures. Use of these procedures will help to avoid incorrect decisions on risk reduction for processes.

1. Introduction

Risk matrices are used widely in process safety to rate and rank risks posed by processes to help with decision making on risk reduction. For example, commonly they are used in process hazard analysis (PHA) to rate the risks of hazard scenarios and determine the need for risk reduction measures (CCPS, 2008; Baybutt, 2013).

When the severity and likelihood levels of a risk matrix are defined in numerical terms, risk levels with numerical definitions necessarily result. Risk levels are associated with requirements for risk reduction to achieve tolerable risk. Therefore, the numerical risks that are tolerated are clearly evident in the risk matrix and a valid basis must be used when assigning risk reductions required by the matrix. Consequently, such risk matrices must be calibrated by using appropriate numerical risk tolerance criteria as a reference point. The process of calibration entails deciding on a tolerable risk value and defining required risk reductions in the risk matrix to achieve it.

Risk matrices are used with events for which a severity and likelihood can be assigned. In the case of their application in PHA, the event is a hazard scenario. In this case, the risk tolerance criteria built into risk matrices must be for single hazard scenarios. However, it is not possible to assign a risk tolerance criterion for a hazard scenario arbitrarily. Such criteria can only be assigned with reference to overall facility risk tolerance criteria which are the only meaningful risk tolerance criteria that can be specified empirically (Baybutt, 2014b). Note that it is erroneous to use overall facility risk tolerance criteria for individual hazard scenarios which would result in tolerating far more risk than intended. The overall facility criteria must be allocated to the contributing scenarios. In such cases, allocation must be part of the calibration process. Also, many overall facility criteria are intended to include risk from all sources of all hazards in a facility, not just process safety hazards. Thus, such criteria must be offset for contributions made by non-process-safety hazards when used in process safety studies.

Calibration is susceptible to various pitfalls. They relate to the nature of risk tolerance criteria and the nature of the events to which they are applied. The pitfalls are described and guidance is provided to help ensure calibration is performed correctly. The guidance was derived by applying key concepts in the field of risk tolerance criteria to risk matrices and their use in process safety. Calibration is described for hazard scenarios but the discussion applies equally to other types of events.

Section 2 of the paper addresses the history of risk matrices in process safety. The process of allocation and calibration of risk matrices is described in Section 3. Procedures for the calibration of risk matrices for individual and group risk to people are described

E-mail address: paulb@primatech.com.

http://dx.doi.org/10.1016/j.jlp.2015.09.010
0950-4230/

in Sections 4 and 5, respectively. Calibration for group risk for other types of receptors is addressed in Section 6. Examples of risk matrices are discussed in Section 7 and conclusions are drawn in Section 8.

2. Risk matrices in process safety

Most PHA studies performed today include risk ranking of hazard scenarios using risk matrices. However, historically, risk ranking of hazard scenarios was not part of PHA studies performed within the process industries using methods such as the Hazard and Operability (HAZOP) study and What-If analysis. Instead, decisions on the need for risk reduction originally were made using engineering judgment. Other PHA methods that were developed in the system safety field, such as Failure Modes and Effects Analysis (FMEA) (MIL-STD-1629A, 1980), used a criticality ranking and the concept of risk ranking was introduced into the HAZOP and What-If methods beginning in the late 1980's when commercial PHA software was first released. For example, the product suite HAZOP-PC, WHAT-IF PC, PHA-PC, and FMEA-PC provided the ability to risk rank hazard scenarios (Baybutt and Marshall, 1992). This was found useful when PHA began to be practiced more widely and its practitioners realized that a more objective basis than engineering judgment was needed for decision making on risk reduction measures.

Furthermore, the U.S. Occupational Safety and Health Administration's (OSHA's) process safety management (PSM) regulation, which became effective in 1992, contains a regulatory requirement in paragraph 1910.119(e)(3)(vii) which states, "The process hazard analysis shall address a qualitative evaluation of a range of the possible safety and health effects of failure of controls on employees in the workplace" (CFR). The preamble to the standard notes that this evaluation of the failure of engineering and administrative controls is for the purpose of guiding decisions and priorities in planning for prevention and control, mitigation, and emergency response. Risk ranking of hazard scenarios provided the means to do so. Subsequently, OSHA clarified that the use of risk matrices is one way in which this requirement can be met (OSHA, 2005).

Little attention has been paid in the literature to the development and use of risk matrices in process safety. Guidelines for hazard evaluation procedures from the Center for Chemical Process Safety (CCPS) provide two examples of risk matrices and briefly describe their use in PHA studies (CCPS, 2008). However, the CCPS guidelines do not address the construction or use of risk matrices.

Use of risk matrices finds favor because they appear to be simple to understand, do not require specialized expertise, and are graphically appealing. However, there are no industry or government standards for risk matrices for process safety. Consequently, risk matrices are constructed intuitively but arbitrarily. Companies develop and use their own risk matrices. Unfortunately, risk matrices often are flawed in various ways, possibly because their development appears to be deceptively simple but is actually more complicated than it seems. Poorly designed risk matrices make the process of risk ranking difficult and produce risk estimates ill-suited for decision making. In particular, there are pitfalls in the allocation and calibration process for risk matrices that often are unrecognized.

3. Allocation and calibration for risk matrices

Allocation involves estimating the number of hazard scenarios possible and dividing an appropriate overall facility risk tolerance criterion by that number. The result is an allocation of the overall facility tolerable risk to individual scenarios such that, if the criterion is not exceeded by any scenario, the overall facility risk tolerance criterion will not be exceeded.

The estimation of the number of hazard scenarios depends on the level of detail used to define scenarios; the nature, scale, and complexity of the process; and the range of hazards addressed (CCPS, 2009). These factors can be highly variable from one situation to another. Also, many process facilities contain multiple processes and the overall facility risk tolerance criteria must be allocated using the total number of scenarios for the facility, not any one individual process. Consequently, the allocation process is challenging (Baybutt, 2014b).

There are various types and forms of risk measures (CCPS, 2000, 2009) and they influence calibration and allocation. In particular, both risk to individual receptors and groups of receptors can be important. For example, both individual and group risk are important for people (HSE, 2001). Individual risk is the frequency at which an individual may experience a given level of harm as a result of exposure to one or more hazards. Group risk is the relationship between frequency and the number of people in a given population experiencing a specified level of harm from exposure to one or more hazards.

Individual and group risk tolerance criteria specify limits for the risks to which individuals and groups of people are exposed. Individual risk criteria protect any single individual from bearing too large a share of the risk. Group risk criteria protect populations of people from bearing undue risk. The distinction between individual and group risk is less important for other types of receptors, such as equipment and property, where the concern is not necessarily with the risk to an individual piece of equipment or property but rather the cumulative, or group, risk for equipment or property. The different nature of individual and group risk mandates that separate risk matrices are needed for each type.

The tolerable risk for each facility and process may vary and the number of hazard scenarios will vary for each facility and process. Consequently, risk matrices must be calibrated for each facility and process for which they will be used. Thus, each facility and process needs its own customized risk matrices.

4. Calibration procedure for individual risk to people

Risk matrices can be calibrated and individual risk to people allocated using the following procedure which applies key concepts from the field of risk tolerance criteria to risk matrices.

4.1. Select a reference risk tolerance criterion for the type of casualty of interest

Casualty types may be, for example, a fatality, a hospitalization, a lost-time injury, or a first-aid case. A reference risk tolerance criterion for individual risk is a single number, although often different values are used for different categories of people, such as facility employees and members of the public. For example, the maximum tolerable individual fatality risk for facility employees from process safety hazards at a facility could be specified as 1×10^{-4} per year.

4.2. Make a conservative estimate of the maximum number of hazard scenarios that contribute to the risk of casualty for any particular exposed person

A particular person may experience casualty by themselves or with other people. Thus, both single and multiple casualty scenarios must be counted. For example, it may be estimated that there are 20 hazard scenarios that contribute to the fatality risk of the maximally exposed person. Conservative estimates favor high