The Art of Assessing Risk

Assessing risk is an art. Risk assessment requires certain skills, knowledge and experience that are rooted in system safety. But the authors believe that it also requires imagination and creativity to successfully anticipate, recognize, assess and treat potential risks. Merriam-Webster's dictionary defines *art* as "something that is created with imagination and skill and that is beautiful or that expresses important ideas or feelings; a skill acquired by experience, study or observation." The art of risk assessment lies partially in the ability to modify appropriate methods to the application and express the information in a way that effectively communicates risk.

It can be said that there are no original ideas, only variations of existing themes. This may be true, especially when considering the use of risk assessment methods and their numerous variants. Many methods have been developed over the years primarily in the system safety realm. These methods have evolved into several known forms. For example, methods such as failure mode and effects analysis (FMEA) or what-if analysis have many variations, some developed for specific industries or for unique applications (ANSI/ASSE, 2011b; Main, 2012). Others are the result of combining existing methods, such as bow tie analysis, which uses a simplified fault tree analysis (left-hand side of bow-tie) to analyze causation of a hazardous scenario (the center knot) and a simplified event tree analysis of the resulting consequences (right-hand side) (Rausand, 2011).

The ultimate purpose of assessing risk is to gain an understanding of a risk's nature, its causes, potential impacts and likelihood, and to determine whether additional controls are necessary so that it is acceptable to the organization and to society (ANSI/ASSE, 2011c).

Risk Assessment Within the Risk Management Process

Exposure to hazards and risks affect organizations each day, some of which are capable of significantly affecting the ability to achieve critical business goals and jeopardize the sustainability of the company. Many of these risks are unknown or unquantified, producing uncertainty for an organization (Lyon & Hollcroft, 2012). Uncertainty has a high cost to an organization in terms of meeting business objectives. Those organizations that can reduce uncertainty will be able to make better decisions that avoid or reduce risk and achieve their goals and objectives.

The risk assessment process is used by safety professionals to systematically assess an organization's operational risks. It is considered the foundation of risk management and the basis for safety practice. Based on the authors' experience, organizations that incorporate effective risk assessment strategies within their risk management plans and operational risk management systems tend to be highly successful organizations.

According to Walline (2015), risk-centric organizations act upon risk rather than hazards through

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Selecting, Modifying & Combining Methods to Assess Operational Risks

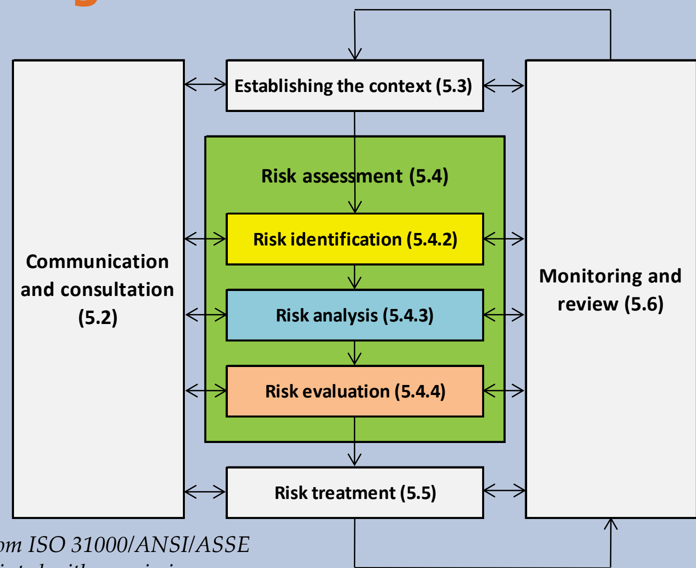
By Bruce K. Lyon and Georgi Popov

IN BRIEF
- Risk assessment is an art that requires skill and imagination. It is the heart of the risk management process, and a critical component of an operational risk management system.
- Several established tools for identifying hazards and assessing risk are available. Selecting the method best suited to the situation may require modification of existing tools or multiple methods to best assess and control risks.
- Safety professionals must be able to properly select tools and, in some cases, modify or combine them. This article presents several examples of modifications and sequential application of tools that OSH professionals can use in certain situations.

Organizations that incorporate effective risk assessment strategies within their risk management plans and operational risk management systems tend to be highly successful organizations.

Figure 1

Risk Management Process



Note. *Reprinted from ISO 31000/ANSI/ASSE Z690.2-2011. Reprinted with permission.*

Table 1

Risk Assessment Methods Listed in Z690.3, Z590.3 & Z10

ISO 31010/ANSI/ASSE Z690.3-2011	ANSI/ASSE Z590.3-2011 PTD	ANSI Z10-2012
--	Design safety review (Sec. 6; Addendum E)	Design review (5.1.3; ES.1.3)
--	Risk assessment matrix (Addendum F)	Risk assessment matrix (Appendix F)
--	Management oversight and risk tree (Addendum G)	--
--	What-if/checklist analysis (Addendum G)	--
B.1 Brainstorming	--	Brainstorming (Appendix F)
B.2 Structured/semi-structured interviews	--	--
B.3 Delphi	--	--
B.4 Checklists	Checklists (Addendum G)	Checklists (Appendix F)
B.5 Preliminary hazard analysis	Preliminary hazard analysis (Addendum G)	--
B.6 Hazard and operability studies	Hazard and operability studies (Addendum G)	--
B.7 Hazard analysis and critical control points	--	--
B.8 Toxicity assessment	--	--
B.9 Structured what-if analysis	What-if analysis (Addendum G)	--
B.10 Scenario analysis	--	--
B.11 Business impact analysis	--	--
B.12 Root cause analysis	--	--
B.13 Failure mode effects analysis; failure mode effects and critical analysis	Failure mode and effects analysis (Addendum G)	--
B.14 Fault tree analysis	Fault tree analysis (Addendum G)	--
B.15 Event tree analysis	--	--
B.16 Cause and consequence analysis	--	--
B.17 Cause and effect analysis	--	--
B.18 Layers of protection analysis	--	--
B.19 Decision tree analysis	--	--
B.20 Human reliability analysis	--	--
B.21 Bow tie analysis	--	--
B.22 Reliability centered maintenance	--	--
B.23 Sneak analysis and sneak circuit analysis	--	--
B.24 Markov analysis	--	--
B.25 Monte Carlo simulation	--	--
B26 Bayesian statistics and Bayes nets	--	--
B.27 FN curves	--	--
B.28 Risk indices	--	--
B.29 Consequence/probability matrix	--	Consequence/probability matrix (Appendix F)
B.30 Cost/benefit analysis	--	--
B.31 Multi-criteria decision analysis	--	--

Table 2

Applicability of Method for Components of the Risk Assessment Process

Method	Hazard/risk identification	Risk analysis: Consequence	Risk analysis: Probability	Risk analysis: Risk level	Risk evaluation
Job hazard analysis	SA	NA	NA	NA	NA
Brainstorming	SA	NA	NA	NA	NA
Structured interviews	SA	NA	NA	NA	NA
Delphi	SA	NA	NA	NA	NA
Checklists	SA	NA	NA	NA	NA
Preliminary hazard analysis	SA	NA	NA	NA	NA
Hazard and operability studies	SA	SA	A	A	A
Hazard analysis and critical control points	SA	SA	NA	NA	SA
Toxicity assessment	SA	SA	SA	SA	SA
What-if analysis	SA	SA	A	A	A
Scenario analysis	SA	SA	A	A	A
Business impact analysis	A	SA	A	A	A
Root-cause analysis	NA	SA	SA	SA	SA
Failure mode effects analysis	SA	SA	SA	SA	SA
Fault tree analysis	A	NA	SA	A	A
Event tree analysis	A	SA	A	A	NA
Cause and consequence analysis	A	SA	SA	A	A
Cause and effect analysis	SA	SA	NA	NA	NA
Layers of protection analysis	A	SA	A	A	NA
Decision tree	NA	SA	SA	A	A
Human reliability analysis	SA	SA	SA	SA	A
Bow tie analysis	NA	A	SA	SA	A
Reliability centered maintenance	SA	SA	SA	SA	SA
Sneak circuit analysis	A	NA	NA	NA	NA
Markov analysis	A	SA	NA	NA	NA
Monte Carlo simulation	NA	NA	NA	NA	SA
Bayesian statistics and Bayes nets	NA	SA	NA	NA	SA
FN curves	A	SA	SA	A	SA
Risk indices	A	SA	SA	A	SA
Consequence/probability matrix	SA	SA	SA	SA	A
Cost/benefit analysis	A	SA	A	A	A
Multi-criteria decision analysis	A	SA	A	SA	A
Design safety review	SA	SA	SA	SA	SA
Risk assessment matrix	NA	NA	NA	NA	SA
Management oversight and review technique	NA	SA	SA	SA	SA

Note. *Color codes: green/SA = strongly applicable; yellow/A = applicable; grey/NA = not applicable.*

the use of a risk assessment process. He defines risk-centric as:

> [T]he state when an organization gains a sense of urgency around a fatal or serious injury/illness level risk as an actual catastrophic event; seeing risk of harm as actual harm itself resulting in the action of mitigating risk in advance of mishaps. (Walline, 2015)

The mind-set of acting upon risk rather than hazards is an important concept. According to ANSI/ASSE Z690.1-2011, Vocabulary for Risk Management (national adoption of ISO Guide 73:2009), risk management is defined as "coordinated activities to direct and control an organization with regard to risk."

OSH professionals must clearly understand the term *risk assessment*. ISO Guide 73/ANSI/ASSE Z690.1-2011 states that risk assessment contains three distinct and sequential components:

- Risk identification: Finding, recognizing and recording hazards;
- Risk analysis: Understanding consequences and probabilities and existing controls;
- Risk evaluation: Comparing levels of risk and considering additional controls.

The art of assessing risk is to accurately anticipate and estimate the worst-credible consequence that could reasonably occur as a result of a hazard or operation, and how likely it is to occur. According to

Table 3
Simplified PHA

Task	Hazard	Current severity	Current likelihood	Current risk level	Recommended controls	Future severity	Future likelihood	Future risk level
SO_2 dosing using 100% SO_2 liquid	Health risk from leak or release; 2 ppm PEL; 100 ppm lethal dose; heavier than air. EPA-regulated product.	4	3	12	Substitute 100% SO_2 with 6% SO_2 and $K_2S_2O_5$ effervescent tables, granular, powder	2	2	4
DMDC metering equipment in bottling area	Health risk to bottling employees from leak or release in area; 0.4 ppm exposure ceiling limit.	4	3	12	Relocate DMDC unit outside building (connected with hose) with open ventilation away from bottling area; continue to follow safety protocols and PPE for operator.	3	1	3

Table 4
Severity Levels

Severity level	Definition
Catastrophic (4)	Fatalities; damage to community, environment and reputation
High (3)	Permanent disability injury or illness; multiple injury events
Moderate (2)	Injury or illness requiring medical attention
Low (1)	Minor injury or first-aid incident

Table 5
Likelihood Levels

Likelihood level	Definition
Very likely (4)	Will happen under right situations; has occurred multiple times
Likely (3)	Likely to happen under right circumstances; has occurred in past
Possible (2)	Can happen in certain situations
Unlikely (1)	Unlikely to happen; remotely possible

Table 6
Risk Levels

	Low (1)	Moderate (2)	High (3)	Catastrophic (4)
Very likely (4)	4	8	12	16
Likely (3)	3	6	9	12
Possible (2)	2	4	6	8
Unlikely (1)	1	2	3	4

The risk levels were defined using the risk criteria shown in Tables 4, 5 and 6, and the hierarchy of controls: risk avoidance, elimination, substitution, engineering controls, warnings, administrative controls and PPE.

ANSI/ASSE Z590.3-2011, Prevention Through Design (PTD) standard, "the worst credible consequence from an incident that has the potential to occur within the lifetime of the system" should be considered when performing risk assessment as opposed to "the worst conceivable consequence from an incident that could occur, but probably will not occur, within the lifetime of the system" (ANSI/ASSE, 2011a).

This estimation is often qualitative in nature, however it can be semi-quantitative or quantitative based (Main, 2012). In any case, the risk level relates to the degree of uncertainty and its effect on an organization's ability to achieve its objectives. Within the risk management process, risk assessment is the primary component (Figure 1, p. 42).

Risk Assessment Process

The process of identifying, analyzing and evaluating risk provides those responsible for making business decisions an understanding of the risk. This understanding allows decisions to be made regarding whether the identified risk is acceptable and what control measures are most appropriate. Ultimately, the output of risk assessment is an input to the decision-making processes (ISO 31010/ANSI/ASSE Z690.3-2011). The cyclical risk assessment process steps are: establish risk criteria; establish context; assemble team; identify hazards; analyze risks; evaluate risks; treat risks; document; monitor/review.

Establishing Criteria & Context

In ANSI/ASSE Z590.3-2011, Prevention Through Design: Guidelines for Addressing Occupational Hazards and Risks in Design and Redesign Processes, the initial steps outlined in The Hazard Analysis and Risk Assessment Process (Section 7) are (7.1) Management Direction; (7.2) Selecting a Risk Assessment Matrix; followed by (7.3) Establish the Analysis Parameters. In the ISO 31010/ANSI/ASSE Z690.3 standard, the process of defining and establishing risk criteria is included in Section 4.3.3, Establishing the Context. These initial steps of establishing criteria and context are essential to the risk assessment process.

Establishing risk criteria and context involves the establishment of a risk assessment matrix. The purpose of the risk assessment matrix is to provide "a method to categorize combinations of probability of occurrence and severity of harm, thus establishing risk levels" (ANSI/ASSE, 2011a). In essence, it is a risk measuring stick and communication tool used to help categorize and prioritize risks within the organization so that decision makers can take the most appropriate action about risks and their treatment. Many sources exist from which to select a risk assessment matrix. An organization should select or develop a risk assessment matrix that its stakeholders broadly agree to use in the risk assessment process.

Selection & Modification of Methods

Defining the risk assessment methodologies to be used is an important component of establishing context for a risk assessment process as described in ISO 31010/ANSI/ASSE Z690.3. Annex A.2 of Z690.3 highlights "Factors Influencing Selection of Risk Assessment Techniques" and includes two tables (Tables A.1 and A.2) that list key attributes of 31 methods that an OSH professional can use to determine the methodology to be selected and employed.

Table 7

Preliminary Job Risk Assessment Example

Job Risk Assessment									
Job: *Equipment Preparation & Rig Up*						**Assessed by:** *J. Doe; B. Smith*		**Date:** *4-1-15*	
			Pre-controls				Post-controls		
Task	Hazard	At Risk	Initial Severity (IS)	Initial Likelihood (IL)	Initial Risk (IR)	Controls	Residual Severity (RS)	Residual Likelihood (RL)	Residual Risk (RR)
1. Assess location to determine the spotting of equipment	1.a: struck by moving equipment	Supervisor; equipment; vehicles	3	3	13	1.a: Spotters; high visibility vest; controlled access; maintain 25' distance from operation	2	2	5
2. Unhook trailers and rig up gin poles	2.a: hand pinch; 2.b: struck by pole; 2.c: struck by moving equipment	Ground crew; equipment; vehicles	4	3	18	2.a: Grabber hooks with safety latches; hand placement; 2.b: certified cables with tags on poles;2.c: Spotter; High-vis vest	3	2	12
3. Unload iron, valves, separators, plug catchers	3.a: chain sling failure; 3.b: manual handling; 3.c: vehicle backing	Ground crew; equipment; vehicles	4	3	18	3,a: certified & tested slings; visual daily inspection; 3.b: use of mechanical aids; proper lifting; 3.c: spotters; high-vis vest; 360 walk around	3	2	12
4. Set & install plug catcher, hydraulic chokes & half pit	4.a: chain sling failure; 4.b: manual handling; 4.c: backing vehicles	Ground crew; equipment; vehicles	4	3	18	4.a: certified & tested slings; visual daily inspection; 4.b: use of mechanical aids; proper lifting; 4.c: spotters; high-vis vest; 360 walk around	3	2	12
5. Set & install sand separator, bypass, & hook up to frac tank	5.a: chain sling failure; 5.b: pinch points; 5.c: manual handling; 5.d: backing vehicles	Ground crew; equipment; vehicles	4	3	18	5.a: certified & tested slings; visual daily inspection; 5.b: proper hand placement; 5.c: use of mechanical aids; proper lifting; 5.d: spotters; high-vis vest;	3	2	12
6. Set & install test separator, flare stack, 3 flow lines, hook up 2 lines to frac tank (oil & water), thrid line goes	6.a: explosion from gas line; 6.b: chain sling failure; 6.c: manual handling; 6.d: backing vehicles	ground crew; other site workers; public; equipment; vehicles	5	3	23	6.a: eliminate ignition sources < 50'; gas monitor; 6.b: certified & tested slings; visual daily inspection; 6.c: use of mechanical aids; proper lifting; 6.d: spotters; high-vis vest; 360	3	2	12
7. Set outriggers on flare stack, swing stack around to assemble, raise stack, attach guy wires, secure	7.a: pinch points; 7.b: stack fall; 7.c: fall from heights; 7.d: sharp edges	setup crew; surrounding workers; equipment; vehicles	5	3	23	7.a: proper body/hand placement; 7.b: verify pins and gusset bars in place; 12' barrier; 7.c: fall protection equipment; 7.d: impact gloves, PPE	3	2	12
8. Flange up or screw in connection to wellhead	8.a: falls from heights; 8.b: pinch points; 8.c: manual handling; 8.d: sharp objects	setup crew; surrounding workers; equipment; vehicles	5	3	23	8.a: manlift; fall protection equipment; 8.b: proper body and hand placement; 8.c: proper lifting; mechanical aids; 8.d: impact gloves, PPE	3	2	12

According to the standard, those selecting the methodologies should consider the complexity and nature and degree of uncertainty of the situation to be assessed, the type data output needed and resources available. Tables A.1 and A.2 in Z690.3 provide guidelines for such selections; however, the authors believe that safety professionals should not be afraid to modify existing tools to incorporate aspects that improve applicability or effectiveness.

Several hazard identification and risk assessment methods are available, some of which are listed in several key risk-based safety standards including ISO 31010/ANSI/ASSE Z690.3-2011, ANSI/ASSE Z590.3-2011 and ANSI/ASSE Z10-2012. All are based on the same fundamental process: hazard/risk identification, risk analysis and risk evaluation.

Table 1 (p. 42) lists and compares techniques covered in each of these three standards. Of these methods, the checklist method is the only one listed in all three standards. Several techniques are listed in at least two of these standards including design reviews, brainstorming, preliminary hazard analysis (PHA), what-if analysis, hazard and operability studies, FMEA, fault tree analysis, consequence/probability matrix and risk assessment matrix.

Each risk assessment technique is designed to provide a general or specific level of information,

Table 8

PJRA Severity & Impact Table

Severity Levels	Impact: Injury	Safety	Damage of Property	Environmental Impact	Public Impact
Catastrophic (5)	Fatality	External Disaster Response	> $250,000 USD	Major environmental impact to public	Serious impact on large community
Critical (4)	permanent disability, life threatening, hospitalization	Internal Disaster Response	$50,000 to $250,000	Off-site release; repreat serious violation	Serious impact on small community
Serious (3)	Lost time	Emergency Response involving external agencies	$15,000 to $50,000	Release contained within facility; repeat violation	Minor impact on families or neigborhood
Moderate (2)	Medical aid, restricted work	Potential emergency response	$1,000 to $15,000	Contained within facility; minimal impact	Minor impact on individual
Minor (1)	First Aid	Reportable occurrence	Up to $1,000	Contained within facility; no impact	Minimal to none

Table 9

Likelihood Levels

Likelihood of Occurrence: Frequent (5)	Likely (4)	Occasional (3)	Remote (2)	Improbable (1)
High probability of recurrence; happens often; expected to happen several times a month; 1 in 100	Likely to occur several times in one year; 1 in 1000	Could occur once during the next year; 1 in 10,000	Unlikely to occur but is possible; 1 in 100,000	Very unlikely to occur; 1 in 1,000,000

analysis and assessment for its selected application in order to provide adequate information for decision making on the treatment or reduction of risk. Since many different types of risk exposures and levels of complexities exist, it is rare that a single method would adequately address every type of risk in a workplace.

As a general rule, when selecting a risk assessment method, the simplest tool or tools that provide sufficient information to make an appropriate risk management decision is advised (ANSI/ASSE, 2011a; Manuele, 2014). In the authors' experience, certain circumstances require customization of a tool and sometimes multiple methods to adequately assess and communicate risk. Table 2 (p. 43) provides a coded scale for applicability to each component of the risk assessment process for methods covered by Z690.3, Z590.3 and Z10.

For this article, three hazard analysis and risk assessment tools were selected to demonstrate how methods can be customized or modified to better fit certain applications. PHA and job hazard analysis (JHA) were selected since they are relatively well known and commonly used by safety professionals. Bow-tie analysis, although less well known, was included since it provides an effective means of visually communicating a specific hazard scenario's risk pathways, and its preventive controls and reactive measures to stakeholders.

Preliminary Hazard Analysis

PHA is an initial analysis of a system design, facility or process currently used in many industries and applications. It was originally developed in the 1960s by the U.S. Army and published in MIL-STD-882 as a method to identify hazards, assess the initial risks and identify potential mitigation measures early in the design stage. It is referred to as a preliminary analysis since it is usually followed by more refined hazard analysis and risk assessment studies in more complex systems (ANSI/ASSE, 2011a, b). Variants of PHA have been developed including hazard identification and rapid risk ranking methods (Rausand, 2011).

OSH professionals can use simplified versions of this method for many applications to help identify hazards, analyze risk levels and prioritize actions. The following example illustrates a simplified PHA for chemical use in a winery operation.

Winery Chemical Risk Assessment Using a Simplified PHA

1) Sulfur dioxide (SO_2). The winery operation had concerns about using SO_2 liquid in a 100% concentration for dosing large tanks both outside and inside buildings during the winemaking process. SO_2 is used to protect the wine from yeast and microbial growth, which can spoil or reduce the quality of wine. The winery originally purchased the 100% liquid SO_2 concentration to reduce costs and limit the amount of solution required for dosing the large tanks. At 100% concentration, SO_2 presents several significant concerns including employee safety and health (including death and blindness), and environmental reporting requirements.

The primary concern in this situation is the risk to employees, specifically the bottling line employees in the event of any leakage or release of SO_2 at this concentration. According to Cal/OSHA, the permissible exposure limit is 2 ppm and the lethal

Table 10

PJRA Risk Matrix

Risk Matrix						
Severity	Catastrophic	21	22	23	24	25
	Critical	14	15	18	19	20
	Serious	6	12	13	16	17
	Moderate	4	5	9	10	11
	Minor	1	2	3	7	8
		Improbable	Remote	Occasional	Probable	Frequent
		Likelihood				

dose is 100 ppm. As described in the SDS, SO_2 gas is heavier than air and can accumulate in closed areas. The configuration and current ventilation of the bottling areas presents a significant risk to employees should an SO_2 release occur in the area.

In addition, the quantity of 45 gallons, which weighs 548 lb, exceeds the threshold planning quantity of 500 lb for U.S. EPA SARA Title III, Sections 302 and 304, Extremely Hazardous Substances.

As a result of the risk assessment, the operation eliminated the 100% SO_2 product from the site and substituted a 6% SO_2 liquid for outside tanks and potassium meta-bisulfite (a much less hazardous product) in the form of granular powder and effervescent tablets.

Table 11

PJRA Risk Action Table

Risk Action Levels	
Risk Level	Action
Unacceptable	Immediate action required. Operation not permissible, except in rare and extra-ordinary circumstances.
High	Remedial action is to be given high priority.
Moderate	Remedial action is to be taken at appropriate time.
Low	Remedial action is discretionary. Procedures are to be in place to ensure risk level is maintained.

2) Dimethyl dicarbonate (DMDC). DMDC is a microbial control agent used in the production of wine and juice beverages to prevent spoilage from unwanted yeasts, bacteria and fungal spores. Trained operators and special metering equipment are used to dose the wine with DMDC in a closed system. The winery had concerns about the location of DMDC metering equipment and potential releases in the bottling area, which had limited ventilation. In the event of a DMDC release, the bottling crew would be vulnerable, with limited ventilation and means of escape. The SDS for DMDC indicates that its exposure ceiling limit is 0.04 ppm, a small quantity.

The "Safety Precautions When Handling DMDC" from the manufacturer states that DMDC is toxic if inhaled and should only be used in well-ventilated areas. In addition, the document warns that in the event of a spill or release personnel should be evacuated immediately. According to the SDS, the odor of DMDC cannot be used as a warning against inhalation exposure, and that "a NIOSH-approved air-purifying organic vapor respirator must be used when concentrations are between 0.04 ppm and 10 ppm"; and "positive pressure air-supplied respirators if concentrations are unknown or exceed 10 ppm or if the workspace is confined and unventilated."

As a result, the winery relocated the system outside the building to reduce risk to employees in the bottling areas.

The risk assessment worksheet (in Table 3, p. 44) outlines both of these tasks and their estimated risk. The risk levels were derived using the risk criteria defined in Tables 4, 5 and 6 (p. 44), and the hierarchy of controls. The risk assessment provides an illustration of the risk levels before and after these additional recommended control measures.

Job Hazard Analysis

JHA is one of the most common hazard-based analysis techniques. Also referred to as job safety analysis, JHA is a simple tool used to help identify, analyze and manage existing and potential hazards in the tasks of a defined job. OSH professionals often use JHA methods to train workers in a job's tasks, associated hazards and control measures as part of a safety orientation, and also as an incident investigation tool.

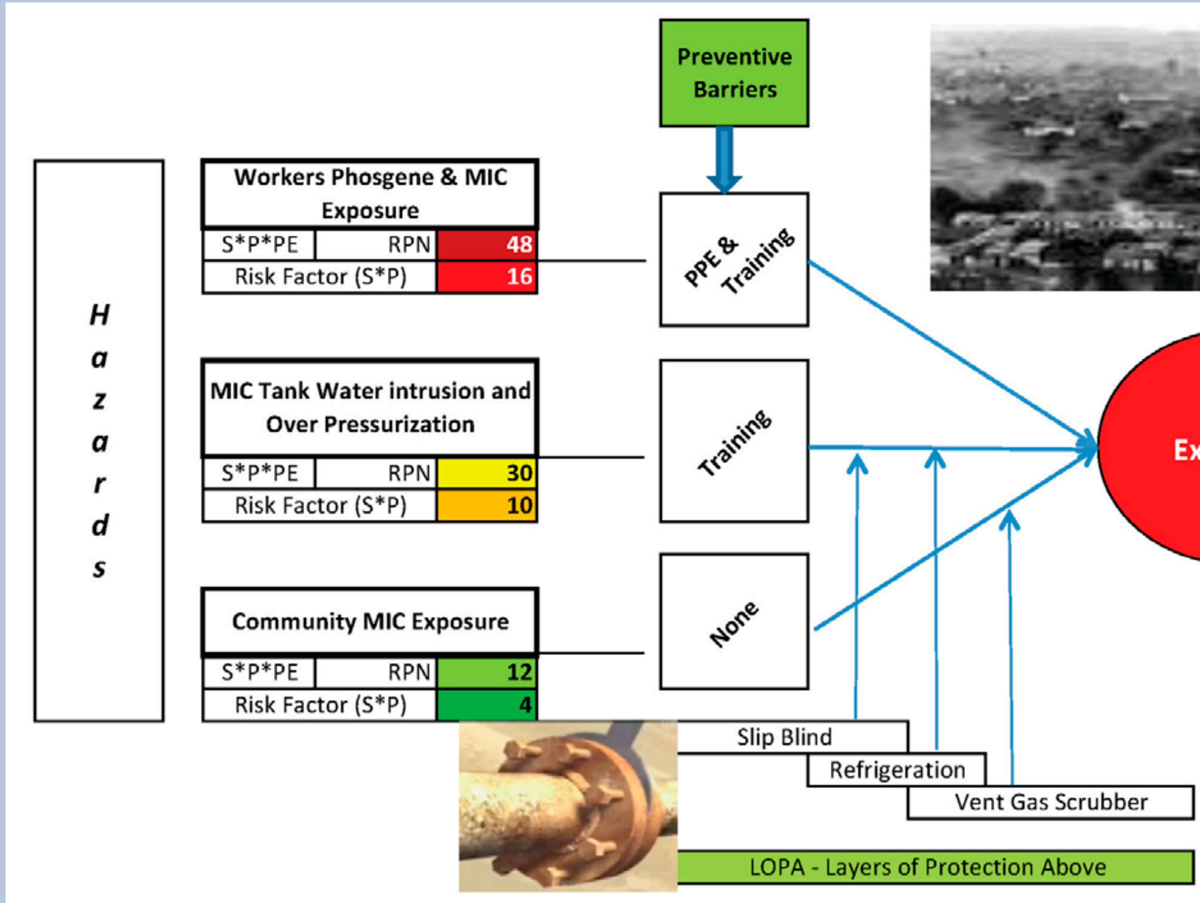
The JHA technique centers on defining a job's sequential tasks, associated hazards for each step and needed control measures. These are typically documented on a spreadsheet with three columns: 1) the task or step; 2) existing or potential hazards; and 3) necessary control measures. OSHA's (2002) booklet, "Job Hazard Analysis" defines it as follows:

> A job hazard analysis is a technique that focuses on job tasks as a way to identify hazards before they occur. It focuses on the relationship between the work, the task, the tools and the work environment. Ideally, after you identify uncontrolled hazards, you will take steps to eliminate or reduce them to an acceptable risk level.

As indicated in Table 2 (p. 43), the traditional JHA method does not typically include risk analysis or evaluation, only hazard identification. However, such methods can be modified and expanded to in-

Figure 2

Modified Bow Tie Analysis With Risk Scoring



clude components for risk analysis and risk evaluation, as well as risk reduction levels for existing and recommended controls (Whiting, 2013). Following is an example of a JHA with such modifications.

Preliminary Job Risk Assessment Example

The JHA can be modified to include risk assessment elements from other techniques to create a customized job risk assessment. For instance, as shown in Table 7 (p. 45), a JHA has been modified to include components of a PHA methodology for the setup of equipment on an oil and gas fracking site. The modified method could be referred to as a preliminary job risk assessment (PJRA) since it combines elements of a PHA with assessments of the initial risk levels prior to implementing controls and residual risk levels after implementing controls (Table 7, p. 45). The risk levels were estimated using the defined risk criteria shown in Tables 8 through 11 (pp. 46-47).

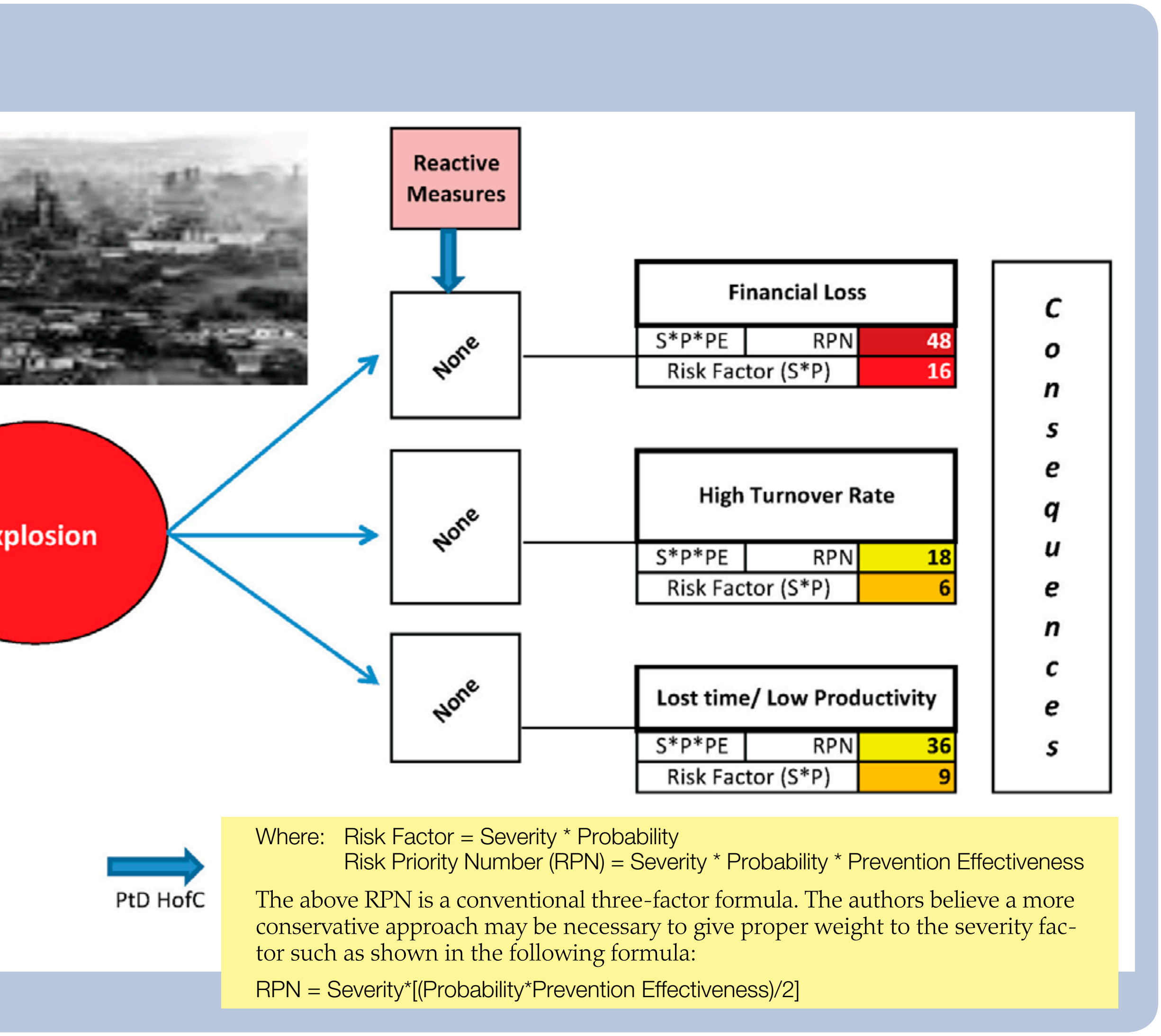
The benefit of adding pre- and post-control risk level assessments for hazards associated with each task helps communicate the importance of controlling higher-risk tasks and applying available resources (since they are often limited) where they are most beneficial.

Bow Tie Analysis

As noted, a conventional bow tie analysis is a combination of a fault tree and event tree analysis used to provide a clear illustration of the risk pathways and control measures in place for situations that do not require a full fault tree analysis. As described in ANSI/ASSE Z690.3-2011, the focus of the bow tie analysis is on the prevention barriers or controls between the causes and the risk, and the protection or mitigation controls between the risk and the consequences. Since the bow tie analysis is not designed to identify hazardous events, brainstorming, PHA or FMEA are often used up front to identify hazards, causes, existing controls and escalating factors for a particular scenario (Rausand, 2011).

As noted in ANSI/ASSE Z690.3, the bow tie analysis method has both strengths and weaknesses. The strengths include 1) its ability to display a big picture view of a process or system to effectively present risk exposures and controls; 2) its attention to both preventive controls and reactive measures; and 3) its ease of use.

Its potential shortfalls include 1) lack of a risk scoring mechanism; and 2) the effectiveness of



control measures is not reflected in the diagram (high-level controls such as substitution and engineering are not clearly distinguished from lower-level controls).

A Modified Bow Tie Analysis With Risk Scoring

A conventional bow tie analysis does not typically include a risk rating or scoring mechanism (ANSI/ASSE, 2011b; Rausand, 2011). However, risk scoring can be incorporated into the model as demonstrated in the example provided in Figure 2. This example of a modified bow tie analysis, which has added severity and probability risk factor ratings and prevention effectiveness ratings for each hazard risk provides the ability to evaluate, compare and rank risks.

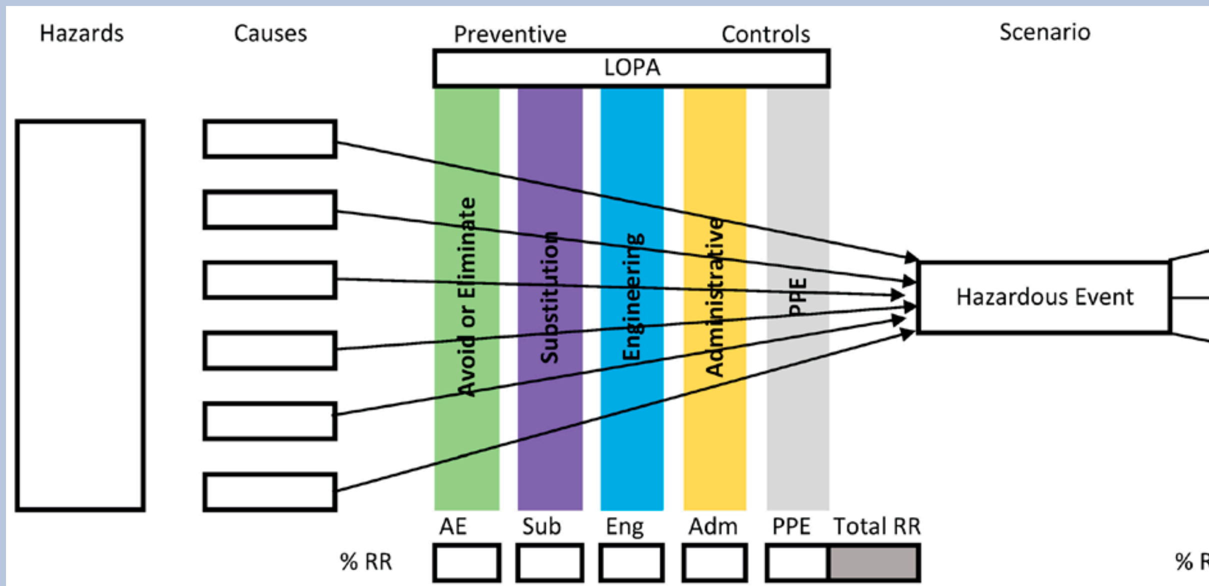
"Striped" Bow Tie Analysis With Hierarchy of Controls & LOPA

To improve on the conventional bow tie analysis model, the authors modified it to include hierarchy of controls stratification along with a layers of protective analysis (LOPA). The striped bow tie analysis (Figure 3, p. 50) was developed to analyze and determine whether sufficient barriers (preventive controls on the right-hand side and reactive measures on the left-hand side) are in place for the undesired event or scenario.

In this model, barriers and control measures are identified in accordance with the hierarchy of controls. Barriers may be preventive, reactive or both, and can include avoidance or elimination; substitution (of less hazardous components); multiple or singular engineering controls; administrative measures; and protective equipment. Reactive or mitigation measures used to reduce the impact of a hazardous event once it has occurred can include engineering controls (e.g., sprinkler systems, ventilation systems); administrative measures (e.g., emergency response, training); and financial measures (e.g., insurance, risk transfer, retention or other risk financing options).

Both preventive and reactive measures are accounted for and analyzed for adequacy in the model. The ranked control columns help to communicate and emphasize the need/preference for high-level controls, while the layers of protection diagram provides a means of evaluating overall

Figure 3
Striped Bow Tie Analysis Model



control of the scenario. It should be noted that preventive controls or frequency-reducing measures in general have a higher priority than reactive or consequence-reducing measures (Rausand, 2011) since they are intended to reduce the frequency of one or more hazardous events, thus preventing the resulting consequence(s).

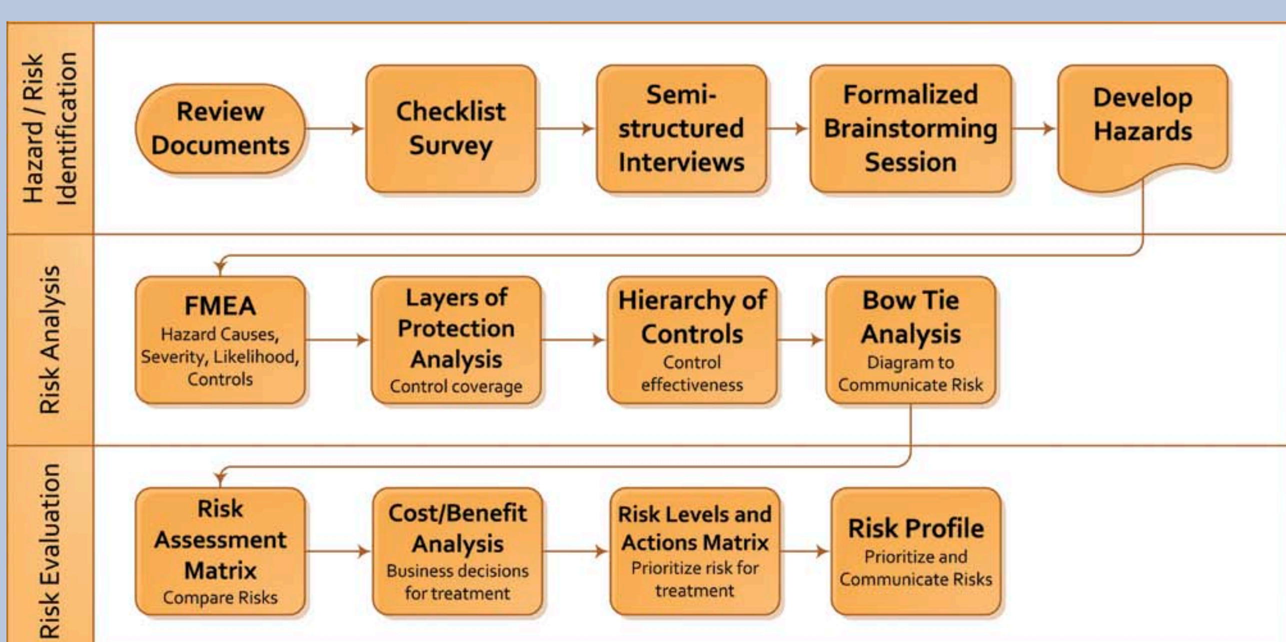
According to Manuele (2014), a hierarchy is a system of things ranked one above the other in order of importance or effectiveness. ANSI/ASSE Z590.3 (2011a) provides a hierarchy of controls.

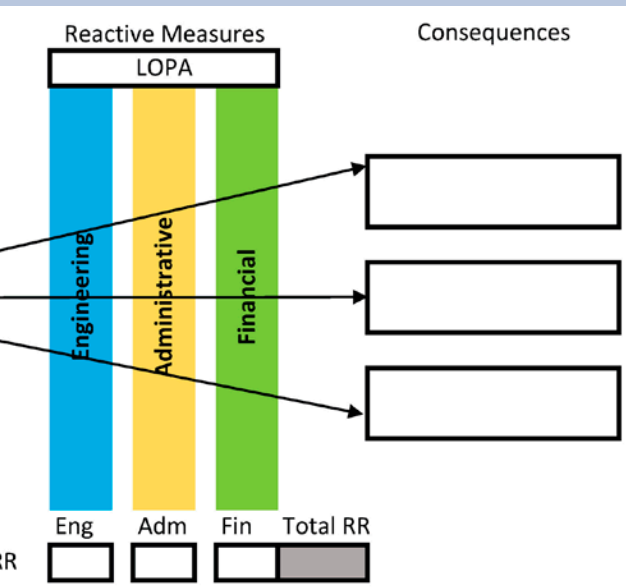
By adding these components to a conventional bow tie, the striped bow tie analysis allows a ranking of control types to be incorporated into the diagram giving increased emphasis on higher-level controls and layers of existing protection and defense as shown in Figure 3.

Sequential Methods for More Complex Situations

Much like building a house, more than one tool is generally needed for more complex risk situations. One can use a sequence of methods to perform the

Figure 4
Example of a Sequence of Methodologies Used in a Risk Assessment





components of a risk assessment as indicated in the following discussion.

Hazard/Risk Identification Methods

Almost all risk assessment efforts begin with some form of brainstorming or checklist method to identify potential hazards. Such efforts can incorporate structured interviews, document reviews, formal brainstorming sessions or simply a quick review of an applicable checklist. The options are many, however, the OSH professional should strive to select the most effective and efficient methods for the circumstances.

Risk Analysis

Once hazards and risks are identified, methods for analyzing consequences, their causes, severity levels, probability or likelihood of occurrence, and existing controls are needed. For example, a FMEA method allows each hazard (failure) to be analyzed in terms of the aforementioned aspects resulting in risk levels or scores. PHA provides a pre-control and post-control view of the risk, however, it may not be as detailed in information. Bow tie analysis has advantages of displaying risk pathways and barriers or controls if risk communication is of high importance to senior management. Again, many options exist and should be leveraged to increase the understanding of the risk.

Risk Evaluation

Upon analyses of the risks and their controls, an evaluation of the existing risk levels is performed to determine acceptability of risks and where certain risks require further treatment. A risk assessment matrix is generally used based on the organization's defined risk criteria as shown in the examples provided in Tables 8 through 11. A cost/benefit analysis or business impact analysis can be useful in providing financial and nonfinancial benefits of a proposed control measures, or in highlighting the need for further study.

An example of a risk assessment process using a sequence of methodologies is provided in Figure 4.

Conclusions

The art of assessing risk requires skill and imagination. Proper modification and customization of methods is an important aspect of assessing risk. Safety professionals should become proficient in this practice and not be afraid to be creative within the principles of the risk assessment process. An OSH professional can incorporate the modified PTD risk assessment tools described in this article into the risk management process. Such a logical process, based on the discussed standards, could be used effectively to develop and present the need for OSH interventions. The practicality, effectiveness, and financial and nonfinancial benefits of the risk reduction measures to be taken should be considered. A sound risk assessment may become a framework to logically develop a PTD business case and support it with relevant financial and nonfinancial benefits information. **PS**

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