THE POWER OF W

Assessing & Understanding

By Bruce K. Lyon and Georgi Popov

TWO SMALL WORDS, when asked in the form of a question, can be most powerful in reducing risk and uncertainty. For serious injuries and fatalities that have occurred, the question is what if the causes, conditions and controls were better understood? Would it have been possible to prevent such incidents from occurring? What if, indeed. However, the time for the OSH professional to ask, "what if?" is before such incidents occur: during the planning, designing, developing, installing, operating and maintaining of systems. What-if analysis and assessment can be a most powerful tool in controlling risks to an acceptable level throughout the life cycle of a system.

For example, in chemical operations, the question becomes "What if an operator mixes two incompatible chemicals?" or "What will happen if sulfuric acid and sodium hypochlorite (better known in its less concentrated form as bleach) are mixed in a quantity that could produce a cloud containing chlorine and other toxic compounds?"; "What if the cloud impacted workers on site and members of the public in the surrounding community?" Such questions can be critical in understanding the effects and preventing or reducing operational risks.

Traditional What-If Methods

Originally developed by the British chemical industry in the 1960s as an easier alternative to the hazard and operability study known as HAZOP, what-if methods have become a common process hazard analysis (PHA) method for process safety management. The primary objectives of what-if analysis are to identify and analyze a system's major hazards and hazard exposure scenarios, causes, deviations or weaknesses that can lead to hazards, existing controls and needed controls to achieve an acceptable risk level (Lyon & Popov, 2018).

KEY TAKEAWAYS
- **The concept of using the what-if question to determine potential effects is important and fundamental to assessing and controlling risk. It is essentially reasoned curiosity for the purpose of discovery to reduce uncertainty.**
- **The traditional what-if analysis has limitations as a hazard analysis technique. It does not estimate risk levels and, therefore, does not distinguish which hazards present the greatest risk.**
- **By coupling the what-if methodology with an estimation of risk, a powerful and valuable tool can be added to the risk management tool kit. The authors propose such a tool with a modified what-if risk assessment that incorporates risk analysis and evaluation. A case study is presented to illustrate its application.**

Like HAZOP and other PHA methods, what-if analysis is used to breakdown a series of actions or steps to understand process-related hazards and their causes and effects. A PHA is a set of organized and systematic analyses of identified hazards and controls associated with a process. It provides information to assist in making decisions for improving safety and reducing operational risk associated with a process. A PHA is directed toward analyzing potential causes and consequences of fires, explosions, releases of toxic or flammable chemicals, and focuses on equipment, instrumentation, utilities, human actions and external factors that may impact the process. In many cases, an additional benefit of conducting such an analysis is a more thorough understanding of the industrial process, leading to opportunities for improving process efficiency and cost reduction.

In the U.K., risk assessments have been legally required of businesses since 1999 by the Health and Safety Executive. However, in the U.S., few hazard analyses and risk assessments are required by law. Two exceptions include OSHA's Process Safety Management of Highly Hazardous Chemicals (PSM) standard, and EPA's Risk Management Plan (RMP) rule, both of which require PHAs (Popov, Lyon & Hollcroft, 2016). Following are brief summaries of these two standards:

- Established in 1992, OSHA's PSM (29 CFR 1910.119) requires process hazard analyses for regulated industrial processes containing 10,000 lb or more of a hazardous chemical for protecting the employees working in and around such processes.
- EPA's RMP rule (40 CFR Part 68 Chemical Accident Prevention Provisions), issued in 1994 because of the Clean Air Act Amendments of 1990, mirrors the OSHA PSM requirements for process hazard analyses in regulated facilities for the purpose of protecting the public and the environment from undesired consequences of explosions or releases.

Specifically, OSHA's PSM standard addresses mandated process hazard analyses in 1910.119(e)(1) stating that "an initial process hazard analysis (hazard evaluation)" of covered processes be conducted by the operation. What-if hazard analysis is one of several PHA methodologies referred to in the OSHA

HAT IF
g Risk

PSM standard and EPA RMP rule as an acceptable method (Popov et al., 2016). Methods listed in OSHA 1910.119(e)(2) considered appropriate to determine and evaluate process hazards are described in Table 1.

In addition to OSHA and EPA, the what-if method is listed as a hazard analysis method in several consensus standards including ISO 31010:2019, Risk Management—Risk Assessment Techniques, ANSI/ASIS/RIMS RA.1-2015, Risk Assessment, and ANSI/ASSP Z590.3-2011(R2016) Prevention Through Design. ISO 31010 also includes an annex that provides a description of the method and its application.

Hazard Analysis, Risk Analysis & Risk Assessment

To know which methods to apply in different situations, it is important to understand several key terms. The term *hazard analysis* is sometimes used interchangeably with *risk analysis* or even *risk assessment*. But OSH professionals should understand specific differences among the terms *hazards, risks, hazard analysis, risk analysis* and *risk assessment*.

•**Hazards** are defined as having the potential for harm and include aspects of technology and activity that, if left uncontrolled, can create risk; in other words, hazards are a source of risk. Hazards are produced by equipment, technology, energy sources, substances and chemicals, and materials, and by human actions and inactions. Basic workplace hazard classifications include physical and mechanical, chemical, biological, ergonomic and psychosocial.

•**Risks** are produced from hazards when their exposures to people and assets pose a chance for loss. This chance for loss or risk (R) is measured by the likelihood (L) of the event occurring and the resulting severity (S) of the loss.

•**Hazard analysis** is the process of determining whether credible means exist from failures or other causes that could lead to an incident or undesired event. Hazard analysis involves analysis of identified hazards, existing controls and potential exposures. As a result, it produces a range of possible consequences and severity estimates.

•**Risk analysis** includes hazard analysis plus the selection of a consequence and its severity level (S), the analysis of how the event could occur and its likelihood (L), and an estimate of risk level.

•**Risk assessment** includes all the steps in risk analysis followed by an evaluation of risk: comparing the estimated risk

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TABLE 1
APPROPRIATE PHA METHODS

Methods listed in OSHA 1910.119(e)(2) considered appropriate to determine and evaluate process hazards.

PHA method	Description
What-if	Uses a multi-skilled team to create and answer a series of what-if type questions. This method has a relatively loose structure and is only as effective as the quality of the questions asked and the answers given.
Checklist	Uses established codes, standards and well-understood hazardous operations as a checklist against which to compare a process. A good checklist is dependent on the experience level and knowledge of those who develop it.
What-if/checklist	A team-based, structured analysis that combines the creative, brainstorming aspects of the what-if method with the systematic approach of the checklist. The combination of techniques can compensate for the weaknesses of each.
Hazard and operability study (HAZOP)	A team-based, structured, systematic review of a system or product that identifies risks using guide words that question how the design can fail due to certain limitations and deviations of the operation.
Failure mode and effects analysis (FMEA)	Technique used to identify the ways systems and their components can fail and the resulting effect.
Fault-tree analysis	Technique used for identifying and analyzing factors that can contribute to a specified undesired event. Causal factors are deductively identified, organized in logical manner and represented pictorially in a tree diagram.

FIGURE 1

COMPARISON OF HAZARD ANALYSIS, RISK ANALYSIS & RISK ASSESSMENT

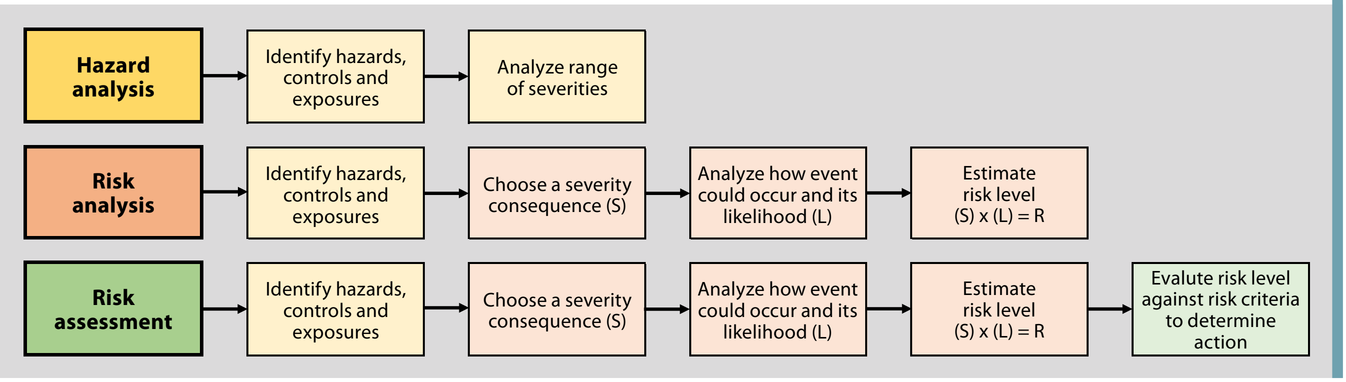
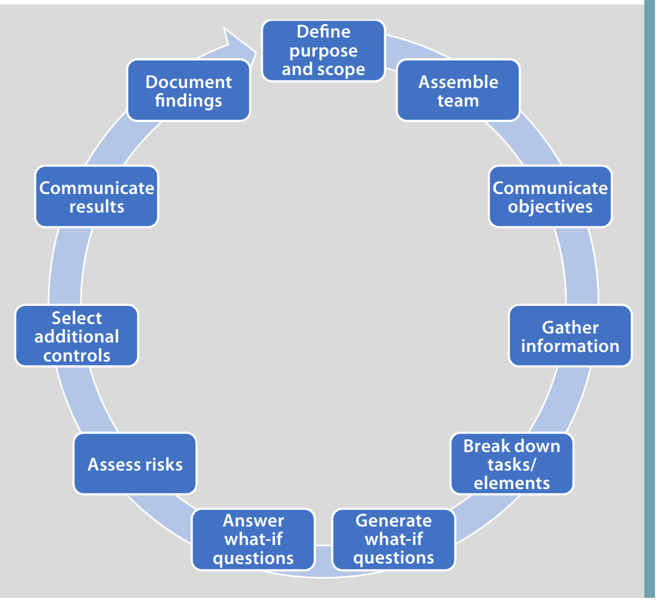


FIGURE 2

WHAT-IF RISK REDUCTION PROCESS



level with the established risk criteria to determine acceptability and actions required (Figure 1).

The traditional what-if method and its variants are considered hazard analyses rather than risk assessments. However, the authors propose modifying the method to include the additional steps of a risk assessment presented in this article.

Application of the Traditional What-if

A traditional what-if analysis is a team-based, qualitative method that uses brainstorming to determine what can go wrong in a given scenario. Variants of what-if include what-if/checklist and structured what-if analysis. Although the method was originally used by chemical and petrochemical industries, what-if and its variations have become widely used in other industries including energy, manufacturing, high-tech, food processing, transportation and healthcare.

What-if analysis can be applied at virtually any point of the life cycle of a system; it is commonly used to identify failures or deviations and the resulting effect so that proper controls can be implemented. It can be used broadly to analyze a system, process or operation, or at a more specific focus such as a piece of equipment, procedure or activity. Some areas where what-if can be useful include:

- process safety management operations that contain hazardous chemical processes (e.g., refrigeration and chiller systems containing ammonia such as meat packing, food processing and storage);
- nonroutine activities such as equipment installations, repair or decommission;
- business continuity threat assessments and tabletop drills to develop emergency scenarios and necessary measures for preparedness, disaster recovery and business continuity;
- design safety reviews of new facilities, systems and equipment;
- management of change procedures;
- procurement of new technology, equipment or materials.

Although relatively easy to apply, this method relies heavily on the experience and knowledge of the what-if analysis team. Therefore, it is critical to assemble an experienced facilitator and team knowledgeable in the process.

What-If Analysis Process

The what-if hazard analysis method uses a cross-functional team to discuss aspects in a random, creative fashion, asking what-if questions to identify any weaknesses, deviations or hazards. The team should include subject matter experts in the system or component being analyzed and be led by an experienced facilitator. While brainstorming, the team identifies potential hazard scenarios and their causes, assesses the risk with any existing controls for these hazards, and selects additional controls needed. The team generates a spreadsheet listing the tasks or elements and posed what-if questions along with resulting consequences, existing safeguards, risk levels and recommended additional controls. A recorder or scribe must collect and document the findings.

Figure 2 illustrates the what-if continuous improvement risk reduction process. The following steps detail this process.

1) Define context. As part of the context, define a clear purpose and scope including the activity or system to be analyzed, boundaries of the analysis, level of detail desired and risk criteria to be used.

2) Assemble team. Select a cross-functional team of trained, experienced and knowledgeable members to conduct the what-if analysis. An experienced facilitator and scribe are also needed. Members from the engineering, design, production, operations, maintenance, and safety, health and environmental departments are generally included. Knowledge of design standards, regulatory codes, operational error potential, incident history, maintenance needs and other practical experience is required.

3) Communicate objectives. The facilitator should clearly communicate to the team the purpose, scope, boundaries of the analysis and team responsibilities. The team must also understand the risk criteria and definitions to be used in the analysis.

4) Gather information. Facilitator gathers applicable information regarding the system, historical information, specifications and instructions, and provides it to the team for review. The team should observe the activity or system in place. Particularly, prior to the analysis the team should gather and study reference materials such as piping and instrumentation diagrams, schematics, drawings, instruction manuals, maintenance and service guidelines, component specifications, and safeguarding elements.

5) Break down into tasks/elements. Using information gathered, break down the activity or system into sequential tasks or elements for analysis.

6) Generate what-if questions. For each task/element, the team generates what-if questions to identify potential hazards and hazard scenarios. The questioning process is applied to each task separately, investigating potential scenarios such as procedural upsets, miscommunications, operator errors, equipment failures and software errors. An unstructured or structured brainstorming method can be used. As team members pose specific what-if questions, the scribe records each question on a flip chart or laptop projection in view of the team. Additional questions are generated during this process and are recorded by the scribe. The facilitator completes and refines the list of what-if questions for the analysis.

7) Answer what-if questions. The team discusses and answers each what-if scenario as to the causes, resulting effects and consequences, and existing safeguards or controls.

8) Assess the risks with current controls. An estimate of severity and likelihood can be included in the analysis. A risk level is estimated based on the severity and likelihood of occurrence. Risk levels are evaluated and compared to a predetermined criterion. If the risk levels are not acceptable, additional risk treatment is recommended based on the risk treatment strategies (Lyon & Popov, 2019).

9) Select additional controls. Apply additional risk reduction measures as necessary. Risk reduction options are identified and selected according to the hierarchy of controls, effectiveness and feasibility.

10) Communicate results. Following the analysis, finalize the spreadsheet and communicate the recommendations to decision makers for further action (Figure 3).

11) Document findings. The what-if analysis spreadsheet can be used as an action plan for documentation, assigning responsibilities and completing recommended risk reduction measures.

Figure 3 shows an example of a traditional what-if hazard analysis form.

Benefits of a what-if analysis technique include that it is easy to use; employees with little risk assessment expertise can participate meaningfully; and it leads to deeper insight, especially for those conducting the analysis. However, it also has some limitations, such as: 1) it is only useful if the right questions are asked; 2) it relies on the intuition and experience of team members; 3) it can be subjective and create greater potential for bias; and 4) it can be more difficult to translate results into convincing arguments for change. Therefore, the success of the what-if technique depends in large part on the experience and knowledge of the facilitator and the team.

SWIFRA: Structured What-If Risk Assessment

A traditional what-if analysis does not typically include a risk estimation and is considered a hazard analysis. Hazard analyses, such as job hazard analyses, are useful in identifying and analyzing hazards, however, they do not provide risk-based information needed for prioritizing, treating and managing risks. ISO 31010:2019 touches on this shortcoming where the standard suggests that the structured what-if technique (SWIFT) "summarize risks" as the team considers the current controls and include the "description of the risk," its causes, consequences and expected controls. For these reasons, the authors have developed the structured what-if risk assessment (SWIFRA), a method that expands the analysis to include how and why with the what-if question and incorporates risk estimation, evaluation and recommended risk treatments.

It is common to use a qualitative or semiquantitative risk assessment method to rank the actions created in terms of priority (ANSI/ASSP/ISO/IEC, 2019). To convert a hazard analysis to a risk assessment, several components must be addressed. First, specific consequences are selected to be analyzed and assessed. Then, for each consequence, an estimate of its severity (S), likelihood of occurrence (L) and risk level (R) are determined. The estimated risk levels are then compared and evaluated with the

FIGURE 3
TRADITIONAL WHAT-IF HAZARD ANALYSIS EXAMPLE

What-If Analysis					
Facility/operation/process:					
Date:	Team:				
A. Process					
ID #	What-if . . .	Causes	Consequences	Controls	Recommendations
A.1					
A.2					
A.3					

FIGURE 4
SWIFRA WORKSHEET

Structured What-If Risk Assessment (SWIFRA)													
#	What-if?	How?	Why?	Current controls	L	S	Risk level	Risk level acceptable (Y/N)	Additional controls	L2	S2	Risk level 2	% RR
1													
2													
3													

FIGURE 5

SEMIQUANTITATIVE RISK ASSESSMENT MATRIX EXAMPLE (5 x 4)

			Severity of injury or illness			
			Negligible (N) First aid or minor medical treatment.	**Marginal (M)** Minor injury, lost workday incident.	**Critical (C)** Hospitalization of three or more people. Disability in excess of 3 months.	**Catastrophic (CAT)** Death or permanent total disability.
			1	2	3	4
Likelihood of occurrence	**Frequent (F)** Almost certain to occur with exposure. Has occurred more than once within past 12 months.	5	**Medium 5**	**Serious 10**	**High 15**	**High 20**
	Probable (P) Very likely to occur with exposure. Has occurred within past 12 months.	4	**Medium 4**	**Serious 8**	**High 12**	**High 16**
	Occasional (O) Likely to occur. Has occurred within past 24 months.	3	**Low 3**	**Medium 6**	**Serious 9**	**High 12**
	Remote (R) Can occur if conditions exist. Has occurred within past 36 months.	2	**Low 2**	**Medium 4**	**Medium 6**	**Serious 8**
	Improbable (I) Unlikely to occur. Has not occurred in past 5 years.	1	**Low 1**	**Low 2**	**Low 3**	**Medium 4**

TABLE 2

RISK SCORING LEVELS & ACTION EXAMPLE

Risk level	Risk score	Action
High	12 or higher	Operation not permissible; immediate action required
Serious	7 to 11	Remedial action required; high priority
Medium	4 to 6	Remedial action recommended
Low	1 to 3	Considered acceptable; action discretionary

established risk criteria to determine acceptability and required action. A second feature is added to the SWIFRA: a multiple questioning process that asks 1) what-if; 2) how it is possible; and 3) why it is possible. The purpose of the multiple what, how and why is to discover the systemic causal factors underlying the surface causes, much like a five-why method.

Figure 4 (p. 39) shows an example of a SWIFRA worksheet. To demonstrate the additional risk assessment steps, a simple semi-quantitative 5 x 4 risk assessment matrix (Figure 5) can be used along with corresponding actions for risk levels found in Table 2.

Case Study: SWIFRA of Chemical Release Event

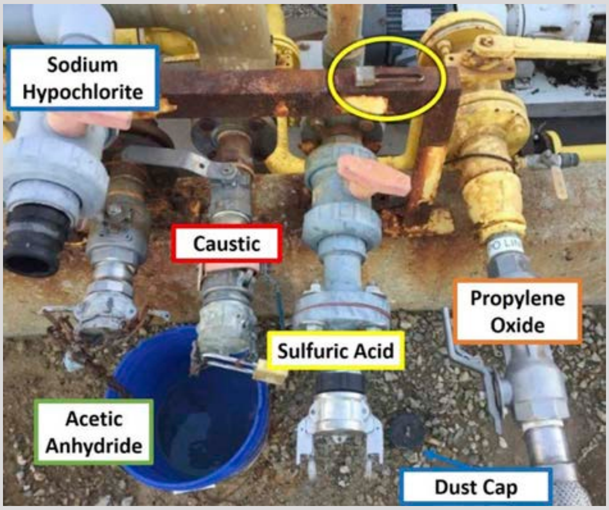
To demonstrate the inclusion of risk assessment in a modified SWIFRA, the authors applied this modified method to the following case study based on the CSB (2018a) investigation from a chemical release in October 2016. Readers can view an animated reenactment of the incident in a video produced by CSB (2018b).

CSB Investigation Summary

On Oct. 21, 2016, inadvertent mixing of incompatible chemicals at a chemical processing facility in Atchison, KS, caused a chemical release. The mixture of the two chemicals, sulfuric acid and sodium hypochlorite (bleach), produced a cloud containing chlorine and other compounds. The cloud affected workers on site and members of the public in the surrounding community. The incident occurred during a routine chemical delivery of sulfuric acid from a chemical supplier cargo tank motor vehicle (CTMV) at the chemical facility tank farm. The county's department of emergency management ordered thousands of community members to shelter in place and others to evacuate in some areas. More than 140 people, including members of the public, chemical processor employees and a chemical supplier employee, sought medical attention; one worker and five members of the public required hospitalization as a result of exposure to the cloud produced by the reaction.

FIGURE 6
CONNECTION AREA

As-found state of connection area post-incident: Sulfuric acid fill line padlock (circled) placed on angle iron; sodium hypochlorite dust cap on the ground beneath the fill lines.



Note. Reprinted from "Key Lessons for Preventing Inadvertent Mixing During Chemical Unloading Operations: Chemical Reaction and Release in Atchison, Kansas (No. 2017-01-I-KS)," by CSB, 2018.

While this incident involved two specific substances, the accidental mixing of many acids and bases or other incompatible chemicals during unloading operations and other activities can lead to dangerous reactions. Chemical unloading operations from CTMVs may be perceived as simple compared to other processes in fixed facilities, but because these operations can involve extremely large quantities of chemicals the consequences of an incident may be severe (CSB, 2018a).

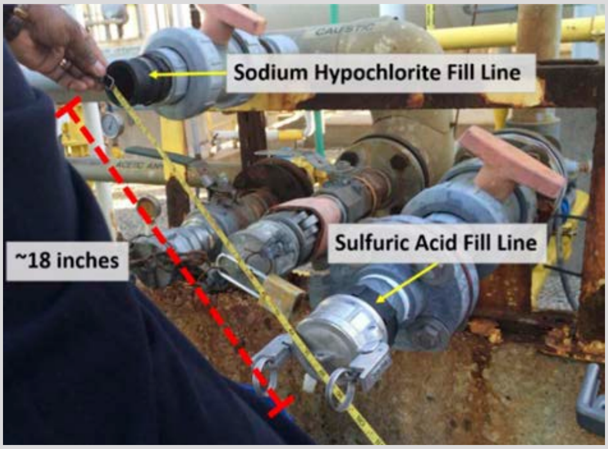
As described in the CSB report, CTMV drivers rely on operators to unlock and identify the fill line designated for the chemical being transferred. Operators show drivers the appropriate fill line. Once the equipment is unlocked, operators return to the control room. Drivers then remove the dust cap and connect the chemical discharge hose from the cargo tank to the fill line.

The connections to the sulfuric acid and sodium hypochlorite fill lines looked the same and they were situated in close proximity to each other. Figure 6 shows the connectors as they were found post-incident: the sulfuric acid fill line padlock (circled) placed on angle iron; sodium hypochlorite dust cap on the ground beneath the fill lines (CSB, 2018a).

CSB found that the proximity of the sulfuric acid fill line to the sodium hypochlorite fill line increased the likelihood for an incorrect connection during chemical unloading. The five chemical fill lines in the chemical transfer area were all located near each other; significantly, the sodium hypochlorite fill line was about 18 in. from the sulfuric acid fill line (Figure 7). In addition to the incompatibility of sodium hypochlorite and sulfuric acid, the other chemicals delivered to facility presented reactivity hazards if mixed.

CSB recommended physically isolating or using distance to separate fill lines to lower the risk of incorrect connections. Physical separation is considered a passive control and can be

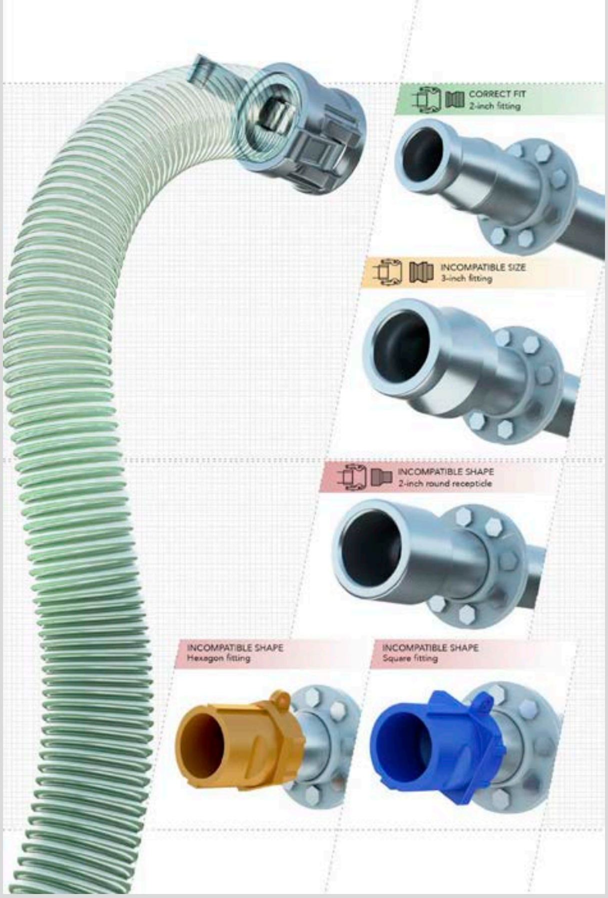
FIGURE 7
DISTANCE BETWEEN FILL LINES



Note. Reprinted from "Key Lessons for Preventing Inadvertent Mixing During Chemical Unloading Operations: Chemical Reaction and Release in Atchison, Kansas (No. 2017-01-I-KS)," by CSB, 2018.

FIGURE 8
UNIQUE FILL LINE SHAPES & SIZES

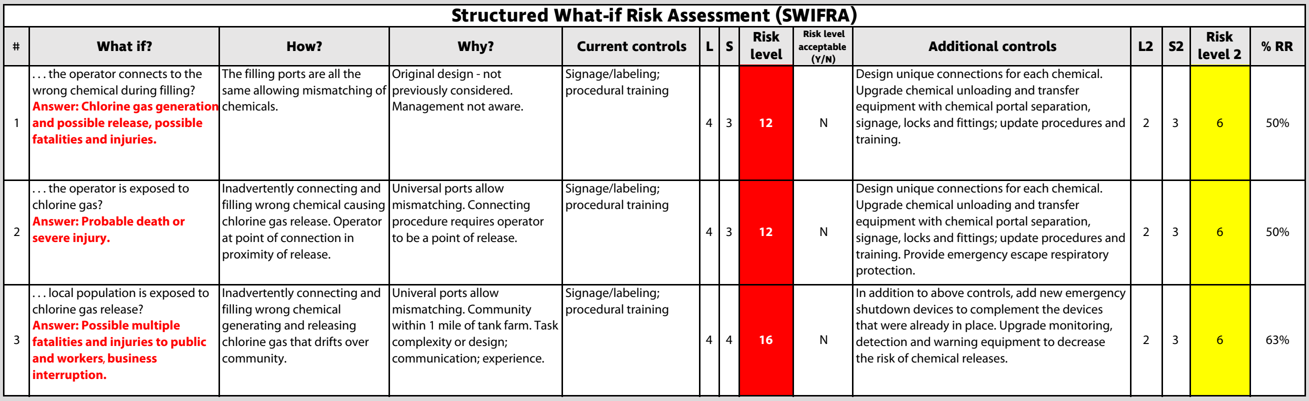
CSB recommended using unique fill line shapes and sizes to avoid mismatching chemicals during deliveries.



Note. Reprinted from "Key Lessons for Preventing Inadvertent Mixing During Chemical Unloading Operations: Chemical Reaction and Release in Atchison, Kansas (No. 2017-01-I-KS)," by CSB, 2018.

FIGURE 9

SWIFRA OF CASE STUDY



Structured What-if Risk Assessment (SWIFRA)

#	What if?	How?	Why?	Current controls	L	S	Risk level	Risk level acceptable (Y/N)	Additional controls	L2	S2	Risk level 2	% RR
1	. . . the operator connects to the wrong chemical during filling? **Answer: Chlorine gas generation and possible release, possible fatalities and injuries.**	The filling ports are all the same allowing mismatching of chemicals.	Original design - not previously considered. Management not aware.	Signage/labeling; procedural training	4	3	🟥 **12**	N	Design unique connections for each chemical. Upgrade chemical unloading and transfer equipment with chemical portal separation, signage, locks and fittings; update procedures and training.	2	3	🟨 6	50%
2	. . . the operator is exposed to chlorine gas? **Answer: Probable death or severe injury.**	Inadvertently connecting and filling wrong chemical causing chlorine gas release. Operator at point of connection in proximity of release.	Universal ports allow mismatching. Connecting procedure requires operator to be a point of release.	Signage/labeling; procedural training	4	3	🟥 **12**	N	Design unique connections for each chemical. Upgrade chemical unloading and transfer equipment with chemical portal separation, signage, locks and fittings; update procedures and training. Provide emergency escape respiratory protection.	2	3	🟨 6	50%
3	. . . local population is exposed to chlorine gas release? **Answer: Possible multiple fatalities and injuries to public and workers, business interruption.**	Inadvertently connecting and filling wrong chemical generating and releasing chlorine gas that drifts over community.	Univeral ports allow mismatching. Community within 1 mile of tank farm. Task complexity or design; communication; experience.	Signage/labeling; procedural training	4	4	🟥 **16**	N	In addition to above controls, add new emergency shutdown devices to complement the devices that were already in place. Upgrade monitoring, detection and warning equipment to decrease the risk of chemical releases.	2	3	🟨 6	63%

especially important when receiving various classes and types of chemicals (CSB, 2018a). The agency also recommended using a combination of fill line shapes and sizes to avoid incorrect connections during deliveries (Figure 8, p. 41).

What-If Analysis

Now, imagine if the company had conducted a traditional what-if analysis and asked what if it was possible to mismatch connections? What if the operator inadvertently connects the wrong chemical while filling tanks? What if the operator had noticed that lines were mixed and was able to shut down the supply line in time? What if only minor quantities of chlorine gas were released?

Certainly, a what-if analysis of the system could prove beneficial in preventing such incidents. However, a traditional what-if analysis has certain limitations and possible deficiencies. For example, an inexperienced facilitator may lead the team to brand it as a near-miss and recommend better procedures and additional training. A more experienced facilitator would use what-if with a risk reduction model and continue to ask what-if questions. S/he may consider cascading what-if questions where the consequences from the previous what-if question would become the next what-if question, much like a five-why method. One such question might be, what if chlorine gas was released? Consequences might be a Clean Air Act violation and an EPA fine of up to $1.7 million. If the near-miss scenario was not considered a catastrophic consequence, a massive fine and the damaged reputation of the organization might be considered catastrophic. In fact, on March 6, 2019, both companies were indicted by the U.S. Attorney's office for violations of the federal Clean Air Act. If convicted, they may face fines of up to $1.7 million.

SWIFRA Model

Similar to a traditional SWIFT method, the SWIFRA model incorporates structured what-if questions, followed by asking how it is possible and then why it is possible. A risk estimation is also added to the method for current state and future state along with a risk reduction percentage to help communicate risk reduction to decision makers. The steps for applying a SWIFRA are:

1) Develop the what-if questions. The team performs research (e.g., document reviews, interviews, past incidents, historical data analysis, observations) to develop a list of valid and relevant what-if questions to uncover possible problems the system.

2) Create the spreadsheet. The team facilitator loads the list of what-if questions into the SWIFRA spreadsheet.

3) Answer the what-how-why. The team goes through each what-if question with a multiple what-if or why question process to determine potential failure modes and their systemic casual factors, as well as controls. For example, in the chemical release case study, the team would ask, "what if the operator mixes sulfuric acid and sodium hypochlorite connections during filling of tanks?" The next questions might be, "how would this possibly happen?" and "why is this possible?" This would likely lead to conclusions that the current design of the filling ports can be easily mismatched with the only existing control measures being procedural and dependent on the individual filling the tanks. The answers generated from the team are entered into the appropriate columns in the worksheet.

4) Identify existing controls. The related controls for the possible what-if are identified and listed in the worksheet.

5) Analyze risk. Based on the answers developed and existing controls, the team estimates likelihood, severity and risk level. Figure 9 provides an example using the case study. Considering the low-level controls, the team estimates likelihood of mixing the lines as probable (4) and severity as critical (3), producing a risk level of 12.

6) Evaluate risk. Evaluating the risk level of 12 compared to the established risk criteria, it is determined that the risk is unacceptable, requiring additional risk treatment.

7) Add controls. Based on the findings, the team uses the hierarchy of controls model to select and formulate additional controls.

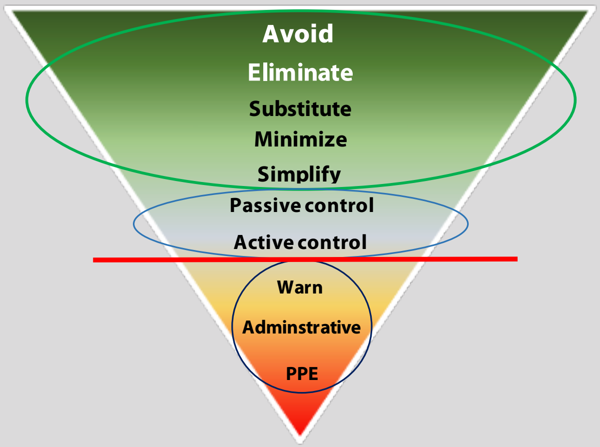
8) Analyze risk reduction. Considering the added controls, the team analyzes likelihood, severity and risk levels for each what-if question, and project a risk reduction factor.

Risk Treatment

The CSB report indicates that as the agency conducted the investigation, the facility managers were also examining their own processes and equipment to identify opportunities to reduce risk and prevent recurrence. As a result, the company implemented several layers of controls specific to the facility's ventilation system and chemical transfer equipment, with special focus on the fill lines, transfer valves, transfer piping, tanks and associated equipment (CSB, 2018a):

FIGURE 10

HIERARCHY OF RISK TREATMENT



Note. From "Risk Treatment Strategies: Harmonizing the Hierarchy of Controls and Inherently Safer Design Concepts," by B.K. Lyon and G. Popov, 2019, *Professional Safety, 64*(5), pp. 34-43. Copyright 2019 by ASSP. Reprinted with permission.

- Upgrading chemical unloading and transfer equipment with chemical portal separation, signage, unique locks and fittings.
- Implementing an innovative key control and chemical unloading sequences.
- Improving movement within the control room by moving the center control console from the middle of the control room to the walls.
- Conducting several PHAs covering propylene oxide, phosphorus oxychloride and acetic anhydride.
- Removing the acetic anhydride process entirely, leaving only four liquid bulk chemicals at the facility instead of five, thus reducing the number of bulk flammable chemicals from two to one.
- Upgrading monitoring and detection equipment to decrease the risk of chemical releases.
- Adding new emergency shutdown devices to complement the devices that were already in place.
- Installing more emergency supplied air packs along the egress path.

As identified by the CSB investigation, these potential failure modes, causes and needed control measures could have been identified and the incident prevented by conducting a thorough risk assessment of the system. Methods such as SWIFRA, HAZOP and failure modes and effects analysis can be used to assess such situations before they result in loss.

The primary objective of OSH professionals is to achieve and maintain an acceptable level of risk, a risk level that is as low as reasonably practicable. The use of a hierarchical system for selecting risk reduction strategies is a fundamental concept in safety management (Lyon & Popov, 2019). As always, risk treatment plans should be built beginning with higher-level controls that seek to avoid or eliminate the hazard, substitute lower hazards, minimize quantities of hazard energy, simplify systems, and incorporate passive and active engineering controls (Figure 10). Risk treatment plans should also incorporate layers of controls that provide multiple layers that prevent, detect, protect, and mitigate as well as provide redundancies for critical failure points.

Conclusion

For the chemical release incident investigated by CSB, what if the organization had conducted an effective risk assessment of the chemical filling process? Would such an assessment identify problems in the system such as the need to design chemical fill lines to only accept the right chemical? The answer is likely yes. However, until such questions are asked about critical systems, uncertainty and risk will remain.

With a proactive risk assessment and management process, organizations can reduce uncertainty and the potential for serious incidents. Methods such as what-if analysis and SWIFRA can be powerful tools in identifying, assessing and communicating risk within an organization. OSH professionals should equip themselves with such tools. The time to ask, "what if?" is now. **PSJ**

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Bruce K. Lyon, P.E., CSP, SMS, ARM, CHMM, is vice president with Hays Cos. He is chair of the ISO 31000 U.S. TAG, vice chair of ANSI/ASSP Z590.3 standard, advisory board chair to University of Central Missouri's (UCM) Safety Sciences program and a director of BCSP. Lyon is coauthor of *Risk Management Tools for Safety Professionals* and *Risk Assessment: A Practical Guide to Assessing Operational Risk.* He holds an M.S. in Occupational Safety Management and a B.S. in Industrial Safety from UCM. In 2018, he received the CSP Award of Excellence from BCSP. Lyon is a professional member of ASSP's Heart of America Chapter, and a member of the Society's Ergonomics and Risk Management practice specialties.

Georgi Popov, Ph.D., CSP, QEP, SMS, ARM, CMC, FAIHA, is a professor in the School of Geoscience, Physics and Safety Sciences at UCM. He is coauthor of *Risk Assessment: A Practical Guide for Assessing Operational Risk* and *Risk Management Tools for Safety Professionals.* Popov holds a Ph.D. from the National Scientific Board, an M.S. in Nuclear Physics from Defense University in Bulgaria and a post-graduate certification in environmental air quality. He graduated from the U.S. Army Command and General Staff College in Fort Leavenworth, KS. Popov is chair of ANSI/ASSP Z590.3 standard, a professional member of ASSP's Heart of America Chapter and a member of the Society's Risk Management Practice Specialty. He received the chapter's 2015 Safety Professional of the Year (SPY) Award and the 2016 ASSP Region V SPY Award. In 2017, Popov received ASSP's Outstanding Safety Educator Award.