Prevention Through Design

For Hazards in Construction

By Bruce K. Lyon, Georgi Popov and Elyce Biddle

IN BRIEF

- As indicated in the prevention through design (PTD) hierarchy of controls model, the most effective means of preventing and controlling occupational injuries, illnesses and fatalities in construction is to avoid, eliminate or minimize hazards and risks early in the planning and design process.
- Applying PTD concepts in the construction process in both the system's physical design and the means and methods of executing the construction tasks are vital in eliminating and reducing risk to constructors and users.
- Despite the recent attention given to PTD in construction, many promising control technologies have not been transferred from research into practice. A significant hurdle to PTD adoption and implementation is the availability of common methodology and risk assessment tools. This article presents a PTD risk assessment tool methodology as a way to address that challenge.

Fatalities and serious incidents that occur in construction work can be directly linked to the level of prevention incorporated into the planning and design of the project. Studies have shown that more than 40% of fatalities that occur in construction work are connected to the design aspect (Behm, 2005). Therefore, decisions made by designers and engineers greatly influence the safety of construction activities.

OSH practitioners and researchers have suggested that one of the best ways to prevent and control occupational injuries, illnesses and fatalities is to design out or minimize hazards and risks early in the design process. The most current demonstration of this belief lies in the development and approval of a voluntary national consensus standard, ANSI/ASSE Z590.3-2011 (R2016), Prevention Through Design Guidelines for Addressing Occupational Hazards and Risks in Design and Redesign Processes. The standard has incorporated key concepts from prior efforts, such as NSC's Institute for Safety by Design and other existing standards.

Despite recent attention to the safety and health of construction workers through the application of prevention through design (PTD) concepts, many promising control technologies have yet to be transferred from research into practice. This leads to the question, why?

Preventing occupational injuries, illnesses or fatalities in construction has often driven industry to make changes. Construction companies continually face increased competition, rapidly changing technology and reduced access to

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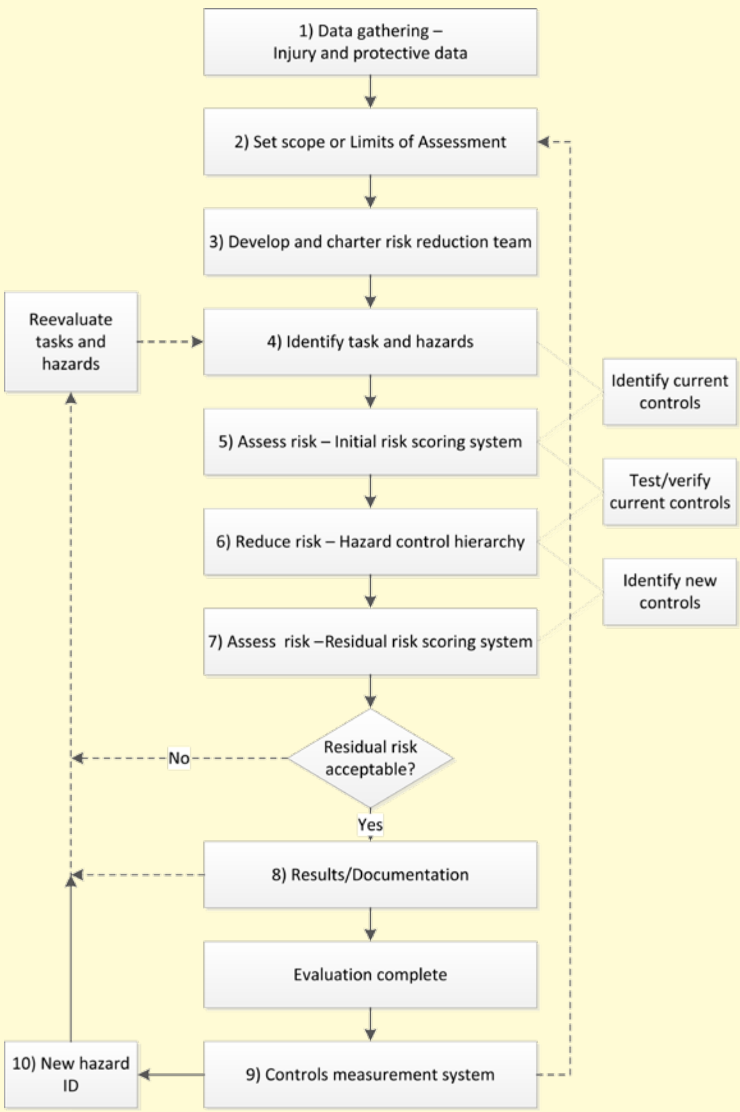
Figure 1

Hazard Analysis & Risk Assessment Process



Note. *From Prevention Through Design: Guidelines for Addressing Occupational Hazards and Risks in Design and Redesign Processes (ANSI/ASSE Z590.3-2011), by ANSI/ASSE, 2011. Des Plaines, IL: ASSE. Reprinted with permission.*

limited resources. Under these conditions, OSH efforts to ensure a safe and healthy work environment must compete with other organizational needs. Without clear risk communication about the value of OSH efforts to the organization, management may view these programs and activities as a lower priority. Thus, the challenge for OSH professionals is to communicate the value of OSH efforts in terms that are understood and accepted within the C-suite. To meet such challenges, a fundamental methodology for assessing risk at the design and redesign stage is required. This article presents such a methodology.

The Development of PTD

Although earlier efforts have been made to establish PTD concepts, a significant milestone was the release of a position paper by ASSE (1994) to promote gathering of knowledge and application of designing-for-safety concepts. This was followed by NSC's 1995 establishment of its Institute for Safety Through Design, whose mission was to integrate hazard analysis and risk assessment into the early stages of the design process so that hazards and risks could be avoided and minimized to an acceptable level. In 1999, the institute published the book *Safety Through Design*, which was composed of examples of efforts now known as PTD from various industries and the benefits derived (Christensen & Manuele, 1999).

More recently, NIOSH launched a national initiative in 2007 to promote the use of PTD concepts. Its goal is to prevent or reduce occupational injuries, illnesses and fatalities by incorporating prevention considerations into all designs that affect workers. The focus is on those who develop and execute the designs, or who work with the products of the design.

One of its goals is to help educate and enable designers, engineers, manufacturers, OSH professionals, business leaders and other stakeholders in the application of PTD principles in the design and redesign phases of facilities, processes, equipment, tools and organization of work. These efforts and the research developed were instrumental in the current PTD concepts and the creation of the Z590.3 standard. Central to the PTD standard is a hazard analysis and risk assessment methodology that can be applied to the design phase, as well as other life-cycle phases of a system.

Current PTD Initiatives Aimed at Designers & Architects

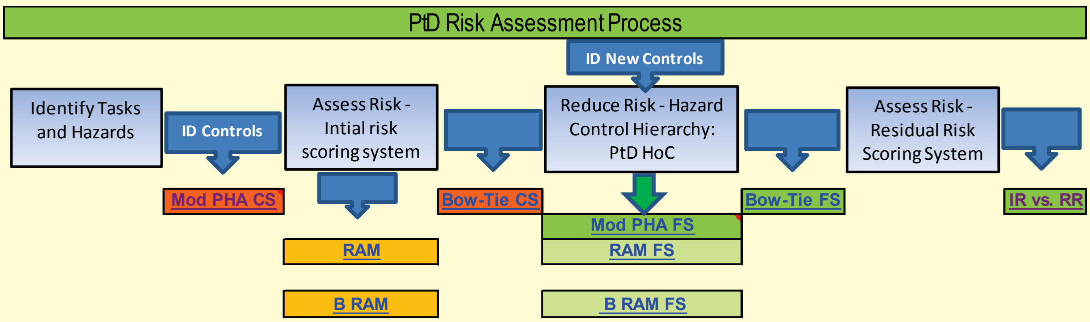
Several key efforts are taking place to further the practice of PTD by designers, engineers and architects of construction. The Design for Construction Safety website (Toole, 2016) provides an excellent source of information on such efforts, including initiatives such as:

- formation of an ANSI/ASSE A10 PTD work group with the goal of producing a technical report on PTD in construction;
- four education modules consisting of an instructor's manual and slide deck outlining PTD, worker safety and health considerations, and specific hazards in the construction design process; one module is specifically dedicated to architectural design and construction (NIOSH, 2013);
- the SliDeRulE (Safety in Design Risk Evaluator) for Buildings tool developed by John Gambatese at Oregon State University to help building designers assess the construction safety risks associated with their designs during the design phase;
- a short course on designing for construction safety by the OSHA Construction Alliance Roundtable;
- presentation to American Bar Association in construction law;
- the inclusion of PTD to the LEED rating system.

According to the NIOSH PTD initiative, strides are being made in research, education, practice

Figure 2

Major Components of the PTD Risk Assessment Tool



Note. Mod PHA = modified preliminary hazard analysis; CS = current state; FS = future state; RAM = risk assessment matrix; B RAM = business risk assessment matrix; HoC = hierarchy of controls; IR = initial risk; RR = residual risk.

and policy making. PTD principles are becoming more prominent in safety management and engineering textbooks, and are beginning to appear in architectural, civil and construction engineering degrees (NIOSH, 2014b).

However, significant opportunity remains for OSH professionals to promote and advance PTD concepts at the design phase within their organizations. Toole and Gambatese (2014) suggest several ways safety can be designed into new construction, including increased use of prefabrication; the use of less hazardous materials and methods; the application of construction engineering; and deeper communication between designers and contractors during the design phase. Their PTD program guidelines contains a list of recommended practices that owners can use to incorporate PTD into the construction design process (Toole & Gambatese, 2014).

The greatest impact OSH professionals can have on reducing risk in construction is to influence those with design responsibilities. As agents of change and knowledge leaders, OSH professionals should take the lead in championing PTD concepts within their organizations. To be successful, safety professionals must become more knowledgeable and proficient in PTD concepts, risk assessment and risk reduction methods related to construction.

Figure 3

Example Risk Assessment Matrix: Numerical Grading & Scoring

Construction Risk Assessment

Assess Risk Associated with Hazard

Risk Assessment Matrix (RAM): Numerical Grading and Scoring

Hazard #		1 S	2 HAV	3 N		
Severity Ranking:	5	5	4	4		
Probability Ranking:	3	3	3	3		
Total		15	12	12		

M PHA Form

Main

		Occurrence Probabilities and Values				
RAM		5	4	3	2	1
Severity Level	5	25	20	15	10	5
	4	20	16	12	8	4
	3	15	12	9	6	3
	2	10	8	6	4	2
	1	5	4	3	2	1

Example: Numerical Values

Conservative PtD Standard Scoring — Very high risk: **15 or greater** High risk: **9 – 14** Moderate risk: **4 – 8** Low risk: Under **4**

Note. 1 S = silicosis; 2 HAV = hand/arm vibration; 3 N = noise; RAM = risk assessment matrix; M PHA = modified preliminary hazard analysis.

PTD Risk Assessment Methodology

Identifying potential hazards and risks before materials and activities begin to take shape is a key benefit associated with PTD initiatives. One way to develop a PTD risk assessment tool is to follow the methodology depicted in Figure 1. Any PTD risk assessment tool should include at least the following:

- task and hazard identification;
- identification of current controls;
- initial risk assessment;
- risk reduction based on the hierarchy of controls;
- a measure of residual risk with the additional control measures in place.

Methodology

The PTD risk assessment tool presented in this article was designed to help OSH professionals make decisions or deliver presentations to the organizational managers charged with resource allocations. The tool can be used to select among alternative solutions or demonstrate the benefits of a solution already selected. The information provided by the tool is expressed in the language understood by all management, not just those in OSH.

The tool consists of four main steps. Before this, as in any risk assessment endeavor, stakeholders should take three steps: 1) gather data; 2) establish the scope and risk criteria; and 3) develop a risk assessment team. For the purposes of this article, only steps four through seven from the PTD standard risk assessment process (from Figure 1, p. 38) are included.

Steps one and two include individual descriptive, analytic tools, or risk assessment methodologies, described in the PTD standard. For example, a modified preliminary hazard analysis (PHA) is used to identify hazards (Addendum G, Z590.3). In order to establish the initial scoring system, utilization of well-established PTD practices may be suggested. Addendum F of Z590.3 offers several examples of risk assessment matrixes and definitions of terms. The matrix provides "a method to categorize combinations of probability of occurrence and severity of harm, thus establishing risk levels" (ANSI/ASSE, 2016). Figure 2 (p. 39) illustrates the major components of the tool.

PTD Risk Assessment Process Steps

Let's review the PTD risk assessment process steps (steps 4 through 7).

Step 4: Identify Tasks, Hazards & Existing Controls

This step involves identifying the OSH-related problems; describing control measures that are currently in place to address the problems; and determining the business unit where the operation takes place. Understanding the current situation is necessary to develop critical baseline information needed to identify interventions and controls that can be implemented or refined to further reduce risk.

Step 5: Assess Initial Risk

A scoring system is used to estimate the initial risk. More specifically, after the hazards are identified, the risks arising from those hazards can be evaluated using a modified risk assessment matrix from the PTD standard. It should be noted that the numbers in the

Table 1

Definitions of the Risk Levels for Severity & Probability

Incident or exposure severity descriptions		
5	Catastrophic	One or more fatalities, total system loss, chemical release with lasting environmental or public health impact.
4	Critical	Disabling injury or illness, major property damage and business downtime, chemical release with temporary environmental or public health impact.
3	Marginal	Medical treatment or restricted work, minor subsystem loss or damage, chemical release triggering external reporting requirements.
2	Negligible	First aid or minor medical treatment or minor medical treatment only, non-serious equipment or facility damage, chemical release requiring routine cleanup without reporting.
1	Insignificant	Inconsequential with respect to injuries or illnesses, system loss or downtime, or environmental chemical release.
Incident or exposure probability descriptions		
5	Frequent	Likely to occur repeatedly.
4	Likely	Probably will occur several times.
3	Occasional	Could occur intermittently.
2	Seldom	Could occur, but hardly ever.
1	Unlikely	Improbable, may assume incident or exposure will not occur.

Figure 4

Modified PHA Form

Construction Risk Assessment

Identify Tasks and Hazards Associated With the Problem

Main

Potential Effect # and a short name	Hazard	Potential effects	Process	Risk Factor	Business Unit/Department	Description of Current Controls	ANSI/ASSE Z590.3-2011: Prevention Through Design, Hierarchy of Controls
1 S	Chemical/ Particles	Silicosis	Concrete grinding	15	Civil Construction	None	None
2 HAV	HAV	HAVS	Concrete grinding	12	Civil Construction	None	None
3 N	Noise	Hearing loss	Concrete grinding	12	Civil Construction	PPE	PPE

Next go to RAM:

Assess Current Risk Associated with Hazard

Note. *1 S = silicosis; 2 HAV = hand/arm vibration; 3 N = noise; HAVS = hand/arm vibration syndrome; RAM = risk assessment matrix. Photo courtesy University of Washington, as cited in "Controlling Silica Exposures in Construction" (OSHA Publication No. 3362-05), by OSHA, 2009, retrieved from www.osha.gov/Publications/3362silica-exposures.pdf.*

example risk assessment matrix (Figure 3, p. 39) were subjectively determined and are semi-quantitative in nature. Table 1 provides definitions for each risk level for severity and probability.

Next, a risk level is calculated. This typically takes the form of a simple multiplication of severity (S) x probability (P). It should be noted that suggested PTD standard rating includes 1 through 5 low-risk rating. However, the authors believe that a more conservative approach may be necessary. For example, a high severity (5) but low probability (1) hazard will result in a low-risk rating.

Manuele (2008) issued a call for a new focus on prevention and later presented major innovations on how to reduce serious injuries and fatalities (Manuele, 2014). Another resource can be found in a series of videos offered by ASSE's Risk Assessment Institute (**www.oshrisk.org/videos**). The video "Fatal and Serious Injury Prevention" defines fatal and serious injury precursors and identifies the role of leadership in fatal and serious injury prevention (ASSE Risk Assessment Institute, 2014). Martin and Black (2015) also suggest that the goal is to "reduce and eliminate every type of injury, but consideration should be given to the allocation of safety resources specifically targeted to the reduction of potential for serious and fatal events." Therefore, a more conservative risk rating is considered in this article.

Similar risk assessment matrixes could be used to evaluate business hazards and risks. To present a 30,000-ft view of the current state, hazards and consequences are presented utilizing a modified bow-tie risk assessment methodology. The bow-tie risk assessment methodology is well described in ISO 31010/ANSI/ASSE Z690.3-2011 Risk Management Standard (ANSI/ASSE, 2011a). The risk level numbers are transferred to the modified bow-tie risk assessment diagram. Although, the bow-tie risk assessment methodology is not specifically mentioned in the PTD standard, the authors believe it is important to include the big-picture overview of hazards and consequences (Popov & Zey, 2012).

Step 6: Reduce Risk

This step begins by identifying the solutions to hazards recognized in previous steps. Consider-

Figure 5

Determining Risk Level for Potential Effects of Identified Hazards

		1 S	2 HAV	3 N
Hazard no.	→	**1 S**	**2 HAV**	**3 N**
Severity ranking:	5	5	4	4
Probability ranking:	3	3	3	3
Total	→	15	12	12

Note. 1 S = silicosis; 2 HAV = hand/arm vibration; 3 N = noise.

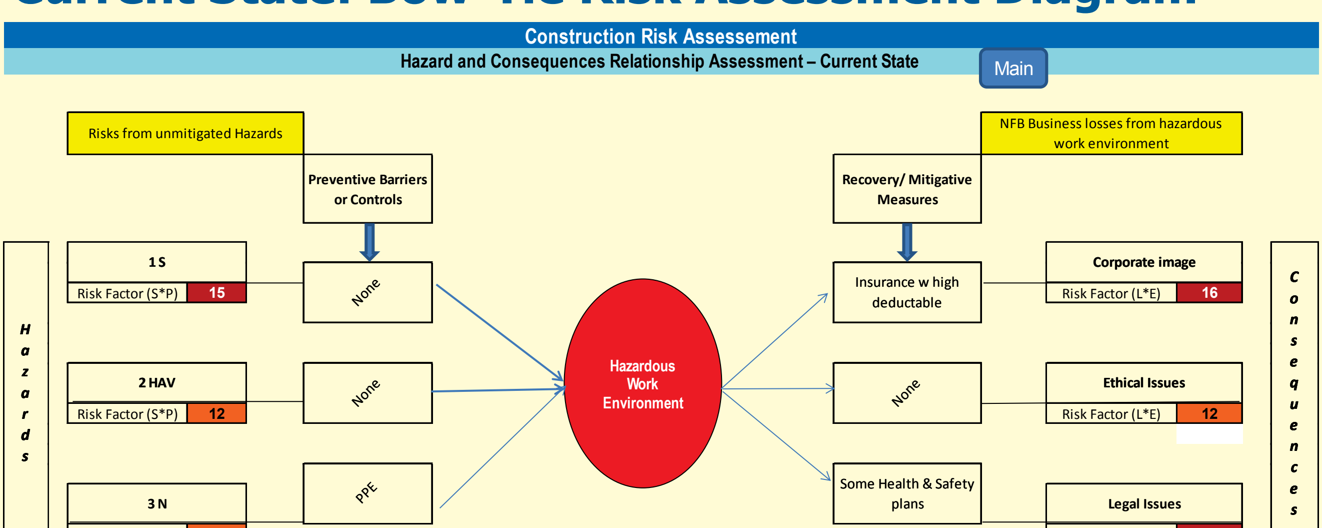
Figure 6

Risk to Business Operations Continuity

Outcomes	→	**Corporate image**	**Ethical issues**	**Legal issues**
Intensity rating:	5	4	3	5
Likelihood rating:	5	4	4	4
Total	→	16	12	20

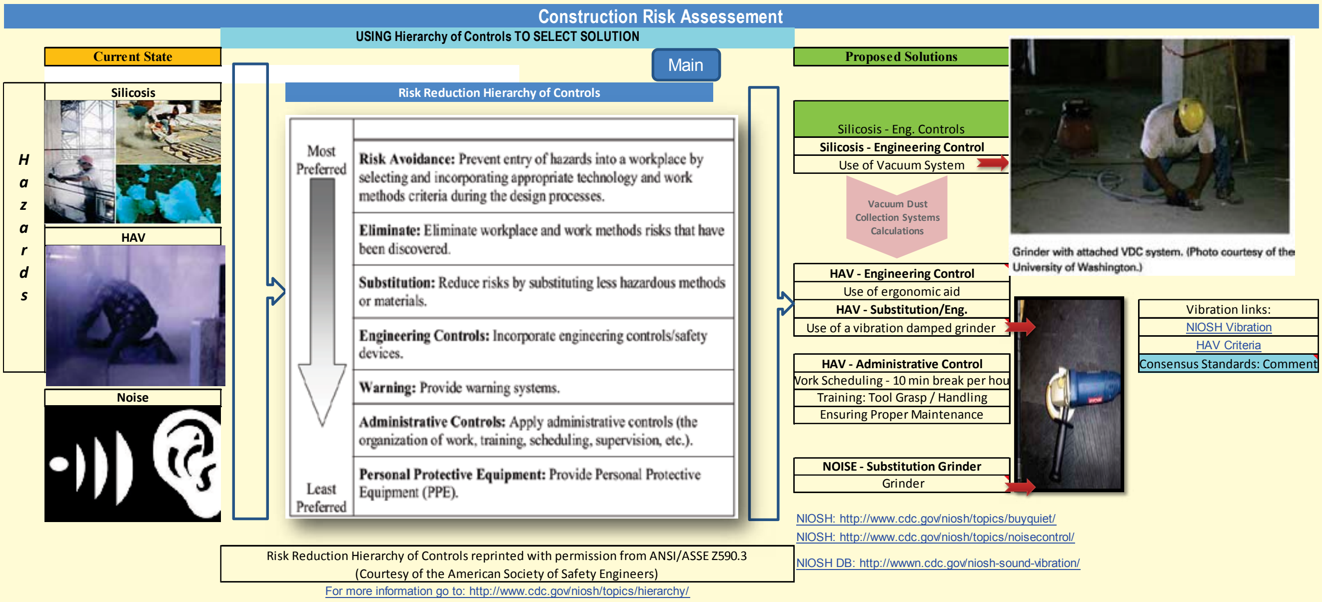
Figure 7

Current State: Bow-Tie Risk Assessment Diagram



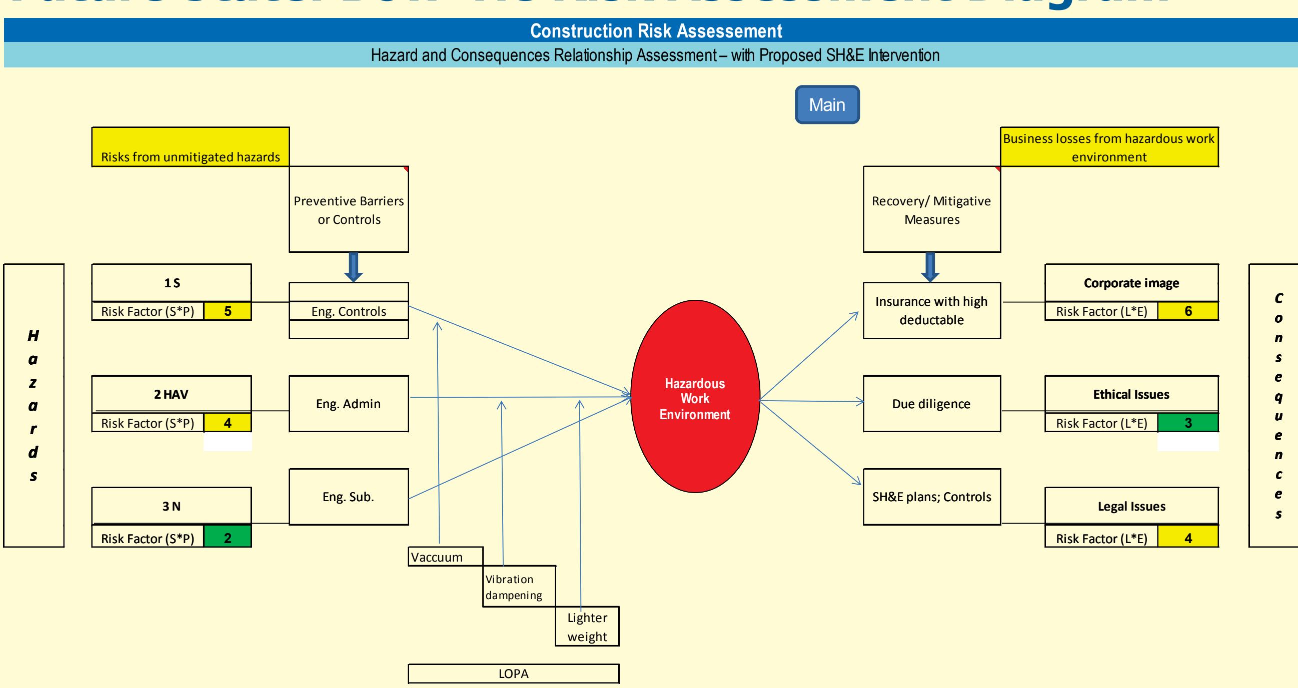
Note. 1 S = silicosis; 2 HAV = hand/arm vibration; 3 N = noise; S = severity; P = probability; E = extent of impact; L = likelihood.

Figure 8
PTD Hierarchy of Controls



Note. *HAV = hand/arm vibration.*

Figure 9
Future State: Bow-Tie Risk Assessment Diagram



Note. *1 S = silicosis; 2 HAV = hand/arm vibration; 3 N = noise; S = severity; P = probability; E = extent of impact; L = likelihood.*

ation of PTD concepts, including the hierarchy of controls, is used to evaluate and select possible solutions for continued analysis. The processes/operations identified in Step 4 are revisited to determine what changes to those processes/operations result from the intervention or solution being considered. These changes again include both the risk of business loss or interruption and the risk of adverse worker safety and health outcomes.

A second risk analysis is performed considering the effect of implementing the intervention options. The relationship of hazard and consequenc-

Figure 10

Residual Risk & Risk Reduction

Construction Risk Assessment

Assess Residual Risk and Risk Reduction

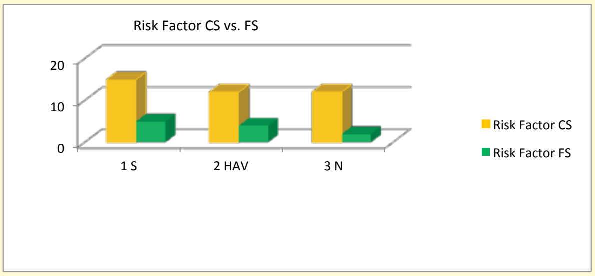
Main

Health and Safety Risk Reduction

	Hazards	Risk Factor CS	Risk Factor FS	% Risk Reduction	% Residual Risk
	1 S	15	5	66.67%	33.33%
	2 HAV	12	4	66.67%	33.33%
	3 N	12	2	83.33%	16.67%
	Total	39	11	71.79%	28.21%
Is this an acceptable level of Health and Safety Risk?			Yes		

BUSINESS Risk Reduction

	Business losses from hazardous work environment	Risk Factor CS	Risk Factor FS	% Risk Reduction	% Residual Risk
	Corporate image	16	6	62.50%	37.50%
	Ethical Issues	12	3	75.00%	25.00%
	Legal Issues	20	4	80.00%	20.00%
	Total	48	13	72.92%	27.08%
Is this an acceptable level of Business Risk?			Yes		



Note. *CS = current state; FS = future state; 1 S = silicosis; 2 HAV = hand/arm vibration; 3 N = noise.*

es is evaluated using tools recommended in ANSI/ASSE Z590.3 and ISO 31010/ANSI/ASSE Z690.3. Another bow-tie risk assessment could be included at the end of this step to present possible risk reduction in hazards and consequences.

Step 7: Assess Residual Risk

Assessing residual risks is considered a critical step. It integrates all previous steps and provides risk reduction calculations, providing a final risk measure—one that calculates the remaining business and OSH risk. This enables decision makers to make better decisions concerning risk reduction measures and their effects on risk to achieve an acceptable level.

As these select steps demonstrate, the tool is flexible enough and can be used in various situations or under various conditions. It can be used in any of the stages of implementing solutions—preoperational, operational, post-operational or post-incident—defined in ANSI/ASSE Z590.3.

Case Study References

The following case study examples help illustrate the importance of risk assessments and the benefits they provide when fully utilized.

1) Control of Hazardous Dust When Grinding Concrete (NIOSH, 2009).

2) Vibration Syndrome (NIOSH, 1983).

3) Controls for Noise Exposure (NIOSH, 2014a).

PTD for Hazards in Construction Tool Applicability

Current research presents opportunities for the OSH professional to explore alternatives with the goal of reducing occupational injury and illnesses associated with grinding concrete. Following is a description of the steps included in the PTD risk assessment tool.

The first step is to identify the main safety and health hazards. OSH professionals are encouraged to identify and list (document) all of the hazards associated with the process/operation. The form provides options to evaluate many different hazards. However, it is common practice to start with the top three ranked hazards. Three hazards are identified and recorded in Figure 4 (p. 40).

With the hazards identified, the next step involves determining the risk level for each of the three potential effects. Risk level could be defined as a combination of severity and a probability of the potential effects based on the identified hazards. Several risk assessment methods exist, but for this project the process was conducted using the simple risk assessment matrix described in the PTD standard. The risk to human safety and health is not the only risk associated with workplace hazards. The risk to business operations continuity should also be considered. A similar risk assessment matrix was used to estimate that risk. Figures 5 and 6 (p. 41) present the risk assessment results for both types of risk.

To present a big-picture overview of the current state, hazards and consequences are presented utilizing a modified bow-tie risk assessment methodology. The risk level numbers are transferred to the modified bow-tie risk assessment diagram presented in Figure 7 (p. 41).

After evaluating hazards associated with the current process/operation, PTD concepts are considered using the hierarchy of controls model, then are discussed and documented. A simple form was developed to present current state hazards and proposed solutions (Figure 8).

The same risk assessment methodology can be applied to evaluate hazards and consequences after the new controls are implemented. Hazards and consequences for the new controls are presented using a modified bow-tie risk assessment methodology (Figure 9).

Notice that below the preventive barriers or controls, layers of protection could be added as needed. Layers of protection analysis (LOPA) and bow-tie method integration can be considered a barrier-based approach to risk. It follows Reason's Swiss cheese model of defenses (EEC, 2006).

To be successful, safety professionals must become more knowledgeable and proficient in PTD concepts, risk assessment and risk reduction methods related to construction.

Calculating the residual risk and risk reduction scores is among the final steps in the risk assessment process (Viator & Spencer, 2010). After implementing all identified control measures, a 71.79% risk reduction can be potentially achieved (Figure 10).

To help communicate the value to decision makers, the financial benefits of the proposed changes are calculated. To be effective, OSH professionals should be able to determine and communicate the potential impacts on workers, business operations (both upstream and downstream) and risk management. Changes in risk measurements will serve as the basis to derive the financial and nonfinancial benefits of modifying the work process by implementing all proposed control measures that can be included in a business case (Biddle & Popov, 2014).

Conclusion

Following the hierarchy of controls model, hazards and risk that can be eliminated, avoided or minimized are the first choice in managing workplace and construction risks. OSH professionals agree that PTD concepts should be employed early in the design and planning stages of construction projects and associated tasks.

Effectively communicating the value of PTD interventions can be challenging for OSH professionals who lack the expertise or experience in such efforts. The PTD risk assessment methodology and tools demonstrated in this article provide an example of how safety professionals can successfully incorporate PTD in construction-related tasks and the overall risk management process. Remember, the output of the PTD risk assessment is a valuable input to the decision-making process. **PS**

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