Safety Management

How Safe Is Safe?

Techniques for advancing and applying machinery risk assessments

By John M. Piampiano and Steven M. Rizzo

SH&E PROFESSIONALS tend to be a conservative community with respect to machinery safeguarding. This predisposition is seemingly validated when considering the machinery-related injury legacy, regulatory environment and today's litigious society. However, this approach may drive overprotection of the hazard. While it is accepted that U.S. industry must conform with all applicable regulations, it can no longer afford to fall back on pre-existing—and perhaps outdated—paradigms if it hopes to remain competitive. Risk assessments may be able to provide industry the ability to determine how safe is safe enough.

In January 2000, ANSI published ANSI B11.TR3, Risk Assessment and Risk Reduction: A Guideline to Estimate, Evaluate and Reduce Risks Associated with Machine Tools. This document provides SH&E professionals with the foundational concepts for establishing risk-based machine safeguarding evaluations. The challenge lies in interpreting and applying these concepts.

Safeguarding risk assessment techniques are generally qualitative. They typically rely on the subjective judgment of an assessment team to estimate severity potential and probability, which can lead to inconsistent estimations. Additionally, the resultant qualitative descriptions such as high, medium, low and negligible do not establish a tolerable residual risk level. The user is left to interpret what the risk outcome means.

Because of this, available risk assessment tools cannot simply be pulled off the shelf and applied in the field. To enhance consistency and usability, it is necessary to expand the concepts established in the industry consensus standards. Specifically, the user must:

- reduce subjectivity when estimating severity and probability;
- define tolerable risk in a way that reflects the company's culture and appetite for risk.

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Strengthening Severity Estimations

Most risk tables define potential injury severity (e.g., death, fractures, lacerations) using graduated categories such as catastrophic, serious, moderate and minor. The weakness in this approach is that the user must rely on judgment to predict the degree of harm a hazard can cause, and this judgment can vary between professionals. Such judgment is necessary because the tables are built using a description of the consequence rather than the force or energy necessary to produce the consequence. Absent a correlation between force or energy with severity potential, the user tends to rely on historic injury data, nonrepresentative tests such as placing a pencil in the point of operation to see whether it breaks, and gut feeling to predict the worst credible harm.

Some data available in literature could help build a correlation between force or energy and injury types. For example, it is known that a 1-second contact with a hot aluminum surface with a temperature below 111 ºF will cause pain but no injury. It is also understood that surface temperatures between 111 ºF and 140 ºF can cause a first-degree burn. Furthermore, temperatures between 140 ºF and 154 ºF can cause second-degree burns, and temperatures above 154 ºF can cause third-degree burns (Chengalur 611-612). These

four categories can now be used as the basis for a severity gradation (Figure 1).

In a similar manner, pressures may be used to estimate injury potential associated with crushing hazards. A literature search suggests that pressure below 12 psi may cause discomfort but no injury. Between 12 psi and 43 psi, a contusion is possible, and above 43 psi, a fracture to small bones can occur (the literature characterizes bones by density and diameter, and generally references fingers, hands and toes as small bones). Exceed 58 psi, and a fracture to large bone can occur (the literature generally references arms, legs and head as large bones) (Mewes and Mauser). It is important to note that these are general guidelines that may be affected by variables such as hazard size, shape and type (e.g., offset edges, shear, torsion, tension, compression).

Correlation of force or energy to injury severity can greatly advance risk estimation by reducing subjectivity. A reduction in subjectivity enables the SH&E professional to predict—more accurately and more consistently—the worst credible harm that a hazard can cause. While some quantitative information is available, many knowledge gaps exist. Information is needed that correlates force/energy to other injury types such as lacerations and soft tissues. Additionally, methods and tools are needed to conduct field measurements. The "gotcha stick" of the future might very well be a simulated hand that detects and records imparted forces or energy.

Building a Better Probability Model

Determining the probability of an occurrence of harm is perhaps the most likely source of risk assessment inconsistency. As with severity estimations, traditional probability models rely on judgment to select from graduated categories such as likely, possible and remote to describe probability. Variables such as incident history, operator skill and operator behavior are frequently considered to predict probability of an event.

Because there is no method to weigh, compare and contrast these variables, those involved are unable to correlate the variables to the probability descriptions. For example, the relationship between operator experience and incident avoidance is indeterminate. Are more-experienced operators less likely to be injured because they know and understand the hazard, or are they more likely to be injured because they are more comfortable with the hazard and, therefore, are more likely to gain access to the hazard? Similarly, does lack of historic injuries indicate low probability or has the incident avoidance simply been a matter of luck?

A less-subjective and perhaps easier risk model to employ links probability to the strength of the safeguard and does not need to definitively describe probability outcomes (Figure 2). This is possible because probability is inherent in the hierarchy of controls. For example, a procedure is more likely to fail in a manner that would allow injury than is an engineering control such as a fixed barrier guard.

Single administrative controls such as procedures, training and certifications rely entirely on human behavior and are considered to be least reliable; therefore, they possess the highest failure probability. The next tier of protection is redundant administrative controls such as railings, presence-sensing initiated warning systems and warning signs. These controls have an operator-independent reminder that helps to influence behavior.

The third and fourth tiers of protection are independent of operator behaviors and are, therefore, less prone to failure. Single-layer engineering controls include fixed barrier guards and presence-sensing devices interlocked to the machine drive with less-reliable control circuits and components. Redundant engineering controls either are self-monitoring or incorporate control redundancy. Examples include fixed barrier guards with control-reliable interlocks, moveable barrier guards with category 4 control circuits, and presence-sensing devices with category 4 control circuits. These controls represent the lowest probability of failure.

By themselves, these four safeguard categories do not entirely predict a safeguard's ability to prevent an injury. It is necessary to further subdivide the safeguard categories, incorporating additional variables that affect how strong the control is and, consequently, its probability to prevent injury. Administrative and engineering controls fail in different ways so the variables considered may be different for each subcategory. Typical administrative variables include distance from the hazard, frequency of performing the task and the task relationship to the hazard.

The engineering safeguard variables include component failure rate, the manner of operator interaction with the hazard, and the motivations that might influence an operator to defeat the safeguard. It is important to state these variables as quantitatively as possible (Table 1). Building a probability model as quantifiably as possible enhances consistency and simplifies the estimation process. It also provides a stronger correlation between probability and severity, and yields a more representative risk estimation (Figure 3).

Figure 1

Severity Matrix

This matrix shows how severity categories might be quantified for temperature and pressure. Similar information can be compiled to describe other hazards.

Increasing Severity

Severity Category	Temperature	Pressure
Catastrophic	>154 °F	>58 psi
Serious	140 °F-154 °F	43-58 psi
Moderate	111 °F-139 °F	12-42 psi
Minor	<111 °F	<12 psi

Figure 2

Probability Illustration 1

In this figure, control descriptions are used rather than qualitative descriptions such as "very likely," "likely" or "remote."

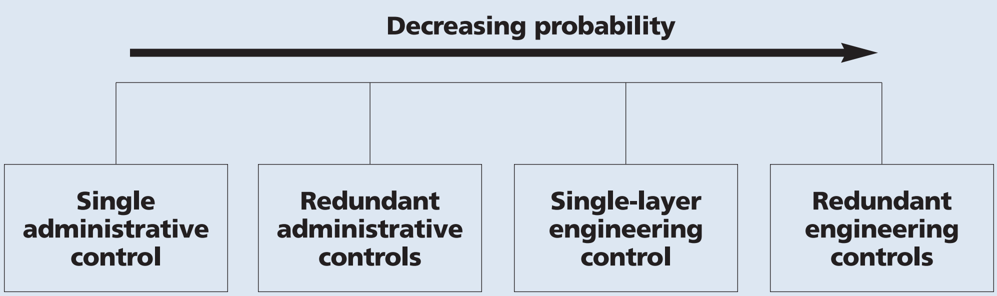


Table 1

Safeguard Variables

Factors that influence a control's effectiveness must be quantitatively expressed.

	Exposure 1	Exposure 2
Administrative	•The task is performed more than once per week. •The task is less than 5 ft from the hazard.	•The task is performed less than once per week. •The task is more than 5 ft from the hazard.
Engineering	•Fixed guard is removed more than once per week. •The task requires entry into the danger zone.	•Fixed guard is removed less than once per week. •The task does not require entry into the danger zone.

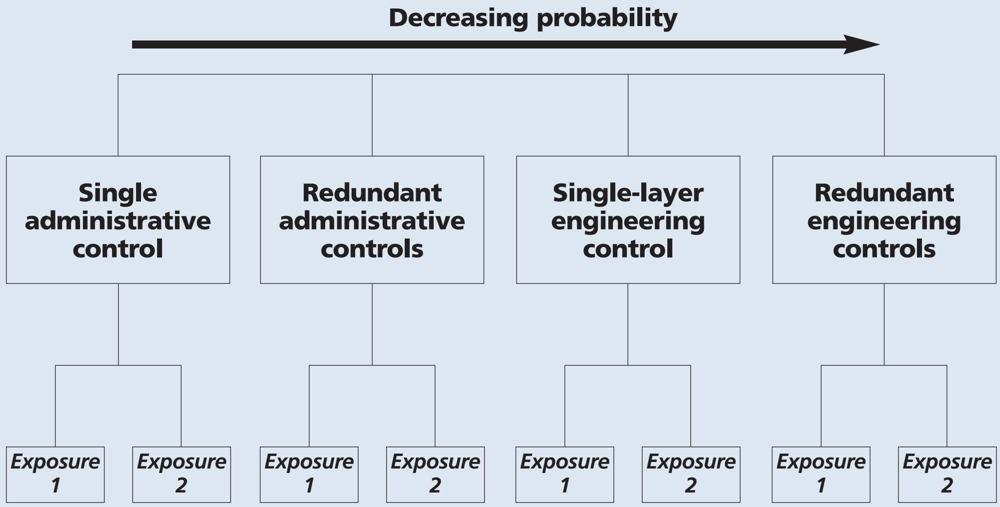
Putting Severity & Probability Together

Risk is defined by ANSI B11.19 TR.3 as "a combination of the probability of occurrence of harm and the severity of that harm." Combining these two considerations generates a risk level that suggests an organization's risk tolerance threshold. The shortcoming is that risk levels are typically described with terms such as high, medium, low and negligible, terms which provide only a perceived threshold of concern and do not indicate actions that need to be taken. In the end, the risk assessment simply becomes a prioritization tool with the same controls applied to all risks but over differing time periods (e.g., high risk receives attention sooner than low risk).

Figure 3

Probability Illustration 2

This figure illustrates how control types and exposure variables can be combined to estimate probability.



Instead, the risk level terms should be defined in an action-oriented manner in order to eliminate subjectivity and instruct management on the controls required. For example, negligible could be defined to mean that further risk reduction is not necessary because the controls are sufficient to prevent the severity of harm evaluated. Low residual risk could mean that the control meets minimum requirements but may not prevent harm in all instances, and that failure modes should be identified to determine whether further risk reduction is necessary, particularly in situations with a history of frequent minor incidents.

Medium suggests that the controls are not adequate for the hazard level. As such, either the safeguard should be strengthened (e.g., moving from single administrative controls to redundant administrative controls, administrative controls to engineering controls, etc.); the inherent severity potential reduced; the manner in which the employee interacts with the hazard modified (e.g., by reducing the exposure frequency or the distance between the task and hazard); or the residual risk accepted only following approval by management. High residual risk should indicate an intolerable risk—either controls must be enhanced or the inherent severity potential must be reduced.

To complete the risk model, a risk level must be assigned to each severity/probability combination. There is no right or wrong answer, and no entity can decide this for a given facility. High and negligible risk levels will be easiest to fit into the risk matrix because those severity/probability combinations represent the extremes. Assigning medium and low will be more difficult and requires trial and error (Figure 4).

Once each risk level is assigned, each must then be validated. This can be accomplished by testing the combinations using real-life examples drawn from incident experiences, similar task/hazard pairs and industry experience. In some cases, the test may suggest that the severity, control or exposure category descriptions need to be modified so that the model best reflects a given organization's value system.

Risk matrixes are simply visual representations of the organization's risk value judgment, prescribing minimum controls for a given hazard. A parallel can be drawn between the way machinery risk levels and chemical exposure limits are used. For example, a low residual risk as determined by a machinery risk assessment tool and a permissible exposure limit (PEL) both describe minimally acceptable conditions; a medium residual risk and a short-term exposure limit (STEL) both describe conditions that are acceptable under certain limited situations; and high risk and immediately dangerous to life and health (IDLH) describe unacceptable conditions. The risk message should indicate whether tolerable risk has been achieved.

Case Study

To illustrate these concepts in practice, let's consider a hypothetical situation in which a machine transports a sheet of thin metal through two counter-rotating rollers. One roller is fixed and the other is on a floating mechanism that allows nip point between the rollers to expand from 0 in. to 12 in.

Determining severity. The maximum force between the rollers was measured to be 30 psi. The severity table (Figure 1) indicates that this condition is a "moderate" severity level.

Determining probability. The machine comes equipped from the manufacturer with a fixed barrier guard, properly sized and distanced to protect an operator from contacting the hazard. A fixed barrier guard is a single-layer engineering control. The employee's task requires manually feeding material through a slot in the guard into the rollers for thread up. The exposure table (Table 1) indicates that this activity is "Exposure 1."

Determine residual risk. As illustrated in Figure 5, the residual risk is "negligible."

Key points. 1) Severity and probability determinations are straightforward. 2) Adding an interlock to the fixed barrier guard is unnecessary, while relying exclusively on a procedure is not protective enough.

Risk Assessment & OSHA Requirements

Industry consensus standards such as ANSI B11.19 TR.3 have suggested that the use of risk assessment concepts is important for evaluating and protecting against machinery hazards. The simple fact remains that OSHA has not formally recognized risk assessment in Subpart O. As a result, some may question its value and may be concerned that the use of this tool will put them at a compliance risk.

However, a strong similarity exists between the elements considered during a risk assessment and those OSHA considers when evaluating compliance. Clearly, OSHA considers protection from hazards that can cause death or serious physical harm to be

Figure 4

Risk Matrix

The risk matrix maps the severity, control and exposure level tables together, and links these three variables to estimate a residual risk level.

	Single administrative control		Redundant administrative controls		Single-layer engineering control		Redundant engineering controls	
	Exposure 1	*Exposure 2*	*Exposure 1*	*Exposure 2*	*Exposure 1*	*Exposure 2*	*Exposure 1*	*Exposure 2*
Catastrophic	*High*	*High*	*High*	*Medium*	*Medium*	*Low*	*Low*	*Negl.*
Serious	*High*	*Medium*	*Medium*	*Medium*	*Low*	*Low*	*Negl.*	*Negl.*
Moderate	*Medium*	*Low*	*Low*	*Negl.*	*Negl.*	*Negl.*	*Negl.*	*Negl.*
Minor	*Negl.*	*Negl.*	*Negl.*	*Negl.*	*Negl.*	*Negl.*	*Negl.*	*Negl.*

an important factor in evaluating compliance. Section 5(a)(1) of the OSH Act states that employers are required to provide employees a place of employment which is "free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees." While the absence of significant severity potential is not enough to vacate a citation, OSHA's *Field Inspection Reference Manual* indicates that where the most serious injury associated with a hazard cannot reasonably cause death or serious physical harm, only "other-than-serious" or *de minimis* violations shall be cited. Risk assessments that evaluate the forces associated with the hazard, qualitatively or quantitatively, can demonstrate that the hazard is not substantial enough to cause death or serious physical injury.

Similarly, the manual states that citations "may be issued when the possibility exists that an employee could be exposed to a hazardous condition because of work patterns, past circumstances or anticipated work requirements, and it is reasonably predictable that employee exposure could occur." This statement suggests a consideration of the probability of occurrence.

A survey of the disposition of contested citations issued as the result of alleged safeguarding deficiencies suggests that OSHA must demonstrate not that the exposure to a hazard is theoretically possible but rather whether employee entry into the danger zone is reasonably foreseeable (Rockwell International Corp.). Specifically, OSHA citations have been vacated where:

- no apparent reason existed for an employee to place his/her hand in the danger zone and no prior accidents existed (Miniature Nut and Screw Corp.; Jefferson Smurfit Corp.; Armour Food Co.; Smurfit Diamond Packaging Corp.);
- worker had no demonstrated need to reach around a partial guard (Miniature Nut and Screw Corp.);
- employees had no demonstrated need to place hands near an unguarded part of a machine (Jefferson Smurfit Corp.);
- contact with a hazard was deemed remote due to the distance between machines (Miniature Nut and Screw Corp.);
- sufficient space existed to pass by the hazard without coming into contact with the hazard (Armour Food Co.).

These cases demonstrate that the manner and frequency with which an employee interacts with a hazard can have a bearing on the extent of safeguarding necessary to protect a machine. As proposed in this article, risk assessments should consider the manner and frequency of exposure to a hazard, and should also consider the strength of controls when evaluating probability.

In the purest sense, risk assessments strive to identify hazards that can cause harm and prescribe safeguarding commensurate to the hazard. If properly conducted, risk assessments can help eliminate the potential for injuries. A thorough and well-documented risk assessment can demonstrate that a hazard cannot cause significant harm and/or is protected well enough to reduce the probability of

Figure 5

Risk Matrix Example

The risk matrix maps the severity, control and exposure level tables together, and links these three variables to estimate a residual risk level.

	Single administrative control		Redundant administrative controls		Single-layer engineering control		Redundant engineering controls	
	Exposure 1	*Exposure 2*	*Exposure 1*	*Exposure 2*	*Exposure 1*	*Exposure 2*	*Exposure 1*	*Exposure 2*
Catastrophic	*High*	*High*	*High*	*Medium*	*Medium*	*Low*	*Low*	*Negl.*
Serious	*High*	*Medium*	*Medium*	*Medium*	*Low*	*Low*	*Negl.*	*Negl.*
Moderate	*Medium*	*Low*	*Low*	*Negl.*	*Negl.*	*Negl.*	*Negl.*	*Negl.*
Minor	*Negl.*	*Negl.*	*Negl.*	*Negl.*	*Negl.*	*Negl.*	*Negl.*	*Negl.*

occurrence to a tolerable level. This leads to the conclusion that risk assessment is not in conflict with the spirit and intent of the OSHA regulations.

Better Risk Assessment Helps Determine How Safe Is Safe

This article has described an approach that could help to build on available risk assessment resources such as ANSI B11.19 TR.3. It has also, in part, shared steps for incorporating objective, observable data into tables for estimating severity potential, control level and exposure mechanisms. Experience has shown that this approach enables risk assessors to consistently identify safeguards and actions which are appropriate to control each hazard. Essentially, the risk assessment "prescribes" the optimum controls necessary for a particular task/hazard pair. In the authors' experience, teams applying this method quickly and easily recognize the relationship between "hazard severity" and "level of control necessary."

While this model removes some subjectivity from the risk assessment process, it cannot be removed from the overall design of the matrix. In refining and implementing these concepts over the past 10 years, many challenges have been encountered. Absent more concrete guidance from consensus standards or regulation, all users of risk assessment must assign residual risk levels for each severity/control/exposure combination in the matrix that reflect the best-available judgment as well as organizational values and tolerance for risk.

However, the concept of using objective and observable data can be expanded and strengthened. Additional research is needed to identify and understand the force/injury severity relationship for all types of hazards in the industrial setting. Tools and methods are needed to readily and easily measure these forces. Finally—and perhaps most importantly—it is crucial that consensus groups and regulators work together to establish a better definition of what is practically meant by tolerable risk. In the end, a company must know, without judgment and with complete confidence, that as the result of the risk assessment process it has determined how safe is safe enough. ■

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