Safe or Safe Enough?

Measuring Risk & Its Variables Objectively

By John M. Piampiano and Steven M. Rizzo

In an article in the June 2006 issue of *Professional Safety*, the authors introduced a series of recommendations intended to build on risk assessment concepts established in long-standing ANSI and European Normative documents (Piampiano & Rizzo, 2006). The article focused specifically on ways to make the process of estimating severity and probability more objective. The main premise was that risk assessment techniques were generally qualitative approaches.

IN BRIEF
- **SH&E professionals are introduced to specific ways to more objectively estimate severity and probability.**
- **A correlation between force/energy and certain injury types is analyzed and a nontraditional probability model that links probability to the strength of the safeguard is presented.**
- **SH&E professionals should revisit risk communication messages and their impact, and understand the effectiveness of behavior-based control strategies relative to machinery risk assessments.**

To improve objectivity, make the results more repeatable and employ more intuitive estimation concepts, a means was needed to make estimation more measurable. To accomplish this, a literature search was conducted and data were found that correlated force and energy to certain injury types. In addition, the authors proposed a probability model that linked probability to the strength of the safeguard.

In 2009, International Electrotechnical Commission (IEC) and International Organization for Standardization (ISO) published ISO/IEC 31010, Risk Management—Risk Assessment Techniques (since adopted in the U.S. as ANSI/ASSE Z690.3-2011). This document provides SH&E professionals with the foundational concepts for establishing risk-based machine guarding evaluations. As with ANSI's B11.TR3-2000, the original challenge confronting SH&E professionals remains: understanding how to interpret and apply these concepts.

As noted by Piampiano and Rizzo (2006), SH&E professionals can use several techniques to apply risk assessment concepts and communicate risk messages. These techniques and the enhancements discussed in this article are based on the authors' experiences assessing risk over the past 20 years. The techniques have not been vetted or tested in a public forum but are offered to provide some guidance to rethink and evolve traditional risk assessment techniques. To understand the enhancements made since 2006, let's begin with a quick review of the concepts as originally proposed.

Severity Estimation

Table 1 (p. 38) illustrates a compilation of criteria often used to estimate severity potential (Lennon, Renfro & O'Leary, 2010; Crystal, 2010; ISO, 2007; BSI, 1996, 1997; AIChE, 1987; ISO/IEC, 2009). Individuals or teams draw on their incident experience to predict the degree of harm that a hazard can cause. Such judgment is necessary because traditional severity tables use a description of the consequence. A weakness in this approach is that incident experience can vary greatly between professionals, leading to inconsistent and potentially inaccurate conclusions.

In contrast, Table 2 (p. 38) illustrates a model that directly correlates energy and force (e.g., current, psi, temperature), the extent of the body exposed to the hazard and injury type (e.g., laceration, fracture, shock, burn) to determine the injury severity potential. This model is simpler to employ because it makes severity estimation more objective and generates more repeatable results between individuals.

Probability Estimation

Determining the probability of occurrence of harm can be a source of risk assessment inconsistency, particularly when considering the myriad ways that probability estimations are represented in literature (ANSI, 2000; ISO, 2007; BSI, 1996, 1997; ISO/IEC, 2009). As with severity estimations, traditional probability models rely on judgment

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to select from graduated categories such as certain, likely, possible and remote to describe probability. Variables such as incident history, operator skill and behavior, and nature of exposure, are frequently considered to predict probability of an event. Because there is no method to weigh, compare and contrast these variables, those involved often are unable to correlate the variables to the probability descriptions.

For example, the relationship between operator experience and incident avoidance is indeterminate. Some safety professionals could contend that a more experienced operator is less likely to be injured because that operator knows where and how hazards manifest, whereas other safety engineers might contend that extensive experience makes an operator comfortable and complacent around the hazard. Consequently, a risk assessment team might assign more weight to the same control in one circumstance than it would in another. It also is possible that the team might conclude that administrative controls are as effective as engineering controls.

In some risk assessment models, probability is described in terms of frequency of occurrence (e.g., 1 in 10 years, 1 in 100 years). While this approach appears to be more quantitative, the data necessary to calculate the appropriate frequency of occurrence, such as defects per opportunity, number of times the task is performed, effectiveness of controls, failure rates and extensive incident history, are not typically available. This could lead to the false conclusion that an event is not likely to occur when in fact the actual exposure and interaction (task-hazard pair) might suggest a much higher probability. It is not statistically sound to make estimations based on a narrow data set. Table 3 (p. 38) illustrates a common approach used to estimate probability (Lennon, et al., 2010; Crystal, 2010; ISO, 2007; BSI, 1996, 1997; AIChE, 1987; ISO/IEC, 2009).

Table 4 (p. 39) proposes a method to enhance probability estimation (Piampiano & Rizzo, 2006). This approach offers a less-subjective and perhaps easier risk model to employ by linking probability to the strength of the safeguard. It does not need to definitively describe probability outcomes. This is possible because the nature of the hierarchy of controls suggests an imbedded probability (reliability) of preventing injury. For example, a procedure is more likely to fail in a manner that would allow injury than is a fixed barrier guard.

Risk Matrix

Once severity and probability estimation methods are established, these definitions can be used to compile a risk matrix. To do this using the revised definitions, one must determine the standard of control that a sample business would seek for a particular severity potential. For example, situations that could result in a fatality or amputation warrant secondary engineering controls. Ideally, administrative controls would only be relied on in situations that could result in less-severe injuries (e.g., moderate, minor). Said another way, the combination of clearer severity descriptors and control levels help to define the company's risk tolerance. Figure 1 (p. 39) illustrates a possible method to compile a risk matrix (ANSI, 2000; Piampiano & Rizzo, 2006).

The next step is to decide whether to accept the residual risk or reduce risk further by introducing a more robust control strategy. This must be a separate and distinct step from risk estimation. Ideally, a negligible residual risk level is desired. Managers determine whether a residual risk is acceptable after evaluating the balance between the proposed change in risk level achieved through risk reduction/mitigation and business variables such as:

- technological feasibility;
- economic feasibility;
- productivity;
- durability and maintainability;
- usability;
- brand image;
- competitive position.

Note that a medium or high residual risk should only be accepted by management if: 1) the existing countermeasure is regulatorily compliant or, if no regulation exists, is recognized as an accepted industry practice; and 2) the technological and economic considerations far outweigh the risk reduction achieved by further countermeasures; and 3) implemented controls are monitored to verify that they continue to function properly.

To improve objectivity, make the results more repeatable and employ more intuitive estimation concepts, a means was needed to make estimation more measurable.

Benefits & Challenges

The authors have applied the revised severity and probability descriptions to evaluate machinery hazards in locations around the world on equipment that had prescribed protective strategies in either regulation or consensus standards as well as equipment covered by no specific regulations. These experiences have helped identify several benefits associated with the revised descriptions as well as some application challenges.

The risk matrix can resonate with professional engineers because it offers an objective and semiquantitative approach to estimate risk that is reproducible between engineers. Residual risk expectations are clearly communicated within the tool, which allows engineers to settle on consistent design criteria even between dissimilar types of equipment. The tool is equally effective on new machines as well as legacy equipment (some of which dated to the early and middle 20th century). The tool can help reduce the time needed to conduct evaluations and arrive at a safeguarding strategy (much of the typical debate that exists regarding safeguard designs can be eliminated because the tool articulates the concepts clearly). Because the risk matrix is less subjective and eliminates most individual judgment, more people can use the tool. The revised severity, probability and residual risk descriptions empower managers and engineers to make their own safeguarding decisions, which allows safety professionals to focus on helping operations personnel understand the nature of hazards rather than spending time defending their risk estimates.

The tool resonates with local operational managers because it provides them a baseline from which to understand risks in their operations, and helps them arrive at conclusions with less conjecture and more concrete analysis. More importantly, because risk tolerance thresholds embedded in the tool are approved and endorsed by senior leaders, local managers immediately understand what is expected. This approach clarifies what controls are necessary for a particular risk level such that the local manager no longer must make independent risk tolerance decisions. As a result, risk assessment discussions between managers and safety professionals transform into focused, productive dialogue regarding the controls needed to effectively reduce the risk.

Table 1

Common Method to Estimate Severity Potential

	SH&E result criteria
Catastrophic	Could result in death, permanent total disability, loss exceeding $1M, or irreversible severe environmental damage that violates law or regulation.
Serious	Could result in permanent partial disability, injuries or occupational illness that may result in hospitalization of at least three personnel, loss exceeding $200K but less than $1M, or reversible environmental damage causing a violation of law or regulation.
Moderate	Could result in injury or occupational illness resulting in one or more lost work days(s), loss exceeding $10K but less than $200K, or mitigatible environmental damage without violation of law or regulation where restoration activities can be accomplished.
Minor	Could result in injury or illness not resulting in a lost work day, loss exceeding $2K but less than $10K, or minimal environmental damage not violating law or regulation.

Table 2

Enhanced Severity Table

	Burns, thermal hot surface	Burns, thermal steam or splash of viscous material	Lacerations	Fracture	Electrical
Catastrophic	> 68 °C (154 °F)	> 60 °C (140 °F)	Lacerations to the face requiring sutures or other closure in lieu of sutures typically caused by head, face or eye exposure to stationary sharp edges. Amputation, typically caused by sharp edges mechanically in motion, offset, blunt edges with forces exceeding 4 psi.	Fracture of long bones in arms, legs or fracture of the skull or spine, typically caused by forces exceeding 58 psi.	Possible ventricular fibrillation (3-second shock): 100 milliamp AC current
Serious	60 °C (140 °F) to 68 °C (154 °F).	44 °C (111 °F) to 60 °C (139 °F)	Lacerations, not involving the face, requiring sutures or other closure in lieu of sutures typically caused by stationary sharp edges, blunt surfaces in motion.	Fracture of small bones (e.g., hands, fingers, toes) typically caused by forces between 43 and 58 psi.	Shock—severe (muscle control loss, breathing difficulty, onset of "let-go" threshold: 15 milliamp AC current
Moderate	44 °C (111 °F) to 60 °C (139 °F)	38 °C (100 °F) to 44 °C (110 °F)	Minor cuts requiring bandage treatment; typically caused by stationary blunt surfaces, offset, blunt edges with forces less than 4 psi.	Contusions and skin abrasion typically caused by forces between 12 and 43 psi.	Shock—painful (no loss of muscle control): 6 milliamp AC current
Minor	< 44 °C (111 °F)	< 38 °C (100 °F)	No injury.	No physical signs, typically caused by forces less than 12 psi.	Slight shock—not painful (no loss of muscle control): 1.7 milliamp AC current

Note. *This is an excerpt from the complete table.*

Table 3

Common Method to Estimate Probability

Very likely to occur	Likely to occur	Possible to occur	Unlikely to occur	Almost impossible to occur
Likely to occur often in the life cycle of the equipment, with a probability of greater than once every 10 years.	Will occur several times in the life cycle of the equipment, with a probability of less than once every 10 years but greater than once every 100 years.	Likely to occur sometime in the life cycle of the equipment, with a probability of less than once every 100 years but greater than once every 1,000 years.	Unlikely but possible to occur in the equipment life cycle, with a probability of less than once every 1,000 years but greater than once every 1 million years.	So unlikely that it can be assumed it may not be experienced, with a probability of occurrence less than once every 1 million years.

The method and approach can be further strengthened by requiring managers to review and document their approval to accept any medium or high residual risk. Inevitably, these will involve situations in which there is reliance on administrative controls associated with relatively significant severity potential.

The requirement to sign off on such scenarios may make some managers uncomfortable and could lead them to argue that the tool is too conservative and that more credit should be afforded to administrative controls. To resolve such situations, two actions are needed:

1) SH&E professionals must help managers understand that administrative controls are inherently weak and fail over time. This will eliminate the argument that administrative controls or combinations of such controls are equivalent to engineering controls.

2) SH&E professionals must demonstrate that high and medium residual risks exist and are tolerated in many situations both in industry and in the general public. These situations are often approved by regulation or, if regulation is absent, are defined in a consensus standard. The residual risk level is a statement and not documentation of a deficiency. In other words, if risk estimation concludes that a condition is a high residual risk (colored red in Figure 1), then that becomes the statement of fact and choosing to accept that risk should not compel the risk assessor to artificially relabel the residual risk as low/negligible (green).

Once managers understand that they are already tolerating high or medium residual risks, they begin to recognize the need to employ more robust engineering controls or to be more vigilant when depending on administrative controls. To illustrate the point, consider that safe operation of a chain saw depends primarily on administrative controls in the form of cautionary instructions (safe work practices) and labels. Clearly, a high severity potential is associated with contacting the chain during operation.

Using the revised risk model, the combination of high severity potential and reliance on administrative controls (safe work practices) would result in

Table 4

Revised Probability Table

5	4	3	2	1
Very likely to occur **Behavior based administrative controls**	**Likely to occur** **Reinforced behavior based administrative controls**	**Possible to occur** **Administrative controls + barrier or impedance**	**Unlikely to occur** **Single layer engineering controls**	**Almost impossible to occur** **Secondary engineering controls**
□ Documented procedures or policies □ Training program □ PPE □ Properly distanced visual perimeter definition (e.g., lines on the floor) □ Signs	□ Specific disciplinary policy □ Formal operator certification process □ Formal management led behavior verification program □ Other methods to ensure procedures are followed	□ Properly distanced physical perimeter definition (e.g., railing, half wall) □ Moveable barrier that is not mechanically secured or interlocked □ Tools sized to keep operator's hands at least 12 in. from the leading edge of the hazard, requires two hands to use, and if a draw-in hazard exists, must also be designed so that the hand is not drawn into the hazard □ Visual/audible warning signals (e.g., horns, alarms, lights, synthesized voice) initiated by machine or personnel motion	□ Fixed barrier guard □ Pressure sensitive contact strips, edges, bars and rods, positioned to auto trip with contact or pressure □ Interlocked movable barrier guard or virtual barrier sized and distanced appropriately utilizing fault prevention circuit design with safety rated components (Note: Circuit designs must be control reliable, cannot be easily defeated and have a positive mode of operation) □ Two-hand controls requiring constant contact throughout the hazardous motion, with an appropriate control circuit. (Note: this provides protection only for the operator using the controls)	□ Fixed barrier guard with an interlock □ Secondary interlocks or virtual barrier guards (e.g., safety mat and a photo eye) □ Interlocked moveable and virtual barrier guards, sized and distanced appropriately, utilizing fault detection circuit design with safety rated components

Figure 1

Risk Matrix

		Probability				
		Very likely to occur **Behavior based administrative control**	**Likely to occur** **Reinforced behavior based administrative control**	**Possible to occur** **Administrative control + barrier or impedence**	**Unlikely to occur** **Single layer engineering controls**	**Almost impossible to occur** **Secondary engineering control**
Severity potential	**Catastrophic**	High	High	Medium	Low	Low
	Serious	High	Medium	Medium	Low	Negligible
	Moderate	Medium	Medium	Low	Negligible	Negligible
	Minor	Low	Low	Low	Negligible	Negligible

a high residual risk. Yet, despite the high residual risk, chain saw designs meet Consumer Product Safety Commission requirements and the risks are tolerated by society. Characterizing chain saw use as a low/negligible (green) residual risk is not an accurate risk communication and could mislead the manager and user.

Implementing the revised risk assessment concepts presents some challenges. The primary challenge is associated with emotional connections to preexisting tools and approaches. Individuals using this revised risk estimation approach must give up a certain degree of control. Risk assessors often like to make risk judgments based on gut feeling, personal experience and acquired knowledge. Using a tool that steers the assessor to a conclusion can be an unsettling proposition because it removes the ability to sway the risk assessment outcome to fit a specific opinion. The revised approach drives everyone to a common risk conclusion, to a common endpoint.

Additionally, the more quantitative approach

Table 5

Other Considerations

	Injury may not occur because . . .	Injury could still occur because . . .
The hazard is in plain view	The operator: •will see and avoid the hazard; •will not initiate the hazardous motion; •will stop the hazardous motion.	The operator: •may be distracted or not notice the machine motion; •may inadvertently activate the machine; •may not react quickly enough to stop the motion.
Speed of the machine/speed of the hazardous motion	•The hazardous motion is so slow that the operator will be able to escape before injury. •Someone will intervene before injury.	•The moment of recognition may not provide enough reaction time to escape or intervene.
Stopping distance	•A hazardous motion with a short stopping distance will move a shorter distance after the stop is initiated than will one with a long stopping distance.	•The operator can be present within the path of travel before a full stop is achieved because the motion will continue a distance determined by the time it takes to identify the hazard, reaction to initiate the stop and the stop time of the machine. •Mechanical wear and tear can increase the stopping distance over time.
Manual activation (can be "hold to run" or trip buttons)	The operator: •will identify someone in the path of the hazard and not initiate motion or will stop motion; •has control over the hazardous motion; •has to make a conscious decision to start the motion and such a decision presumes a safe condition exists.	•Incorrect reaction exacerbates the hazard (e.g., wrong direction, increased force, natural reaction puts operator into harm's way). •Inadvertent activation. •Hazardous situation arises after you activate (a second operator walks in after the motion).
Warning properties such as machine noise (Note: These are noises innate to the machine)	•It is obvious that the motion is underway. The operator will notice the hazard and escape.	•Becomes background noise. •At the time the noise presents itself you can already be in harm's way.
Ability to avoid	•The operator is agile, attentive, and has space or room to move and avoid the hazard.	•Cannot account for differences in people's agility, physical ability and mental attentiveness.
Ability to escape before injury is sustained (e.g., can pull hand out of pinch point before an arm is drawn into the machine)	•The operator can pull out of the hazard if caught.	•Force is too great for some to escape due to variables such as elasticity, tensile strength, friction, body alignment and strength of a machine component.
Experienced operator	The operator will: •not make a mistake even though a mistake is possible; •know how and when hazard will manifest and when to stay out of the area; •be more likely to recognize the hazard. Experienced operators have never had an incident.	•Incident data shows that trained operators continue to be injured. •Cannot guarantee the level of attention they bring to the task each time it is performed. •Tend to be comfortable with the hazard. •Come to accept a certain threshold of pain or injury. Muted acceptability.
Distance from the hazard	•The hazard is out of reach and requires the operator to move closer.	•A reason that can't be anticipated will arise and cause the operator to move into the hazard path.

Table 6

Administrative Controls Success Principles to Shift the Personal Risk Assessment

Controls (priority order)	Reliability/how to increase reliability	Reinforcement
1) Change the task by making conformance more positive to the employee: •simplify the steps; •make the job steps less physical; •more accepted (e.g., "cooler" safety glasses, hardhats with football logo).	**Low:** Reliability and effectiveness are dependent on how much personal benefit the employee sees to doing the job "by the book."	Requires intermittent management enforcement.
2) Change the reinforcement by making it more immediate and/or certain: •provide routine and regular oversight; •provide routine and regular communications and reminders; •change the way you detect nonconformance.	**Very low:** Reliability and effectiveness are dependent on how much you have changed the employee's perception of the probability of getting caught. Communications/reminders must be frequent.	Requires constant management enforcement and constant message repetition.

presents conclusions that do not always align with an individual's personal risk judgment. In some cases, the tool can conclude that a condition has an inherently higher residual risk than the risk assessor would prefer to characterize it. While some individuals may view this as a shortcoming, in essence this was the very problem intended to be resolved by the tool.

Risk assessment teams can find it difficult to accept that high or medium residual risks exist. This can lead the team to bring up factors that concern characteristics of the machine, environment or behavior modification. The argument is that these "softer" factors reduce the risk; however, what they actually offer are considerations for whether to tolerate a residual risk.

Rather than use these factors to modify severity or probability, a better approach is to incorporate the factors as risk acceptance considerations. Table 5 identifies some of these factors and provides the rationale (pros and cons) teams should consider when determining how significant these factors are in a particular situation. It is impossible to know with any certainty or consistency how much these factors will affect probability or severity, so great care must be taken when relying on these factors in risk acceptance decisions.

Making Administrative Controls as Effective as Possible

Administrative controls in the form of procedure modifications, retraining, operator certifications, warning signs and PPE are often relied upon as a primary control for hazards having high severity potential more frequently than safety engineers desire. As noted, this can be attributed to many factors, including the economic feasibility associated with applying engineering solutions to the vast array of hazards. In many instances, the residual risk can be an accepted condition even in regulation and/or consensus standards.

This reality drives a deeper examination of which administrative controls are more effective than others. To determine which controls are stronger, one must understand how administrative controls fail or succeed in preventing injury. People act as they do for various reasons:

1) People do what makes sense to them—at the moment.

2) People do what benefits them—if they think about their action.

3) People do what they have always done (rote).

4) People will do what does not make sense to them if there are overriding consequences.

5) People just react without thinking (rote).

6) Nobody does anything if they think they will get injured.

When considering the mechanics of these behavior principles, it seems that individuals conduct personal risk assessments as they consider performing a task, and the conclusions of their personal risk assessment govern all their actions. A personal risk assessment is not objective because people often are unable to accurately assess the correct probability of a given severity.

It may be that the benefits of the unacceptable approach get in the way. For example, if taking a procedural shortcut reduces the time needed to perform a task and increases break time, then this benefit could cause a worker to downgrade the probability of being injured. This becomes the dilemma of relying on behavior-based controls. Human nature can distort an individual's perception of probability. As a result, a person resolves the probability of the unacceptable consequence to zero for that moment in time during which s/he performs the task (Lennon, et al., 2010; Crystal, 2010; Hosier, 2009; McMath & Prentice-Dunn, 2005; Williams, 2007).

Qualitative probability and severity estimations are based on personal experience, knowledge and personality traits. Because it is human nature for people to justify what they want to do, most will modify their perception of probability or their perception of severity. Some behavior management theorists postulate that positive, immediate and certain consequences have a stronger influence on behavior than negative, uncertain and future consequences (Daniels, 1989). This seems to have relevance when exploring why an individual chooses to take a shortcut. When a worker considers a shortcut, the positive, immediate and certain benefit of gaining more break time drives that individual to resolve the probability of an injury to zero.

Completing a task in a way that is inconsistent with an individual's personal risk assessment does not make sense to the individual. As a result, s/he will only follow a procedure that is inconsistent with a personal risk assessment if overriding and certain consequences result. Administrative controls such as procedures are often used to manage risk, but they are not sustainable solutions because they rarely change a worker's perception of probability.

Therefore, to use administrative methods to control risk, one must either change the task in a way that promotes the desired behavior (e.g., a positive, immediate and certain benefit to the worker), or change a person's perception of the probability of getting caught performing unsafely or getting injured (e.g., a negative, immediate and certain consequence) (Table 6, p. 41).

Influencing behavior requires clear communication and commitment.

1) Communicate the issue.

•Provide new information that will change the employee's perception of severity or probability.

•Stress the positive benefits of performing a task safely versus the negative effects of getting caught performing it incorrectly.

•Combine a "fear message" with an easy solution. The higher the fear, the easier the solution must be or the reaction is to avoid or suppress the message rather than take action.

2) Gain commitment to work the organization way despite what makes sense to the individual.

•This is done most effectively one-on-one.

•Peer influence will affect some, but not all, individuals.

•Recognize that conformance tends to erode over time and often breaks down during high-stress situations. Constant reinforcement is required.

These concepts (reliability and effectiveness) are incorporated into the revised probability estimation table (Table 7) to ensure that the techniques to

Table 7
Probability Table With Behavior Reliability/ Effectiveness Factors

5	4	3	2	1
Very likely to occur Behavior-based administrative controls	**Likely to occur Reinforced behavior-based administrative controls**	**Possible to occur Administrative controls + barrier or impedance**	**Unlikely to occur Single-layer engineering controls**	**Almost impossible to occur Secondary engineering controls**
□ Documented procedures or policies □ Training program □ PPE □ Properly distanced visual perimeter definition (e.g., lines on the floor) □ Signs	□ Specific disciplinary policy □ Formal operator certification process □ Formal management-led behavior verification program □ Other methods to ensure that procedures are followed	□ Properly distanced physical perimeter definition (e.g., railing, half wall) □ Moveable barrier that is not mechanically secured or interlocked □ Tools sized to keep operator's hands at least 12 in. from the leading edge of the hazard, requires two hands to use, and if a draw-in hazard exists, must also be designed so that the hand is not drawn into the hazard □ Visual/audible warning signals (e.g., horns, alarms, lights, synthesized voice) initiated by machine or personnel motion	□ Fixed barrier guard □ Pressure-sensitive contact strips, edges, bars and rods, positioned to auto trip with contact or pressure □ Interlocked movable barrier guard or virtual barrier sized and distanced appropriately utilizing fault prevention circuit design with safety rated components (Note: Circuit designs must be control reliable, cannot be easily defeated and have a positive mode of operation) □ Two-hand controls requiring constant contact throughout the hazardous motion, with an appropriate control circuit. (Note: this provides protection only for the operator using the controls)	□ Fixed barrier guard with an interlock □ Secondary interlocks or virtual barrier guards (e.g., safety mat and a photo eye) □ Interlocked moveable and virtual barrier guards, sized and distanced appropriately, utilizing fault detection circuit design with safety-rated components
Very low reliability and effectiveness	**Low reliability and effectiveness**	**Moderate reliability and effectiveness**	**Effective and reliable in controlling the hazard**	**Very effective and highly reliable in controlling the hazard**
Is dependent on: •c**hanging** employee's perception of severity or probability; •how much personal benefit the employee perceives in doing the job "according to the procedure." •gaining employee commitment. To be most effective: •stress the benefits of doing it safely versus the negative of getting caught doing it incorrectly; •provide new information; •provide specific steps to avoid the hazard; •provide constant message repetition; •eliminate steps; •make task less demanding; •mistake proof; •provide positive reinforcement.	Is dependent on: •employee's perception of the probability of getting caught; •immediacy of getting caught; •severity of the consequence. To be most effective: •detection of nonconformance must be certain; •negative consequence must be immediate; •negative consequence must be significant to the employee.	This type of control inhibits, but does not prevent, access to the hazard. They provide a "physical" separation or reminder for the hazard. They are ultimately "behavior based" and subject to the same limitations described in Probability/Control Levels 5 and 4.	Single-layer engineering controls are not behavior-based controls, so they are much more effective and reliable. When properly installed, limitations are related to the component failure. Systems should be designed to "fail safe." Follow manufacturer's recommendations for inspection and testing.	Redundant engineering controls, each independently capable of controlling the hazard, are the most effective and reliable choice.

make the administrative controls more effective are always considered during a risk assessment.

Example Case Study

To illustrate these concepts in practice, consider a hypothetical machine that transports a continuous sheet of polyethylene terephthalate (PET) via two counter-rotating rollers. One roller is an idler that rotates as the sheet is conveyed and the other is a driven roller. The in-running nip point created between the PET sheet and either roller is not protected physically and the operation relies on operator awareness, training and procedures to prevent injury. The employee's task requires manually feeding material through a slot in the guard into the rollers for thread up.

Utilizing various test methods, the risk assessment team determines that the PET sheet has a high tensile strength and imparts 50 psi on any impetus entering the in-running nip point created between the conveyed sheet and either roller. Consulting Table 2 (p. 38) and considering the type of injury that would result if a hand were caught between the sheet and the roller, the team determines that the severity potential is serious.

Next, consulting Table 6 (p. 41), the team determines which probability level is most applicable. Given that the operation relies on simple behavior-based strategies, the group concludes that the probability of sustaining the worst-credible severity event is very likely to occur.

Combining the severity and probability estimates into Figure 1 (p. 39), the resulting residual risk associated with the task is presumed to be high. This would be a disconcerting outcome and the risk assessment team would be encouraged to explore engineering methods to reduce the residual risk. If management decides to accept or tolerate the risk, it must apply the administrative controls success principles (Tables 6 and 7).

Key Learning

This risk assessment model forces the user to think more about the hazards as well as the controls. It helps teams arrive quickly at the severity potential associated with a hazard, then establishes a standard of control associated with the hazard threat based on internal/company risk tolerance.

This model can be successful because it provides estimation criteria that are clear and well defined, which ultimately minimizes subjectivity during risk estimation. Embedded in this model is a fundamental philosophy that risk managers should attempt to prevent exposure to the hazard because this, by extension, reduces the probability of an injury (e.g., with no exposure to the hazard, injury is not possible).

The model does not try to dismiss residual risk. Rather, it specifies a control methodology relative to hazard severity. The tool separates risk estimation from the risk acceptance/tolerance discussion. In this way, risk tolerance responsibility is placed firmly with management. While this can be intimidating, the tool provides a clear understanding of the nature of the hazard and the strength of the protective strategy, and management is provided adequate information to make prudent risk tolerance decisions. Correspondingly, risk communication must be changed in a way that helps management recognize that residual risk always exists and that sometimes it is high. Embracing this concept helps to highlight the shortcomings associated with administrative controls.

Application of these concepts can create a more actionable outcome and enhance the ability to achieve a more predictable, sustainable and safe work environment. It also can help risk assessment teams realize that the result of a risk assessment is not necessarily a conclusion that the condition is safe, but rather an acceptance that the condition is safe enough. **PS**

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