Risk Assessment

Residual Risk Reduction

Systematically deciding what is "safe"

By George D. "Don" Tolbert

Abstract: *Examining how risk arises in workplace systems and the effects it produces is essential to continuous safety improvement and it is one of the best opportunities for technical growth within the SH&E profession. By examining how risk is generated within systems, an organization can more effectively assess what risks may be acceptable. This article describes a risk assessment technique used to examine the situation in which risk exists (qualify) as well as the extent of risk (quantify) for specific harmful events.*

IN COMPANIES THAT ASPIRE TO EXCELLENCE, the SH&E practitioner may find that lagging indicators (such as incident frequency and severity rates) of safety are inadequate to guide decision making. Incident trends that once provided clear direction for safety activities have become less distinct as controls for their causes have improved and complexity in the workplace has increased. By moving upstream from incident or loss to risk, a new dimension for the safety process is possible.

To be human is to be a risk taker. Willingness to take personal risk—and the belief that risk taken is fortune won—is a trait widely sought in leaders. It does not take much examination of the stories people tell, or the language used to tell them, to find this common thread of risk-taking as a quality to be admired. In fact, the English term "risk" is derived from the Italian "risacare," which means "to dare" (Bernstein 8). In Chinese, risk is denoted by two characters, one meaning danger, the other meaning opportunity (Damodaran 3).

Choosing a course of action in which uncertainty of the outcome exists, daring to grasp the opportunity represented by risk, is a hallmark of innovation. Often, however, the opportunity is taken before the danger is understood. The tendency to choose and act seems to overwhelm the lesson of experience that suggests "gather more information first."

Most—if not all—decision making is influenced by risk assessment. The positive consequences believed to result from a course of action are weighed against what is understood about the possibility and degree of harm that could result. "A thing is safe if its risks are judged to be acceptable" (Lowrance 8). Lowrance published this perspective on safety as a judgment of the acceptability of risk in *Of Acceptable Risk, Science and the Determination of Safety.* By defining risk as "a measure of the probability and severity of harm to human health," he introduced an important concept. Safety judgments incorporate two activities: measuring the risk and deciding whether it is acceptable. Both are conducted at all levels of human endeavor—personal, organizational and social—if often imperfectly.

An effect of human endeavor is increasing complexity. Incremental progress creates additional opportunities that when taken not only sustain advancement, but also interact in ways which may be difficult to predict. Where risk and its management are concerned, history is a storyline of trading one danger for another. The "miracle cures" for the plagues of one generation may become the plagues of the next. Risks that are comparatively acceptable or not even "on the radar" can be considered imminently dangerous as understanding of them increases.

Because this phenomenon is occurring at an increasing pace, the SH&E profession has never had more opportunity to contribute or more diverse contributions to make. Three roles of the SH&E professional are essential to meeting this opportunity:

• Guide the measurement of risk so that decisions on its acceptability can be made.

• Influence the reduction of risk to acceptable levels.

• Foster and support an ongoing examination of the types and extent of risk that is acceptable.

Residual Risk Reduction™ (R3™) is a process intended to leverage these three roles. It provides a framework to qualify, quantify and reduce risk in systems. R3 facilitates group process with teams of people who work within the systems studied. It aims to help them:

• identify specific risks at the source;

• qualify those risks according to the degree of control that currently exists for them;

• quantify the risks using a set of scales that provide a comparative measure of the probability and severity of harm;

• examine system factors that contribute to the creation of the risks and to which reduction strategies may be applied;

• compare the type and extent of risk reduction achieved via different intervention strategies.

When applied as an ongoing process, this process can help organizations redefine the nature, extent and level of risk that is acceptable. Risk generally arises in pre-

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dictable ways in the systems employed. When setting out to understand, measure and reduce it, the perspective that risk resides in all activities is essential.

A Systems Perspective

Webster's Dictionary defines *system* as "a grouping combined to form a whole and function interdependently and harmoniously." This definition serves well to describe the gamut of systems, from most simple to most complex. A Boeing 777 is a system—one of the most complex ever assembled. Pencil and paper is a very simple system. Either example meets this definition.

The terms *system* and *process* are sometimes used interchangeably, yet they are not synonymous. Referring once again to *Webster's*, "process" is defined as "a series of actions, operations or changes that produce an outcome. It could be said that systems and processes are interdependent; neither exists without the other.

Systems in which people work can be described in terms of three sets of characteristics (Figure 1). Environmental elements are those that comprise the physical characteristics—what can be designed or built as part of the system. Capability factors comprise what the person who interacts with the system is able to do. These elements include physical abilities, skill sets, and the knowledge of fit and purpose of the system. Motivation characteristics include behavioral cues and consequences that govern performance—what signals people to act and the consequences of those actions.

The three types of system characteristics are linked to the extent that they cannot be separated. Whether examination of the system begins with environment, capability or motivation, one must remember that each affects—and is affected by—the other characteristics. Engineering changes most often demand additional education and training. People cannot be motivated to perform if they cannot meet the physical demands of the job, or do not know what to do, how to do it or why. The most skilled and motivated people cannot execute optimally without adequate tools.

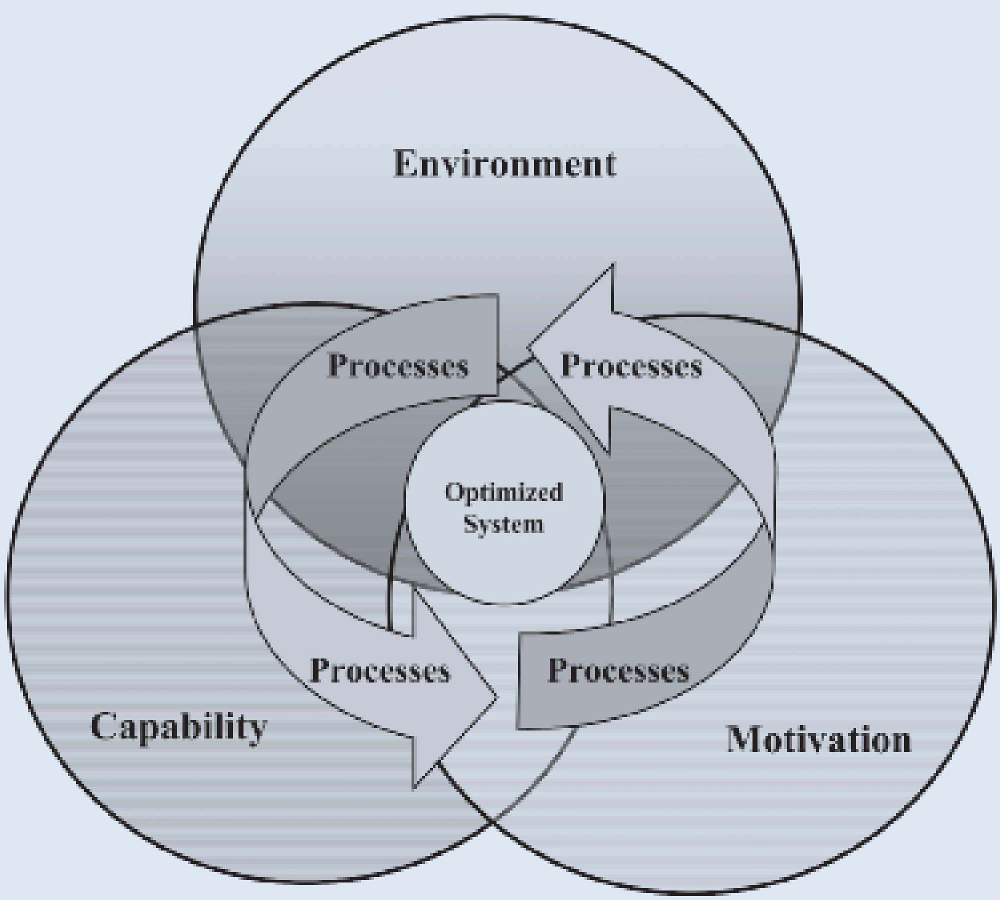
Another perspective on systems is that they exist to convert input to output (Figure 2). Work is performed using environment, capability and motivation inputs to produce a set of outputs. The inputs encompass everything that goes into the system, the process encompasses what is done to or with them, and the outputs include whatever is produced. Systems are not "black boxes." Inputs can be identified, the processes central to them can be described and the outputs can be listed.

Perfection is as elusive in systems as it is in everything else. While continuous improvement initiatives can reduce variance to extremely low levels, sustaining systems with no variance in output is not possible in practical terms. System output is actually a range that includes what is intended (productive) and what is unintended (nonproductive). Most readers will accept that in the typical system productive output significantly exceeds the nonproductive. If it does not, the system is redesigned or adjusted.

Nonproductive yet acceptable output, such as minor waste, so far exceeds what is unacceptable that occurrence of the latter is comparatively rare. Unacceptable system outputs such as injurious events can be so rare that they are not recog-

Figure 1

Systems at Work



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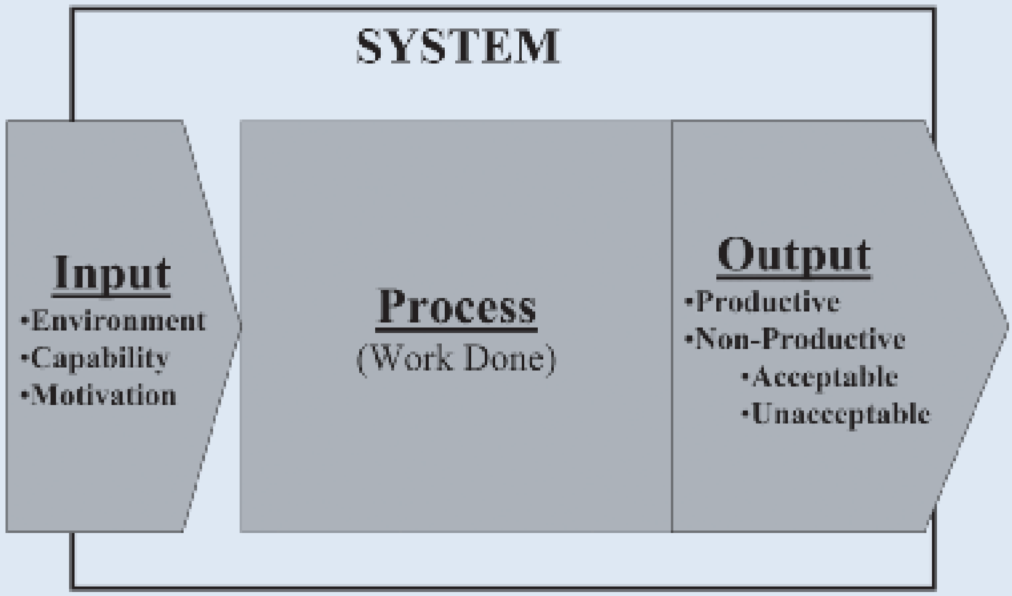
nized as products of a system which is not functioning optimally. A common challenge for SH&E professionals is to help organizations recognize that while injury-causing events may be outliers relative to other system outputs, they are not "freak" occurrences. All are products of systems that have the capacity to produce them.

Figure 2

Converting Input to Output



Measuring Risk

A requirement for the measurement of anything is at least a basic understanding of its nature. This is certainly true of measurement of risk. Three elements of risk, while widely accepted, bear repeating:

- **Risk in a system can never be a zero quantity.** Nothing is free of the ability to do harm. However, reduction of specific risk to increasingly lower levels is possible to the extent that acceptability is reached, then redefined. Examples of this exist in every discipline and field of study touched by the SH&E profession.
- **Risk is situational.** The variables that influence risk acceptability and the myriad ways they can interact are as numerous as the situations in which they exist.
- **Probability governs the occurrence of the effects of risk.** Events that produce harm—those for which risk can be described and measured—are distributed normally in the array of outcomes from activities.

These elements are revealed in simple games of chance such as one of the most ancient—dice. In Figure 3, the 11 possible outcomes of rolling two dice are listed across the top. One white die and one black die are used to illustrate the 36 possible combinations. The combinations are sorted by the outcome produced. The "odds" of each outcome are listed across the bottom of the graphic.

It is easy to see why seven is often referred to as lucky. Seven can occur in six ways. Knowing this, one might expect a seven to occur once in every six rolls of the dice. Indeed, if the dice are rolled a large number of times, the outcomes are distributed according to the probability of their occurrence.

Charting a thousand or so rolls of the dice, as depicted in Figure 4, produces the familiar bell curve of normal distribution. This is all a gambler needs to know, right? Not quite.

Each roll is an independent event; none have any effect on any of the others. While a two is a comparatively rare outcome, it could occur on the first roll, on any rolls after that or quite easily on several successive rolls. The gambler has no control (with unadulterated dice) over the outcomes and cannot affect the distribution illustrated in Figure 4.

In dice, skill is not a factor. Influencing risk in this system is possible only by affecting the number of rolls and the bet on each one. The problem for the gambler at the craps table is that s/he does not have a large number of rolls to make use of this and cannot change the variables which affect the outcome of the next roll. This is what the aspiring gambler really needs to know.

Risk can be managed and reduced for practically every other industrial system. The first step is to define its characteristics for specific events or outcomes. Once defined, risk can be quantified to the extent that a judgment of its acceptability can be made. System variables can then be adjusted so that the characteristics used to define risk of an undesired outcome are affected.

As the definition provided by Lowrance suggests, risk is the product of probability and severity. Severity is relatively easy to describe in plausible terms for harmful events that could be expected as outputs of systems. Probability, on the other hand, can be more difficult to grasp and measure. Few, if any, industrial systems are as simple and straightforward as rolling dice.

As Figure 5 suggests, probability can be more easily considered in risk assessment by recognizing that it is the product of two interacting components. The opportunity for a specific event or outcome to occur is a function of the likelihood of the occurrence and the extent to which the situation exists in which its occurrence is possible.

Using the rolling dice example, the probability of a 12 occurring is 1/36. For even one 12 to occur, however, the dice must be rolled. The more the dice are rolled, the more closely practical experience demonstrates the mathematical odds of rolling a 12.

Frequency

In this model, frequency addresses how often the system or work activity that produces the hazard occurs. Frequency is influenced by the scope of exposure and how often the exposure is present. Objective measurement parameters are easily established for this component.

Likelihood

The likelihood of an incident occurring is more difficult to measure and is usually subjective. Exposure may exist at very high levels for long periods without incident or it may produce harmful events only from a rare and short-lived occurrence. Opportunities exist to reduce this subjectivity. Obviously, if there has been a history of certain incidents and no real change to the system, it is reasonable to assume that their occurrence will continue. Research data provide another source of objective information on the likelihood of specific incidents. In ergonomics alone, considerable data speak to the likelihood of strain injury according to the parameters of a task.

Severity

Severity describes the degree of harm produced by the event. While it is valuable to use the worst-case scenario, plausibility is an important consideration when assigning a value to this component. For example, fatal contact with the ground is a reasonable outcome for the skydiver whose fall is not arrested by a parachute. Data, as well as practical experience with acceleration due to gravity, are available. Low back pain due to body position when climbing into the airplane might also be a system output of skydiving. However, it does not directly cause the death of the skydiver. Comparatively, it is a simple matter to assess the severity of these two undesired system outputs. As with the frequency variable, objective parameters can be assigned to severity.

Figure 3

Odds on Two Dice

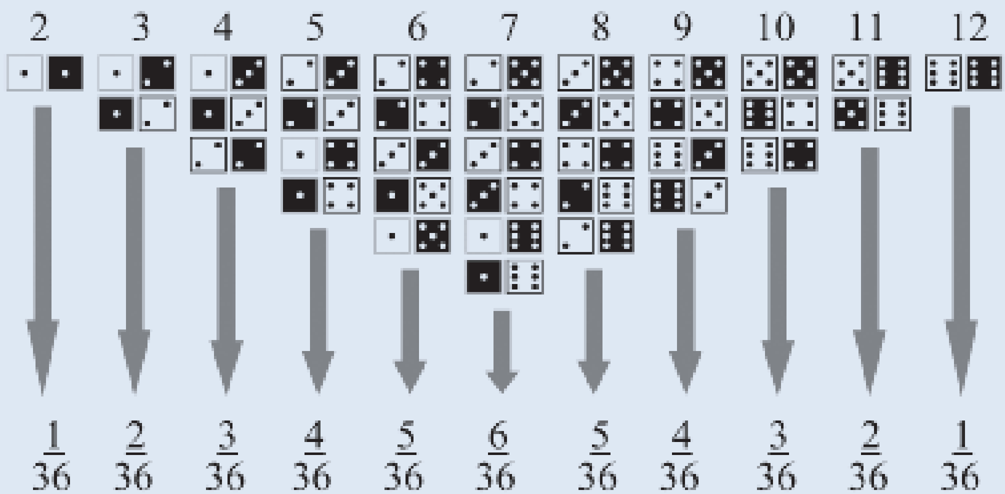


Figure 4

Rolling Two Dice

Risk Assessment

Measuring risk is often considered synonymous with risk assessment. It is important to remember that measurement is performed so that judgments of acceptability can be made. These judgments—decisions on whether a thing is safe—are by nature, subjective. They are affected by context and situation to the degree that what might be judged as acceptable at one time, in one place or setting, or even for one individual or group, may be unacceptable when the circumstances are slightly different. Risk assessment encompasses the measurement of the probability and severity of harm as well as the judgment on whether the quantity measured is acceptable.

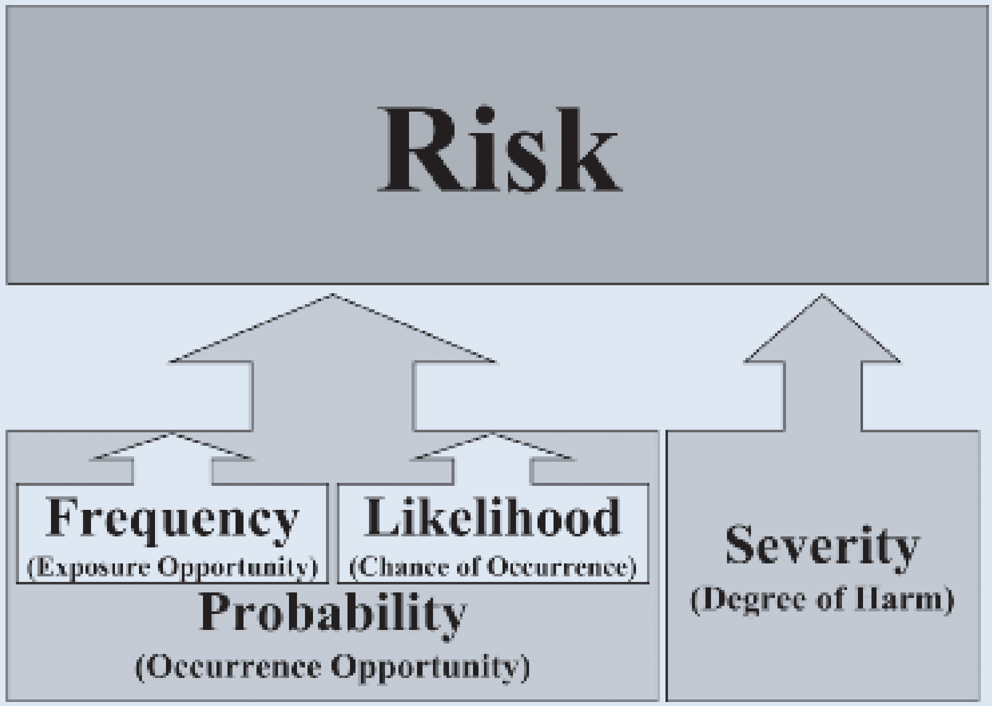
The notion of assessing risk in a system before it produces harmful events is certainly not new. In the early 1960s, system safety engineering (SSE) introduced a host of useful tools and concepts to the SH&E profession. This new discipline provided a framework with which to examine the increasingly complex systems of the space age.

Conceptually, SSE embraces both quantitative and qualitative analysis techniques. It emphasizes objective analysis for the purpose of informed, if often subjective, decision making. SSE draws on both deductive ("how could it happen") and inductive ("what would happen if") reasoning. The scope of techniques encompassed by SSE is broad and diverse with each being matched in complexity to the applications for which they are intended. Because many of the techniques are involved, some organizations have the unfortunate and often-misplaced perception that SSE processes are too complex for day-to-day use. In fact, much of the methodology integral to even the most rudimentary risk examination techniques draws heavily on SSE principles.

Preliminary hazard analysis (PHA) is among the most notable and fundamental of the risk assessment tools borne out of SSE. It promotes the systematic identification of potentially harmful events and the gauging of the impact of any single event. PHA and its various adaptations influence the focus of resources on those risks that exceed what the organization deems acceptable.

Figure 5

The Nature of Risk



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Influential proponents who have advanced risk assessment methodology through leveraging and building on SSE principles are too numerous to list. Among them, however, are at least two whose contributions are, in the author's opinion, pivotal.

The U.S. military, in MIL-STD 882A, provided guidelines on assessing hazard probability and severity levels in terms of "maximum credible consequence." The matrixes, terminology and assessment process contained in this standard form the basis for many effective methodologies used in risk management and safety.

ANSI and its contributing organizations continue to provide a wealth of process and methodology to the assessment of risk that are both application-specific and adaptable in principle for general use. ANSI B11.TR3, Risk Assessment: A Guideline to Estimate, Evaluate and Reduce Risks Associated with Machine Tools, was particularly instrumental in shaping the R3 process. This technical report, while directly addressing machine tools, provides valuable insight into the nature of systems and their examination for risk assessment for virtually any application.

ANSI B11.TR3 defines the term residual risk as "risk that remains after protective measures have been taken" (AMT 2). This gives rise to the concept that residual risk is the amount of risk in the system at the point in time in which its examination occurs. It is the baseline risk level before additional deliberate change projects are undertaken. This sets the stage for the measurement of risk reduction relative to a baseline.

The R3 Process

As noted, R3 was designed to be applied by a group of people with broad knowledge of the systems to be addressed. The multiple perspectives possible with a cross-functional team reduce the possibility that important facts will be omitted from the analysis and that errors due to incorrect assumptions will arise.

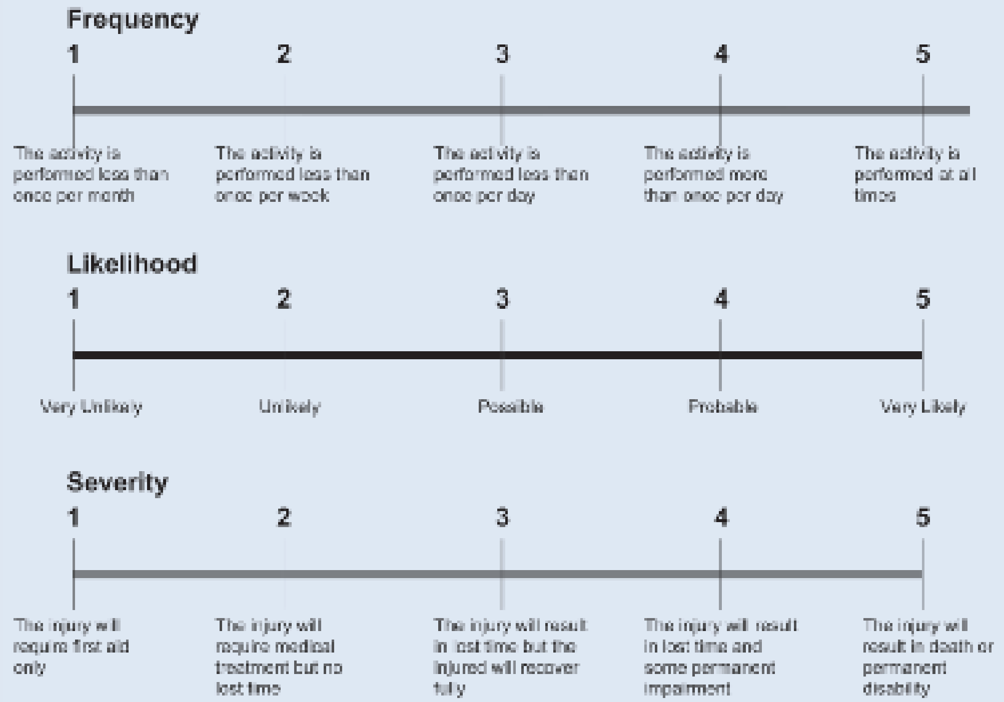
Mounting evidence suggests a relationship between employee involvement in decision-making processes, job satisfaction and a healthy working life. In *Healthy Work: Stress, Productivity and the Reconstruction of Working Life,* Karasek and Theorell offer this insight:

> Labor has become an item of consumption (in the sense of the need for a job), instead of just an input to production, and creative challenges at work are important aspects of well-being (28).

Even in the most progressive companies, opportunity remains to tap the potential of system experts. While it is possible for R3 to be completed by one or two individuals with knowledge of the system to be studied, users will find that the benefits of assembling a "jury of system experts" for analyses far outweigh the resource investment. The output will be of

Figure 6

The F-L-S Technique



higher quality, the people closest to the risk in the system will be tuned in to its reduction, and the increased associate involvement in the safety process will have far-reaching effects.

The terminology used in Figure 6 may be familiar to those who involve teams in problem solving. The "F-L-S Technique," as it is widely known, is a qualitative method for assessing the criticality of a concern. It is typically a group-processed activity used in the same way as criticality matrix (Prouty) analysis, pair-wise ranking and similar activities. It uses a Likert scale to rate and rank frequency, likelihood and severity for a given occurrence.

Using R3, the user defines the five points on frequency, likelihood and severity scales to reflect situation and application. Figure 6 illustrates a typical set of scales for workplace safety and health application.

Figure 7 provides a general overview of the R3 process flow. Step one is to identify the system for which risk is to be assessed. It is important to note that while the process is adaptable in complexity to the system being studied, practical experience has shown that the simpler the system, the more efficient the analysis will be. Large, complex systems will require complex and sometimes onerous examination. Most users will find it beneficial to reduce complex systems into subsystems.

Work activities, as they would be described by those who complete them, provide a particularly useful means for defining the systems to be studied. The system limits, inputs and outputs are readily identifiable and the processes used are well understood. Brainstorming operational work activities not only provides an inventory of systems to examine, but is also an excellent way to build team cohesiveness. Selection of the actual system to be studied should be influenced quantitatively through examination of incident trends by activity and qualitatively in which the team agrees on activities with the most urgent need for risk assessment.

Step two is the identification of the injurious events, usually described as concerns, for which the opportunity for occurrence exists. Again, both qualitative and quantitative means of identifying concerns are used. If incidents or near-hits have arisen in the activity in the past, including these in the list of concerns to be analyzed is a given. Hazards for which risk exists without incident occurrence are equally important. It is identifying these concerns for which a jury of system experts is most important. In "Severe Injury Potential," Manuele describes critical incident analysis: "Skilled observers interview a sampling of personnel, eliciting their recall of critical incidents that caused them concern, whether or not injury occurred" (Manuele 29). This perfectly describes the qualitative identification of concerns by R3 team members.

Once concerns have been listed, the next step is to identify the existing state of control for each. This provides context for the risk rating that will follow, facilitating consensus within the team on the nature and extent of risk which resides in the system for each concern identified.

Step four is the actual rating of risk for each concern. The rating process is virtually identical to that described earlier for the F-L-S technique—except that the scales defined and adopted by the team are used in lieu of Likert scales. The risk score for each concern is the multiplicative product of the ratings assigned to it for frequency, likelihood and severity. The sum of risk scores of the concerns provides the initial (baseline) residual risk index for the system/activity.

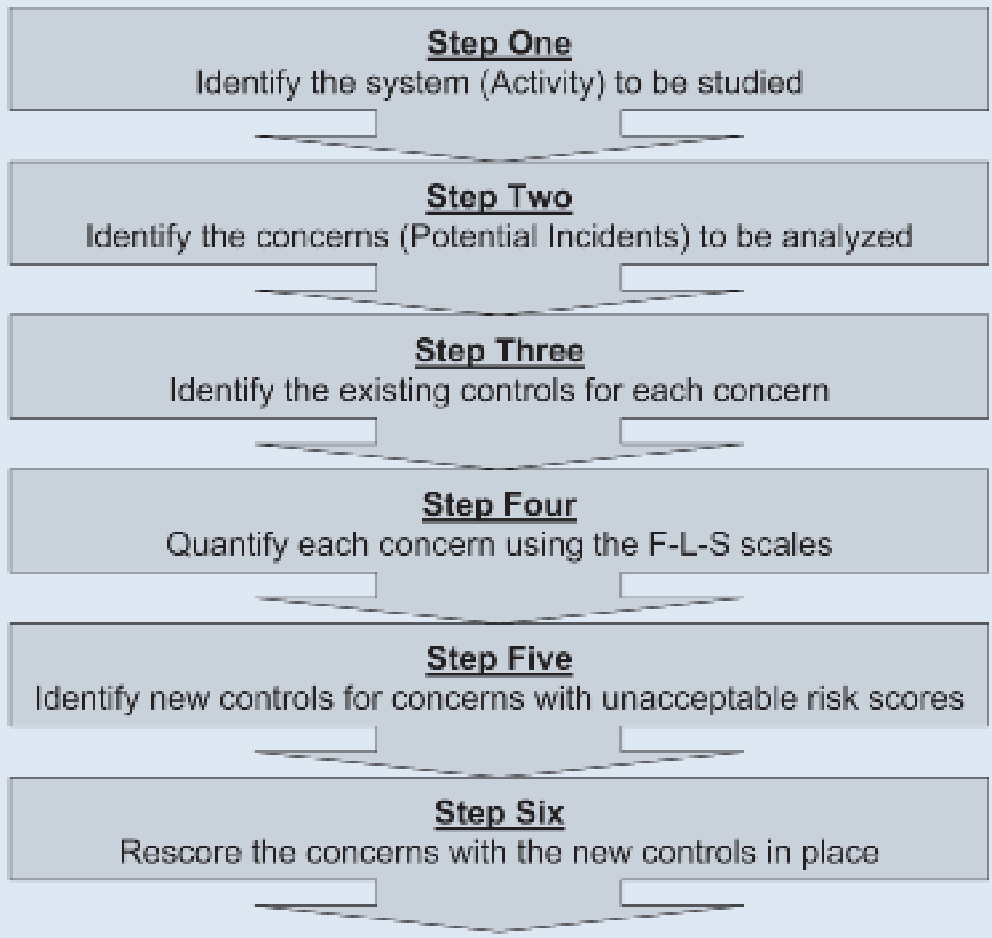
At this point, the team has established a measure of risk through consensus for each concern identified as having an occurrence opportunity. The process of quantifying residual risk through group consensus also serves to qualify how it originates in the system and/or is allowed to exist. Practical experience with groups applying the process has revealed that they intuitively differentiate between low-probability/high-severity risks and those with comparatively higher probability but lower severity, even when the numerical risk scores are identical. Mounting evidence such as that summarized by Manuele suggests this is a productive line of thinking in risk assessment. "Incidents resulting in severe injury are, mostly, unique and singular events; that their causal factors are different than those for accidents that result in minor injury; and that preventing their occurrence requires special safety management techniques" (Manuele 26).

Step five in R3 is identifying new controls where risk is judged to be unacceptable. It is at this point that the team examines how the system inputs can be adjusted and assesses the extent and nature of the effect of the adjustment on residual risk in the system. In other words, various risk reduction strategies can be compared on the basis of the degree and type of reduction achieved and the resources needed to achieve them. The group will naturally place greater urgency on risk reduction for the concern with the highest "score." They will begin to identify risk reduction opportunities and will recognize the risk component on which specific countermeasures can be expected to act. In many cases, the team will be pleasantly surprised to find that a particular countermeasure can affect risk in multiple concerns.

Finally, after new controls or countermeasures are in place the hazards are rescored (step six).

Figure 7

The R3 Process Flow



Measuring Risk Reduction

As noted, R3 analysis provides a means to measure risk reduction progress relative to a baseline residual risk level. In addition to facilitating comparison of the extent and nature of risk reduction achieved through various interventions, anecdotal evidence from users suggests that seeing risk scores improve is highly reinforcing for the behaviors that contribute to the reduction. People like to see scores improve and to know that their efforts as part of a team which achieved the improvement contributed to it.

While numerous measures of process can be applied to R3, the central and most obvious metric is percent improvement from baseline or residual risk reduction. Residual risk reduction is calculated by:

$$\frac{\text{Baseline Risk Index - Subsequent Risk Index}}{\text{Baseline Risk Index}} \times 100$$

Applying the numbers from the case study described on pp. 32-33 as an example:

$$\frac{342 - 116}{342} \times 100 = \text{66-percent residual risk reduction}$$

The utility of this metric for comparing various risk reduction strategies will be readily apparent. Some relationship can be calculated between risk reduction achieved and change in downstream measures (incident frequency and severity rates) of safety performance.

Understanding these relationships will better prepare the user to predict and/or take action to affect the downstream measures. Where R3 is adopted as an ongoing process, particularly across multiple facilities within a company, numerous additional measures will be apparent.

Conclusion

In the 17th century, when two gamblers, Blaise Pascal and Pierre de Fermat, proposed the founda-

Case Study: Container Manufacturer

A manufacturer of paper food containers was interested in increasing associate participation in the plant safety process. The plant had been operating for more than 20 years, printing and diecutting retail packaging for baked goods produced by its customers. Approximately 300 associates were employed in the operation across three shifts. Low back pain complaints and cumulative trauma incidents dominated the loss history that was slightly higher on an incident rate basis than the rest of the corporation, but lower than industry average. R3 was identified as a means for increasing associate involvement as well as focusing the safety process on continuous, upstream improvement.

A cross-functional team of 13 production associates and supervisors was formed. After an overview of the R3 process, chartering by the plant manager and review of loss trends by work activity, the team unanimously selected a system with no incident history as the first to be analyzed.

Because of the variety of packaging products produced, the plant was designed to accommodate an extensive storage volume in an attached facility known within the plant as the "high-bay." This automated storage and retrieval system (ASRS), housed in a 100-foot-tall structure, consisted of an automated forklift that traveled on rails between two open storage racks. Bar-coded pallets of product were scanned by the ASRS unit and transported/lifted to a designated storage slot for the particular product.

More than 20 years of use had introduced enough variance into the mechanical equipment that what was once a rare occurrence—a pallet of product becoming "jammed" so that the ASRS unit could not retrieve it—became an almost daily event. Procedure called for a maintenance technician to climb into the rack and straighten the pallet using a six-foot pry-bar. The activity was known within the plant as "unjamming the high-bay." The team completed an initial analysis (Table 1) using a set of scales identical to those in Figure 6. Group discussion, including interviewing other associates involved in the activity, resulted in the risk reduction strategy and subsequent rescoring of the concerns depicted in Table 2.

Note that the risk reduction strategy in Table 2 is abbreviated and that the new controls are not necessarily aligned with the concern for which they may have been selected. While it may not be necessary to point out, the integrated nature of risk reduction strategies such as this has compounding effects on the system inputs. Obtaining fall arrest equipment designed specifically for the application, designating individuals to be trained and certified in its use, and requiring a "performance partner" who observes the activity can

Table 1
Case Study: Baseline Assessment

Concern	Existing Controls	F	L	S	Risk Score
Head injury: Fall from elevation	Minimal informal training	3	3	5	45
Various injury: Struck by, using pry bar	Fall protection available, but impractical and inadequate	3	3	3	27
Head injury: Struck by, falling pry bar	Cage on crane	3	2	5	30
Torso injury: Caught between load and rack		3	3	3	27
Muscle strain: Using pry bar		3	4	3	36
Extremities fracture: Fall between racks		3	3	3	27
Electric shock: Contact with ASRS circuits		3	1	5	15
Extremities injury: Fall from ASRS unit while traveling	Harness provided but not used consistently	3	4	5	60
Torso injury: Caught in machine pinch point, automatic motion	Procedure to place crane in manual mode	3	2	3	18
Pedestrians in aisle struck by falling skids	Gate locked, sensor cable to detect full bins, no items stored in aisles	3	1	4	12
Head injury: Falling object, hoist chain failure		3	3	5	45
		Risk Index			342

tinuous examination of risk at its source and the ability of the modern worker to participate in it. Employers that depend on continuously evolving systems have invested in having employees with in-depth knowledge of process variables operating in them. It is good business. The advantages are obvious and too numerous to list. The same is true for risk. It is good business to have the people closest to it understand and be involved in its measurement and reduction.

No risk assessment methodology is universally suited to the immense variety and scope of systems that benefit from continuous examination. R3 is no exception. However, to quote a respected friend and long-time collaborator, "The most important contribution of R3 is in taking decision making on risk out of the back room onto the plant floor."

Nothing can substitute for a rigorous, repeatable process that produces factual answers to questions.

tions for probability theory, metals were being worked in industrial settings. Metal workers likely had no more knowledge of metallurgy at the molecular level than they had of the risk variables they faced each day at work. As the complexity of industry has increased since then, so has the need for conbe expected to work in concert to motivate use of the new procedure.

In this case, the team members had no specific training or experience with system safety or organized risk assessment before joining the group. At the beginning of their first four-hour meeting, they had no knowledge of the R3 process. The strategy summarized in Table 2 was the result of their second half-day meeting.

No amount of commentary can adequately describe the level of discussion within the group about the effects of the interventions on the risk parameters quantified. Team members intuitively recognized that a significant opportunity existed to affect frequency, likelihood and severity. Repairs and preventive maintenance to the racks and ASRS unit as well as "squaring" product on pallets could be expected to reduce the occurrence of jams. Thus, the frequency of the activity is reduced and occurrence opportunity for all concerns associated with it decreases. Interventions such as securing tools with lanyards and use of observers to influence performance of specific behaviors reduce the likelihood of occurrence of specific concerns when it is necessary to perform the activity. Furthermore, severity is reduced in the event of occurrence when PPE such as state-of-the-art fall arrest devices is used.

The team expressed some trepidation about presenting the results of its first R3 analysis to the plant leadership group. Submitting and defending proposals for expenditures on improvement projects was as new to some as risk assessment and system analysis. After all, no incidents or loss costs had been associated with unjamming the high-bay.

As it turned out, the leadership group had parallel initiatives to explore principles of lean manufacturing and Six Sigma. The leadership group immediately recognized that the R3 team had identified an activity with significant opportunity for improvement. In addition to the significant risk reduction that could be achieved through implementation of the proposed new controls, efficiency would also be increased as the number of jams decreased. Expenditure for the proposed risk reduction strategy was enthusiastically approved, and the team was thanked and encouraged to continue its work through weekly meetings.

Table 2

Case Study: Subsequent Assessment

Concern	New Controls	F	L	S	Risk Score
Head injury: Fall from elevation	Update proximity sensors to increase sensitivity	2	2	3	12
Various injury: Struck by, using pry bar	Conduct daily test of the system	2	3	3	18
Head injury: Struck by, falling pry bar	Repair and realign racks	2	1	3	6
Torso injury: Caught between load and rack	Secure pry bars with rope	2	2	3	12
Muscle strain: Using pry bar	"Square-up" loads on skid before placement on ASRS picking station	2	2	3	12
Extremities fracture: Fall between racks	Provide solid cover over operators' platform	2	1	2	4
Electric shock: Contact with ASRS circuits	Consult with fall protection equipment supplier on integrated fall arrest system	2	1	5	10
Extremities injury: Fall from ASRS unit while traveling	Jam-clearing procedures written and audited	2	2	3	12
Torso injury: Caught in machine pinch point, automatic motion	Train and certify technicians	2	2	3	12
Pedestrians in aisle struck by falling skids	Use an observer when a technician is in the rack	2	1	4	8
Head injury: Falling object, hoist chain failure	Provide a clutch brake on the ASRS platform	2	1	5	10
		Risk Index			**116**

However, one must remember that people must ask the questions. The R3 process has been applied in hundreds of settings across a broad spectrum of industries. The groups that use or adapt it continue to demonstrate eagerness to ask the questions, diligence in finding answers to them and competence in making sound decisions based on those answers.

In *Against the Gods: The Remarkable Story of Risk,* Bernstein provides insight into the importance of the qualitative judgment on what is "safe." "The great statistician Maurice Kendall once wrote, 'Humanity did not take control of society out of the realm of Divine Providence . . . to put it at the mercy of the laws of chance'" (Bernstein 329). ■

References

Assn. for Manufacturing Technology (AMT). Risk Assessment and Reduction: A Guideline to Estimate, Evaluate and Reduce Risks Associated with Machine Tools. ANSI B11.TR3. McLean, VA: AMT, 2000.

Bernstein, P. *Against the Gods: The Remarkable Story of Risk.* New York: John Wiley & Sons Inc., 1998.

Damodaran, A. *Value and Risk: Beyond Betas.* New York: Stern School of Business, 2003.

Karasek, R. and T. Theorell. *Healthy Work: Stress, Productivity and the Reconstruction of Working Life.* New York: Basic Books, 1990.

Lowrance, W. *Of Acceptable Risk: Science and Determination of Safety.* Los Altos, CA: William Kaufman Inc., 1976.

Manuele, F. "Severe Injury Potential: Addressing an Often-Overlooked Safety Management Element." *Professional Safety.* Feb. 2003: 26-31.

U.S. Dept. of Defense (DOD). Military Standard System Safety Program Requirements. MIL-STD-882A. Washington, DC: DOD, 1977.