Assessing a Fatal HAZRIN

A case study with links to chaos & complexity

By William M. Montante

THOROUGH ACCIDENT ANALYSIS often requires use of an accident causation model and causal tracing techniques. The fatality described in this article was analyzed using several, including a systematic causation model for hazards-related occupational incidents (HAZRINs). Links to the concepts of chaos and complexity are introduced. The results of the analysis dispel the belief that this death was caused by an unsafe act, and further emphasize the roles management and design play in causation.

Analyzing a Fatality

Few events in an SH&E professional's career are more troubling than the investigation of a fatality. Initial feelings of guilt or responsibility may persist long after the event. Those emotions may give way to anger and resentment toward a specific or perceived source. Then, there is the lingering image of a funeral, a grieving spouse and children whose loss can never be assuaged. And always, those nagging "why" and "how" questions that force the focus to return to finding solutions and corrective actions.

Those factors were all in play during this investigation. Sharing this experience in the hopes that the victim did not die in vain, that others might learn from the incident and take action to prevent similar losses has, in a small way, helped to achieve closure.

This was not a unique HAZRIN, which is defined as "an unplanned, unexpected process of multiple and interacting events, deriving from the realization of uncontrolled hazards and occurring in sequence or in parallel, that is likely to result in harm or damage" (Manuele 76). This term better defines the accident phenomenon—and it is better than simply calling this an "undesired event," an "accident" or an "incident." Those terms are well-entrenched in the SH&E professional lexicon, but are less precise and prone to different interpretations. HAZRIN "encompasses all incidents which are the realization of the potential for harm or damage, whether harm or damage resulted or could have resulted" (Manuele 61).

The causal sequence leading to the next HAZRIN may be identical to what this investigation found or may follow some other seemingly probable, or chaotic, course to a similar or perhaps less-severe outcome. Upon completion of this investigation, it was not surprising to learn from SH&E professionals in this industry that four nearly identical events had occurred in a period spanning less than 12 months. Two cases resulted in fatalities, one in a serious disabling injury and one was a near-hit.

The sequence of events was reconstructed as thoroughly as the investigation would allow. But, as is often the case, some questions will remain unanswered. Some of those interviewed were unwilling to share potentially useful information. For various reasons, site management and its legal advisors limited the on-site investigation to one day, and restricted access to certain records and key personnel. As a result, various presumptions, extrapolation of facts, and professional and personal biases were unavoidable. Names, revealing data and specific references to industry and machinery type have been changed or omitted.

The HAZRIN: Machine Operator Crushed

The victim, "Steve," was 30 years old, married with children and had worked for this company as a machine operator for three years. The plant manager described him as a skilled employee and produced documentation showing that Steve had completed coursework at an industrial training school. Steve was a member of the company's Accident Prevention Committee and had been elected by coworkers as their representative. Before taking this assignment, he attended a regulatory-required safety training class. A few days before this HAZRIN, Steve and his coworkers had set a new production record and were due to receive recognition for the achievement. He was performing routine job duties on the day of the accident.

William M. Montante, CSP, CXLT, *is a vice president and senior consultant for March USA Inc., based in Atlanta. In this role, he primarily consults on issues related to SH&E management, ergonomics and tribometry. Montante holds a B.S. in Industrial Engineering and Human Factors from the State University of New York at Buffalo. He is a professional member of ASSE's Georgia Chapter and is a past president of the Chattanooga Area Chapter.*

Incident Reconstruction

Three hours into his shift, Steve's production machine began to malfunction. He quickly concluded that a sensor was out of alignment. Maintenance work orders had been submitted on several occasions to address this problem. Once repaired, it was only a matter of time before another adjustment was needed because machine vibration would loosen the sensor from its mounting bracket. No information was available to the investigators on repair frequency for this problem.

Several months before this HAZRIN, management had decided that operators would make minor repairs and perform routine servicing of their assigned machine. Although maintenance personnel had previously been called to fix the sensor, Steve either knew (or rationalized) that this repair was minor and, therefore, his responsibility. During the investigation, no one could (or would) say whether this was the first time Steve had made this adjustment or made it in the "nonstandard" manner in which he did. Perhaps he had seen maintenance performing this repair and from that formulated his repair strategy. Perhaps he consulted the operator's manual or simply relied on prior knowledge.

Based on the machine position and where control settings were reportedly found, Steve had switched the machine control status to "manual mode" and jogged the machine's transfer head down, closer to the discharge conveyor, which gave him easier access to the sensor. Next, he switched the control to "emergency mode," perhaps presuming (wrongly, as it turned out) that the machine was in a zero-energy state. Up to that point, Steve was conforming to instructions in the manufacturer's operator's manual. However, the investigation confirmed that this machine had two instruction manuals: one for operators, one for maintenance personnel. Perhaps Steve was not aware that two manuals were available or that the maintenance version contained critical system safety information not included in the operator version.

The machine's start-key was found in position on the control panel, which reportedly was a violation of the lockout/tagout (LOTO) procedure. Steve should have taken the key with him after setting it to emergency mode. However, this would only have prevented someone else from starting the machine. Perhaps with no one present and production slowing with each passing minute, Steve was not concerned about this procedural deviation. Furthermore, he may have dismissed the LOTO procedure because, as the investigation revealed, conformance applied only to maintenance personal performing major repairs. He proceeded to make the (minor) repair in order to get the machine back on line.

Steve's next action puzzled coworkers interviewed during the investigation. He took a shortcut from the control panel, climbed an access ladder to a platform above the transfer head, then descended to the discharge conveyor. "Normal" practice, according to other operators, was to walk around the machine's perimeter to access the sensor via the machine's interlocked doors. Again, Steve may have believed that the machine was in zero-energy mode, thus making his unconventional entry into the machine relatively safe and expedient.

Once on the conveyor bed, Steve maneuvered into a space roughly 12 inches wide at one corner of the transfer head, between a row of moveable grip-forks and the pressure plate of the transfer head. While Steve made the adjustment, the sensor was triggered—perhaps a finger or some other body part crossed its plane. Sensing "no product" between the forks and plate, the grip-forks, still under pneumatic pressure, quickly closed, pinning and crushing Steve's chest. When product failed to flow downline, curious coworkers came to check. They found Steve pinned in the machine and had to disassemble the transfer head to free him. It is doubtful this delay made a difference in the outcome. He was pronounced dead at the hospital.

Initial Investigation Findings

Plant management immediately conducted an investigation and asked the machine manufacturer to do the same. This independent investigation began nearly three weeks after the event occurred. Most of that time was consumed waiting on approvals, then only one day on site was authorized.

Following a review of the accident scene, the plant manager, engineering manager and several coworkers were interviewed. Coworkers said Steve was skilled at his job and conscientious about safety; they uniformly described his actions as puzzling. "He did an unsafe act" (i.e., failed to access the machine head from the perimeter; placed his body in the danger zone) was the typical indictment. The machine manufacturer also considered this an act of a careless worker and denied any responsibility for the fatality.

The engineering manager arranged tests on this machine and one at a sister plant in an attempt to reconstruct the accident sequence. These tests revealed that the same situation (sensor activation) would recur when the machine was switched to the emergency mode. Interviews also confirmed that workers perceived adjustment of this sensor to be routine service (not maintenance) and, therefore, not an action covered by the LOTO procedure.

Although not produced for review, management and the manufacturer both confirmed the existence of two instruction manuals. The operator's manual reportedly contained less-detailed information on machine systems, operation and maintenance than did the maintenance manual. A subsequent interview with the manufacturer's representative revealed that switching the machine to emergency mode would take it to a "near" zero-energy condition—except for pneumatic power to the transfer head. This feature, not described in the operator's manual, was designed to prevent possible damage to the product being held in the elevated transfer head. Should pressure be lost or switched off, the product could drop from the head's grip, causing damage and posing potential injury exposure to workers in the immediate area.

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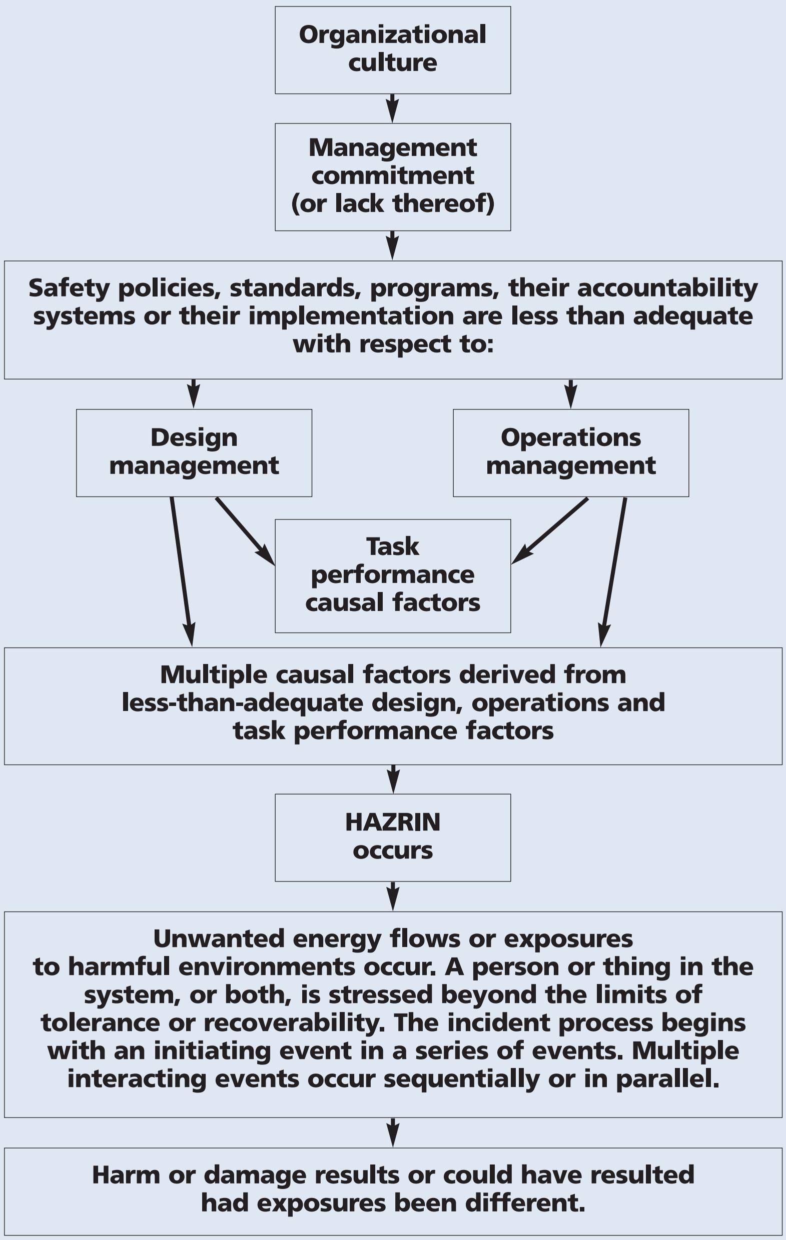
Figure 1

Systematic Causation Model for HAZRINs



Preliminary Analysis

As noted, thorough analysis of such an event often requires the use of several accident causation models and causal tracing techniques. No single model or technique can cover all potential causal categories. It is also too easy to prejudge a probable cause or sequence based on first impressions or readily visible factors and, as a result, possibly head toward an incomplete or erroneous analysis. Based on its frame of emphasis (e.g., management aspects, system safety), each model leads the investigator through a logical progression of potential causation factors, ultimately revealing a set of probable root causes and corrective actions. In *On the Practice of Safety,* Manuele describes a versatile causation model for hazards-related occupational incidents (Figure 1). This model emphasizes causal factors that arise from less-than-adequate attention to task performance, design management practices and operations management practices—all factors that weighed heavily in this HAZRIN.

Analysis began by listing decisions and/or actions actually or probably taken by Steve that led up to the event (Table 1). That information was then traced through several causation models to arrive at a long list of possible causal factors (pg. 30). Causal factors derived through supposition were also included, even though fact or observation might not substantiate them. Management-imposed limitations on the investigation made it necessary to expand the list of possible causal factors so that from this larger sampling, a most-probable causation sequence and optimum corrective actions set could be generated. The collective output from several causal-tracing techniques (e.g., MORT, SCAT, PPAS and TOR) produced more than 30 potential causal factors. This list was then compressed and sorted into three categories—task performance, design management and operations management—consistent with Manuele's model.

Seeking a Most-Plausible Sequence

How did the many varied sequential, parallel and chaotic causation elements come to interact? Certainly, management controls the majority of actions and decision making in the business system. The machine manufacturer also has a legal, ethical and moral obligation to provide a "safe" system. Therefore, the worker is largely at the mercy of those who design the system and those who manage it. This is illustrated in Figure 1 by the subordinate linkage of task performance causal factors positioned between those of design management and operations management.

A case (albeit weak) could be made that this HAZRIN was the result of an "unsafe act" by a fallible human being, as coworkers and the machine manufacturer concluded. One can quickly move beyond this myopic, symptom-level conclusion by asking the simple question, Why? Asking it enough times will reveal a deeper, underlying reason for Steve's decision and actions. A rational, specially trained and skilled employee would not place himself in the "tiger's jaws," let alone enter such a situation without certainty of emerging unscathed (Haddon). Tracing backward through the HAZRIN causation model reveals a most-plausible sequence. To set the stage, it is helpful to define the causal space (see "Chaos" sidebar) prior to the event.

There was the machine. In place for several years, with an element of complexity designed into its energy controls, it offered limited information feed-

Table 1

Probable Decision/ Action Sequence

- Initiating event = machine malfunctioning.
- Perform diagnostic.
- Determine problem source = sensor/bracket.
- Develop corrective action plan.
- Initiate corrective actions.
- Place machine in manual mode.
- Lower transfer head close to conveyor.
- Place machine in emergency mode.
- Access transfer head by ascending platform.
- Place body between plate and forks.
- Attempt to adjust or tighten sensor.
- Transfer head cycles.
- Operator crushed.

back at the display panel interface to the operator. The machine represented one causal stream parallel to operations management. Whenever the machine exhibited chaotic behavior causing the sensor bracket to vibrate loose, maintenance personnel would repair it, relying on knowledge most likely gained from a maintenance manual that described the pneumatic power feature and how to manage it. An initially more robustly designed sensor bracket—or a retrofit by management—would have controlled one chaotic element of this system and might have altered the course of events.

There was a skilled operator who was sequentially aligned with operations management, its adequate (or less-than-adequate) practices, programs, procedures, systems, etc., and to an organizational culture that managed its business to an acceptable level of control. Up to this point, no attractor was present. Worker/machine performance within this causal space might have functioned incident-free, unaffected by the varied inadequate controls, conceivably forever, until something altered energy flows, giving chance an alternate path toward a HAZRIN.

On the day in question, chaotic machine vibration once again had loosened the sensor. As per the model, "A thing in the system is stressed beyond the limits of tolerance or recoverability." Sometime before this, management had made machine operators responsible for routine servicing. The causal space now had its attractor. Allocation of routine servicing versus maintenance duties was not well-defined, perhaps left to chance or operator judgment.

Management controls had not changed. A recent production record and an expected recognition motivated Steve and may have served as an antecedent to his subsequent behaviors. Energy flows began to converge. He was faced with a situation now within—or perceived to be within—his responsibility, and the sequence in Figure 1 played out.

Steve controlled the situation, guided or limited by the knowledge in the operator's manual, his motivation and the values of the organizational culture. A manufacturer's design/complexity tradeoff placed priority on preventing product damage and did not make the complete status of energy potentials visible to the operator. A warning light on the control panel might have altered the course of events. Steve processed the available information and executed a corrective action strategy under a

The Concept of Chaos in Accident Causation & Analysis

The definition of HAZRIN, as with similar definitions related to accident causation, needs to evolve to embrace the concept of chaos. Causation can flow sequentially or chaotically, but not in parallel. Parallel energy flows would never interact—unless an "attractor" is present to draw events and unwanted energy flows together. Chaologists use the term "strange attractor" which can be described as that 3-D space (phase space) bounding or describing all possible positions of a particle or characteristic state within that space. Identifying that attractor is at the foundation of accident causation.

To connect safety to chaos, one can draw an analogy between "phase space" and Steve's work area. This space contained:

- Steve (his duties and his positions within the work space);
- the machine (its inputs and outputs);
- external environment/internal ambient factors;
- internal business cultural factors, and management goals and objectives;
- psychosocial and work organizational factors (including supervision);
- all controls or weaknesses in controls (e.g., safety programs, procedures);
- all influences (inputs) and outputs (actions, decisions) at any point in time.

One could draw an analogy between "phase space" and a workstation, a factory delimited by its four walls or an entire corporation. The attractor might be a decision or action, the task itself, or the culture within the confines of that workstation, plant or corporation. From an accident causation perspective, this can be called the "causal space."

A HAZRIN occurs when and where energies flow from various sources, in series, in parallel and along chaotic paths, ultimately converging on or attracted to a position and point in time. Chaos, as it relates to safety and accident causation, is a leading-edge concept (or should be) for SH&E professional practice.

Possible Causal Factors

This lengthy, yet incomplete, list of possible causal factors will reinforce a fundamental safety precept. "For almost all hazards-related incidents—even those that seem to be the least complex—there will be multiple causal factors, deriving from less-than-adequate policies, standards or procedures that impact on workplace and work methods design, operations management and task performance practices" (Manuele 61). The challenge is finding the most-plausible sequence of decisions and actions—that path of least resistance chance took in this case, ultimately defining this HAZRIN.

Task Performance

- **Improper position for the task.** Worker placed himself inside transfer head.
- **Failure to follow procedure.** Worker did not access sensor from machine perimeter. Entered machine without notifying coworkers or supervisor. Did not properly execute LOTO. However, proper job and/or LOTO procedures may not have existed.
- **Lack of awareness.** Worker not aware of or familiar with all machine subsystems, energy sources and controls. Also not aware of two instruction manuals.
- **Used equipment improperly.** Worker improperly de-energized power sources (likely the result of lack of awareness).
- **Inadequate mental/psychological capability.** Employee exercised poor judgment, experienced possible memory failure, and committed possible errors of commission or omission.
- **Mental or psychological stress.** Worker encountered conflicting demands—maintenance versus routine servicing. Striving to keep production at a high level consistent with past achievement or expectations. A machine down and production being lost is a stressful situation, especially after setting a new production record.
- **Improper motivation and inadequate reinforcement of proper behavior.** Employee was motivated to maintain production performance for which this crew recently received recognition and was to receive a reward. Negative reinforcement may have shaped behaviors (i.e., decisions and actions).
- **Performance of risky behavior(s).** Willingness of a skilled person to place himself in a dangerous position could be construed as a reflection of an operating culture that reinforced risk-taking or stressed production over safety. Possible errors of commission or omission, failure in judgment, or failure to adequately perceive or assess risks and outcomes. Misdirected motivation or overconfidence may also have been involved.

Design Management

- **Inadequate engineering or design deficiencies.** Sensor was prone to misalignment due to machine vibration. Its support bracket could not withstand external stress. A machine subsystem remained energized even when in emergency position. Control panel gave no visual or auditory warning or feedback on system status when switched to emergency mode. Choice to have two manuals containing different information not communicated to operators. Inadequate failure-mode analysis, assessment of system complexity and/or human factors assessment of task demands versus error potentials.
- **Inadequate guards and barriers.** Ability to access machine head from other than the guarded perimeter. Manufacturer designed power system controls and control/display interface with inadequate failure-mode analysis.

Operations Management

- **Lack of knowledge or experience.** Inadequate initial training or refresher training of machine operators, especially following the management decision to require operators to perform routine maintenance. Management/engineering possibly lacked or had incomplete knowledge of the unique system power status during emergency mode setting. Operator not informed about two manuals by management or manufacturer.
- **Inadequate skill transfer.** Inadequate initial instruction, testing, review or reinforcement. Inadequate knowledge transfer from maintenance personnel to operators following management's decision to change operator duties. Standards for machine operator proficiency may have been absent or lacking. Management and manufacturer not communicating on decision to change operator duties nor what impact that decision would have and management responsibilities it carried.
- **Inadequate leadership or supervision.** Possible conflicting goals (safety vs. operational efficiency). Incomplete knowledge of system or of potential hazards. Limited supervisor involvement in or accountability for safety. Safe behavior not reinforced.
- **Inadequate work standards/practices.** LOTO procedure did not apply to routine servicing by an operator. Operator expected to do routine or limited maintenance. SOPs limited in scope and did not include safety controls or safe practices.
- **Insufficient instruction or training.** Possible deficiencies in providing initial or refresher training on machine operation, hazard awareness and LOTO procedure. No training needs assessment conducted. Two manuals differed in content. Probably no training conducted on LOTO procedure for affected personnel following decision to change operator duties.
- **Hazards assessment lacking.** Inadequacies could be linked to both manufacturer and management. Management had not conducted JHAs or process safety assessments. Debatable whether risk/benefit tradeoff of key design feature (retaining pneumatic control) was justified. If justifiable, were controls adequate in light of the greater risks? Thorough failure-mode analysis might have led to better warning systems, as well as better written procedures and/or function allocation. Management decision to require operators to perform routine servicing likely made with incomplete assessment of risk and/or implementing necessary controls. No task analyses for critical or high-hazard tasks and, as a result, no task/behavior observation.
- **Inadequate preventive maintenance.** Reportedly, the bracket holding the sensor had a history of coming loose due to machine vibration. Source of vibration not identified or controlled. Operators had submitted work orders for the same repair.
- **Inadequate procedures.** LOTO limited to maintenance personnel and not routine servicing by an operator.
- **Standard operating procedures.** SOPs did not include safety controls. Possible role conflict in that operator performed repairs as routine servicing of a machine and not a maintenance procedure subject to stricter controls (e.g., LOTO or maintenance manual) or allocated to more highly skilled and trained personnel.

Complexity as an Element of Causation

From a human factors/ergonomics standpoint, system complexity can be responsible for most of an operator's difficulties in using and maintaining systems, with resultant error and stress (Meister 10). System complexity played a role in the HAZRIN described in this article.

Complexity has physical and behavioral dimensions. The first is transformed into the second when the designer selects certain component functions to be represented at the display interface in the form of useful information. Consequently, only those components made "visible or transparent" to the operator impact his/her performance. Therefore, the designer's goal is to select only the information an operator needs to run or maintain the system. Some leeway is allowed, as the precise number of component interactions to be displayed is a matter of informed judgment (Meister 11). Judgment (informed or otherwise) is based on the designer anticipating what would happen if the operator did not have certain information.

In this case, the designer may have rationalized the need to maintain pneumatic control to the transfer head by making primary the need to prevent product damage. Maintenance personnel, presumably guided by their more-complete instruction manual, would be aware of this feature and know how to control it. The operator, by the nature of this job's typical duties, would not be expected to perform maintenance and, thus, would not be exposed to this aspect of system complexity. Such thinking may have guided design decisions at the control/display interface, making it unnecessary to inform (i.e., make visible to) the operator potential hazardous system states.

misconception of safety, guided by less-than-adequate design management and operations management, all (including chance) taking a path of least resistance. As a result, a HAZRIN occurred, and as per the model, "a person in the system is stressed beyond the limits of tolerance or recoverability."

Post-Accident Corrective Actions

Before solidifying an opinion on probable causation (or accepting the author's)—especially if leaning toward calling this an unsafe act—consider these words and the actions taken by management and the manufacturer. Assignment of "unsafe act" to a worker should not be made unless and until the following preventive steps have been shown to be adequate: 1) hazard analysis; 2) management or supervisory detection; and 3) procedures safety reviews (Manuele 80). Hazard analysis "is the most important safety process in that, if it fails, all other processes are likely to be ineffective" (Manuele 79).

- The manufacturer reprogrammed the controls so that when the machine was in emergency mode, mechanical movement of the transfer head would not be possible, although air pressure remained available.
- The manufacturer launched a study of other possible hardware/software modifications.
- All production operators received refresher training on LOTO and general machine safety procedures.
- Warning labels were placed on the control panel and machine perimeter.
- The staircase to the transfer head was removed and replaced by a platform with access controlled by an electronic barrier. If triggered, the machine would automatically default to emergency mode.
- The sensor mounting bracket was affixed to a metal plate, making it much less vulnerable to machine vibration.
- The manufacturer combined the operator and maintenance manuals and updated both to reflect safety changes made.
- Management contracted an outside firm to conduct a hazard assessment of all machinery, systems and critical tasks. Based on the results, management was advised to review duties and functions of machine operators and maintenance personnel in order to determine the optimum task allocation, prepare job hazard analyses (JHAs), and reassess needs for training and function-specific procedures.
- Periodic monitoring or observation of compliance, using JHAs as evaluation tools, was encouraged, as was the use of behavior-based safety initiatives.

Conclusion

Many of the complex, interwoven causation factors identified during this investigation occur across all industrial settings. This fatality event will likely be repeated in another place, at another time, involving some unsuspecting worker whose tolerance for risk-taking will lead him/her to test the relentless nature of chance.

Design decisions shaped a machine and its complexity. A culture defined priorities, values and expectations. Management chose to reshape a job and its task demands without giving adequate attention to hazard assessment, controls, programs and standards, thereby attracting all of these elements together. And, a machine operator played his role, behaving in both predictable and unpredictable ways. The outcome was undesirable, unexpected, final and, as this analysis revealed, predictable. A high price to pay for making the world a safer place. ■

References

Haddon, W.J. Jr. "On the Escape of Tigers: An Ecological Note." *Technology Review.* May 1970.

Manuele, F.A. *On the Practice of Safety.* 2nd ed. New York: John Wiley & Sons Inc., 1997.

Meister, D. "Complexity as a Dimension of Ergonomics Design." *Ergonomics in Design.* Spring 2002: 10-14.