PTD BEFORE RIS
A Historical

By Michael A. Taubitz

PREVENTION THROUGH DESIGN (PTD) AND RISK ASSESSMENT are getting a lot of attention lately. Have you ever wondered why and how the ideas for their use originated? Based on its origins, how can PTD help safety professionals identify and reduce risks, and what might the future of PTD be?

This article presents a narrow slice of history as known by the author, beginning with employment at General Motors (GM). It chronicles the foundations and evolution that brought those engaged in the practice of engineering and safety to the current state of PTD in one company. Many forces and efforts have led those of us who are engaged in the practice of safety to where we are in PTD today, but with this article the author presents a glimpse of the fundamental occurrences in one industry that have led to the progressive use of PTD in other industries.

Other companies and industries may have had their own lessons and contributions to the current state of the art. Lack of knowledge prevents providing a broader scope. It is hoped that others will offer their own history and lessons learned to help promote broader and more effective usage of PTD concepts in all industries and academia.

This article will show that before risk assessment innovative initiatives that might currently be considered PTD efforts resulted from collaboration of safety and engineering personnel primarily relying on assessments of feasibility. Applying lessons learned from individual projects was problematic because no practical risk assessment methodologies were in use. The advent of risk assessment for manufacturing in the late 1990s established the foundation for today's PTD initiatives.

The author's lessons learned related to PTD are presented throughout the article.

KEY TAKEAWAYS

- **Early efforts to design out hazards were sporadic and based on assessments of feasibility. Lack of practical risk assessment methodologies constrained PTD efforts.**
- **Collaboration of individuals around PTD led to development of risk assessments that could be integrated into daily business in general industry.**
- **With 2 decades of experience in risk assessment, it is time for collaborative efforts of government, professional organizations and safety professionals to make risk assessment fundamental to the practice of safety.**

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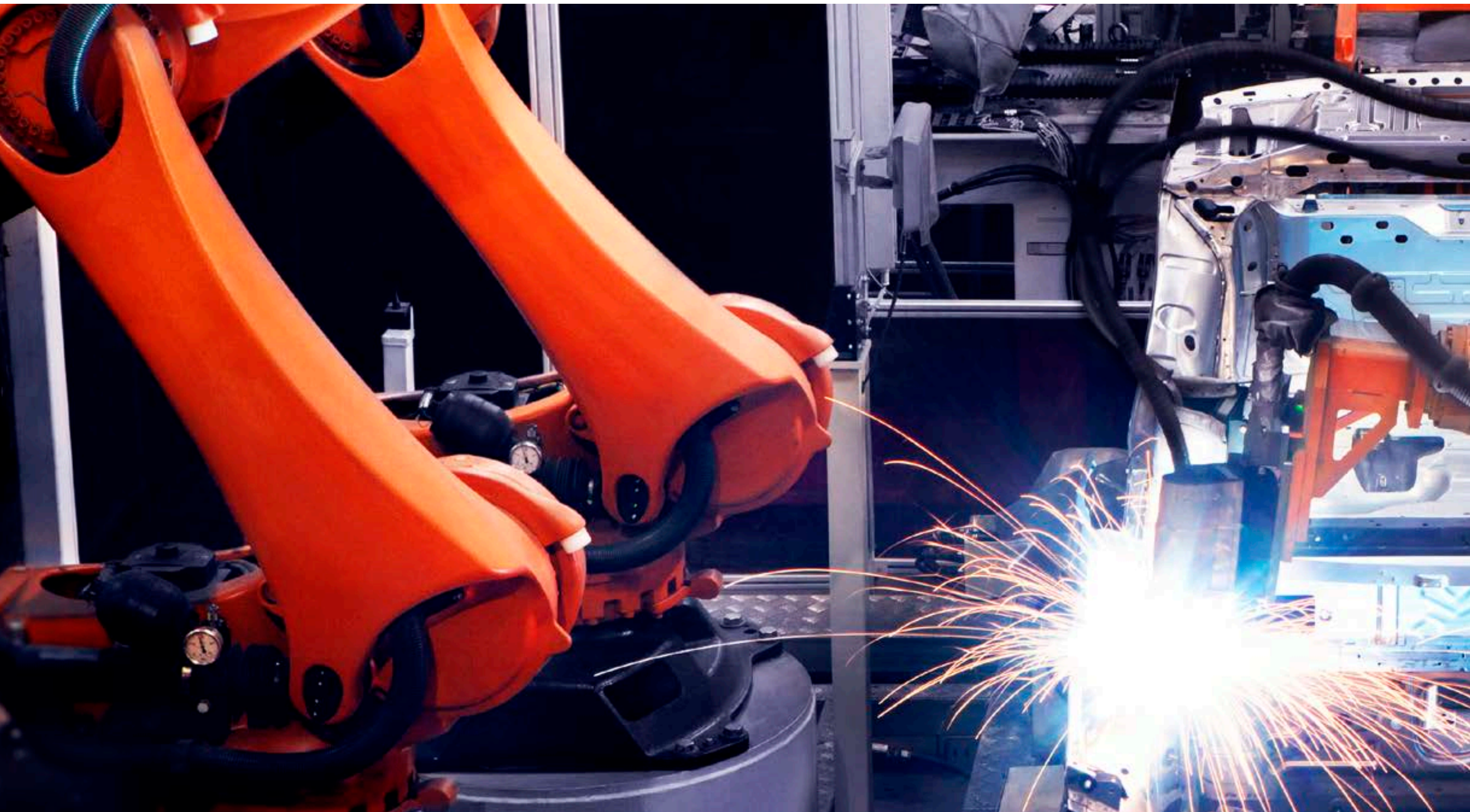


SK ASSESSMENT

Perspective

Lesson: *Future advances in PTD can only be made when risk assessment and corresponding feasible risk reduction are part of an overall strategy in academia, government, industry and labor.*

1970s

The experiences begin with process engineers who first engaged concepts of PTD due to the new OSHA safety regulations and emphasis on noise reduction. These engineers were responsible for purchasing new and rebuilt machines and equipment at the Chevrolet V8 engine plant in Flint, MI, in the 1970s.

Developing the processes by which V8 engine parts would be machined and made ready for assembly was the responsibility of the master mechanic process engineering department (equivalent to today's manufacturing engineering). The process engineers:

- developed bid specifications and requests for quote;
- recommended suppliers;
- placed purchase orders;
- followed design and build;
- oversaw commissioning of machines;
- maintained production operations for safe and efficient operation.

The OSH Act became effective in 1971 and its requirements placed additional responsibilities on employers. Uniquely within the Chevrolet Motor Division, the V8 engine master mechanic (the head of the master mechanic group) declared that process engineers would be responsible for noise control and implementation of machine guarding for OSHA compliance.

When the group complained that they did not know anything about OSHA, the response was "Neither does the safety staff. You buy equipment and we expect you to handle this as part of your bid specifications."

Lesson: *Engineers work on what management demands.*

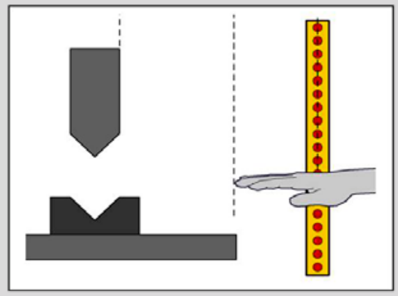
Fortunately, the process group knew how to write detailed bid specifications and hold machine suppliers accountable for those specifications. At that time, a common industry practice was for a supplier to claim, "My costs for noise control are included in the base machine cost." There were several problems with this practice:

- It was difficult for process engineers to compare different proposals on an apples-to-apples basis.
- Without the line item and detail of proposed controls, the process engineer could not follow the design and implemen-

FIGURE 1
DESIGNED-IN SAFETY

A perishable carbide tooling with unevenly spaced teeth. Such design solutions were devised to address noise control issues. These concepts began to be described as "designed-in safety," a precursor phrase that later became PTD.

FIGURE 2
LIGHT SCREEN



tation of noise controls concurrent with other design reviews after a supplier was awarded the bid.

•Noise control evaluation was typically first addressed during machine runoff (before acceptance at the supplier's plant). If the machine had sound levels higher than 85 dbA, sound enclosures became a necessary retrofit that inhibited efficient operation and tool change while adversely affecting the life of machine components.

Lessons:

1) Poorly designed noise control enclosures resulted in ongoing battles with operators and maintenance to keep those controls in place.

2) Properly engineered controls resulted from machine suppliers being forced to consider noise during concept and design of the process.

The process engineers created a standardized system that held suppliers accountable for a line-item breakout of proposed noise controls in their competitive bids. Suppliers that could not break out the noise control costs from those of the base machine were not considered for the project.

This was the process engineering group's first experience with feasibility. Once the supplier was selected, the suppliers' commitment to follow all elements of their quotation on noise was reaffirmed during the pre-award process, a step before formally issuing the purchase order.

Lesson: *Engineered controls that are considered after design and build are often not feasible. But those same controls may be feasible if part of the initial concept and design.*

The best machine suppliers invested in their own noise control concepts, instruments and development of engineered controls to gain a competitive advantage before the next request for quote.

One supplier discovered that offsetting the mill cutter teeth reduced the harmonics and vibration with an attendant decrease in sound level and improvement in surface finish (Figure 1 shows perishable carbide tooling with teeth not evenly spaced). The process engineering group began to describe these concepts as "designed-in safety," a precursor phrase that later became PTD.

Lesson: *PTD concepts can be a competitive advantage.*

A simple lesson came from one ingenious master mechanic general foreman, who came up with an idea that dramatically reduced sound levels in hydraulic pumps while increasing the life of the pump. In the 1970s, hydraulic power was used extensively to power most of the machining operations. The industry standard was to mount the pump above the tank.

Much ambient noise resulted from pump cavitation, which is the formation of bubbles or empty space in the oil typically caused by the movement of the pump impeller moving the oil. The general foreman decided to mount the pump and motor underneath the hydraulic tank. Not only was sound level dramatically reduced due to less cavitation and vibration, but also pump life increased significantly. By then, the engineers had learned that noise is merely waste, and anything they could do to eliminate waste improved the process.

Lesson: *PTD lessons proliferated because they make sense.*

Machine Design Improvements

During the 1970s, many engine components were machined on large transfer lines. A transfer line is a manufacturing system consisting of a predetermined sequence of machines connected by an automated material handling system and designed for working on a defined family of parts. Parts can be moved or indexed singularly to the next station for further machining.

Vertical drill heads (gear boxes with drill spindles) were used to drill or ream holes in the parts. When complete, the head was retracted by weights and chains, thus using gravity to return the head to home position awaiting the transfer of the next part. When changing drills, taps and other perishable tools, the operators would reach under the raised head to perform their tasks.

With the growing awareness of safety and potential for malfunction, the question was raised about what could happen if a chain broke, releasing the gearbox onto the worker. The PTD solution incorporated into new machines was to automatically pin the slide when it was in the up position, thus providing a mechanical lock to protect the worker. Older machines were retrofitted with a swing-in block that provided protection for the worker.

Lesson: *This technique of pinning a slide would become important a decade later for mechanical power press transfer machines. If part of concept and design, it cost nothing; if retrofit, the cost was prohibitive.*

Another innovation was having a transfer line time out 30 seconds after it was supposed to cycle. For transfer equipment when parts or fixtures did not correctly transfer a signal was given to make the next part transfer. Upon diagnosing the problem, it was common for an operator or maintenance worker to adjust a switch whereupon the machine went back into automatic cycle. "Making the limit switch" was the source of many fingertip amputations because the machine cycled immediately upon getting the signal. The time-out feature not only protected the machine but dramatically reduced finger injuries and amputations.

Lesson: *PTD can protect both machines and people.*

When I was promoted from the process engineering group to safety supervisor, I sought advice from my older brother, an experienced and respected toolmaker at another Chevrolet plant. My brother said, "If I listen to all that stuff you guys tell me, I'll follow your rules, shut you down and you will never run again." To underscore his point, he continued, "If a car was an industrial machine, you guys would interlock the hood and never allow the engine to run with the hood open." He noted that it was impossible to troubleshoot problems and set engine timing without the engine running.

This was the era when the general safety practice was to lock out the machine if removing a guard. This was also the beginning of a dawning awareness that existing industry practice of locking out a machine whenever a guard was removed was not always feasible. Sometimes a guard had to be off while the machine was running to perform troubleshooting, vibration analysis, belt alignment or cleaning. Hence, skilled trades would remove the guard and, of necessity, ignore the rule to shut down and lock out power.

Lesson: *First illustrated in 1977, this issue is, unfortunately, still an issue in today's world. Many tasks simply cannot be performed according to prescribed safety rules for lockout that may be ideal but will not work in the real world.*

The confusion and battle over zero energy and machine lockout would be the source of many problems over the next 20 years.

Lessons:

1) Without risk assessment, safety professionals were inhibited by their individual beliefs; some mistakenly believed that zero risk was attainable.

2) The lack of an accepted and workable risk assessment method seriously constrained efforts that would have saved lives and improved productivity. This is the key reason the author wrote this article.

The author was subsequently assigned to the central office with oversight for 28 manufacturing and assembly plants. During this period, two plants concurrently came up with the same idea. Light screens were in their infancy and were often used as a backup to the traditional two-hand control to initiate machine cycle. Independently, two plants inquired, "If we use a light screen to prevent hands getting into the point of operation, why can't we load the fixture and design the control system to initiate cycle as soon as the operator's hands pull away from the hazard and clear the invisible plane of light?" (Figure 2).

The concept made sense because the machine could only cycle when the hands were pulling away and clear of the hazard. Moreover, if the operator were to reach back into the point of operation, the light screen would detect the presence of a body part and stop the machine before an injury occurred. Subsequently, corporate safety approved the concept for use on hydraulic machines (e.g., hydraulic press welders, assembling two components, part inspection) where experience with emergency stops validated that stopping on those machines was nearly instantaneous. Mechanical presses were excluded due to concerns over stop time. [Note: This predates presence sensing device initiation (PSDI) that was typically applied to mechanical power presses.]

Safe distance for location of the light screen was determined empirically working with engineers, safety, union representatives and workers. Ultimately, the concept was used on thousands of machines in different locations. These machines were typically one operator, hydraulically operated and short cycle time (less than 10 seconds) with the ability to stop almost instantly.

Lessons:

1) Words and terms have real meaning. The term light screen cycle initiation *was used to differentiate from PSDI, which was associated with power presses.*

2) The use of PTD concepts became more broadly known as design-in safety in Chevrolet and GM.

While no formal procedure for design-in safety existed, the process evolved to:

- identify an idea;
- assess for feasibility with engineering;
- determine compliance with OSHA and state regulation (Note: few ANSI or voluntary standards existed at the time);
- propose a pilot program;
- test the concept on the factory floor with involvement of engineers, safety, union representatives and workers;
- debug/modify as necessary;
- communicate and expand the concept.

In retrospect, the continuous improvement model of plan-do-check-act/adjust/abandon was the model for improving safety and production.

1980s

From the late 1970s, the company was struggling with achieving a lockout/tagout (LOTO) zero-energy state for service and maintenance tasks (Note: this was long before OSHA's regulation for the control of hazardous energy).

During this same period, many fatalities occurred involving LOTO. The problem was that many tasks could not be done without power, and workers ignored their training to lock out machines. The concepts of alternative methods and task-based risk assessment were still years away, and no other technical tools existed to help counter the belief that without power, workers could not be injured. While that is typically true, try asking a mechanic to tune up a vehicle without the hood open and the engine running. It cannot be done.

Zero energy was a popular term among many management, safety and union representatives. Engineers, who were under pressure to control capital expenditures, found that the concept could help control the capital cost for new equipment. If all work was to be done with no power, a single disconnect for large, complex machines should suffice. The thought of zoning or leaving power on to certain parts of the equipment (e.g., to heaters so that product would not solidify) was not considered because the safety department specified zero energy. The engineers may have known that a single disconnect would not suffice for an entire line, but they saved money by following the safety department's direction.

In the early and mid-1980s, dozens of standard four-robot cells with interlocked gates were brought into plants with one disconnect for all robots. Workers were forced to ignore the lockout procedures for many reasons. Power was needed for a specific robot during teach mode, and there was no way to control the potentially hazardous energy of other robots because those engineered controls were not included in the design and build of the cell. A single 480-V disconnecting device was used to shut down and lock out all power. The dilemma was that workers knew they could not do their jobs without power. Worse yet, these were hydraulic robots that would lose position when power was turned off. Hence, workers would have to reposition each robot back to the home position before production could continue.

Hard lessons were also learned when skilled workers pushed back that zero energy would crash overhead robots that were used to weld and assemble vehicles in assembly plant body shops. Energy was needed to hold these robots in the up position. When all energy was shut down, the overhead robots came down and created an unplanned maintenance situation, commonly referred to as "crashing the body shop." Blind insistence on zero energy and not understanding the control of hazardous energy forced skilled workers into what the company's safety termed *malicious compliance*. Following supervisory instruction resulted in significant downtime and increased hazards to get the plant running again.

Lessons:

1) Injuries and deaths resulted from the mistaken belief that zero energy would make things safer for workers.

2) From a personal perspective, it was troubling to recognize that workers were injured and killed when attempting to follow safety rules. Without risk assessment and the misguided belief in Heinrich's triangle (discussed later), zero energy sounded like a good principle. Words from my brother rang in my ears: "You guys give us eighth grade tools to fix college-level problems."

It bears mentioning that when OSHA promulgated 29 CFR 1910.147, Control of Hazardous Energy, in 1989, there was no mention of zero energy in the preamble or in the regulation itself. Even today the myth of zero energy lives on in some companies. Perhaps zero energy works with simple operations where no service and maintenance tasks require power, but in most companies today, zero energy as a broad-brush policy is a failed concept that should be and has been abandoned.

Lesson: *Myths and beliefs are hard to let go.*

By the late 1980s, the number of serious injuries and fatalities (SIFs), coupled with the growing awareness about the deficiencies of LOTO and the words of my skilled trades brother, it became painfully apparent to me that many machines were simply not designed from the perspective of skilled trades and others performing maintenance work. Without this perspective included in the design process, workers would continue to face unnecessarily high risks in performing maintenance work.

Machines and their safeguarding systems needed to be designed differently to facilitate maintenance workers performing necessary tasks for operations that break down. However, management and safety professionals believed that reducing minor injuries would reduce the risk of SIFs, although the exposure issues related to SIFs were different from those associated with recordable and minor injuries. For example, the hazards associated with a qualified electrician performing diagnostic work on live 480 V panels are dramatically different from those that contribute to soft-tissue and other common recordable injuries.

Manuele's 1993 book, *On the Practice of Safety,* first addressed this matter; his later book debunked the Heinrich myths (Manuele, 2002). The exposure to hazards of serious and fatal injuries are not the same as for minor injuries but industry labored on with the belief that reducing minor injuries to near zero would somehow magically reduce fatal incidents. The point bears repeating: The hazard exposures are entirely different.

Lessons:

1) For those investigating SIFs, it was clear that the exposures of those workers were significantly different from those of minor incidents and recordable cases.

2) Striving for a zero rate of recordable injuries does nothing to ensure that SIFs will not occur because of the differences in hazard exposure.

Understanding SIF Exposures

Attempts to better quantify exposures of skilled trades workers came as a result of a lockout fatality. OSHA proposed to settle the case if the company agreed to develop a procedure for every task where power was required to be on. At this time, the company still had dozens of manufacturing and assembly plants with several hundred thousand workers in the U.S. Corporate safety set out to understand OSHA's proposal in a factory environment.

A stamping plant with 2 million sq. ft, several hundred production machines and approximately 2,000 workers had records of their planned maintenance tasks. Their Maximo system documented more than 90,000 discrete or individual tasks that would be performed each year (Note: Maximo is a software product that tracks the operation, maintenance and disposal of assets). The amount of downtime for planned maintenance activities was less than 20% of overall downtime. The vast majority of downtime was due to machine breakdown or unplanned maintenance.

The company's maintenance executives estimated that 95% of all breakdown tasks would require power at some point in the task, whether for troubleshooting in automatic, observing, jogging, positioning or testing. OSHA's proposed solution was estimated to result in nearly 250,000 procedures per plant. Whether the actual number would have been 200,000 or 300,000 was a moot point; determining it was simply not feasible. GM settled the case without the OSHA proposal.

Although this example was for one facility in one U.S. company, the results apply broadly. Unlike recordable injuries, the exposure of maintenance workers needed to be managed but could not be measured.

Lessons:

1) How could management know the hazards and requirements of unplanned maintenance tasks?

2) What if a task variable created unknown risks? What did we provide for the worker as suitable risk reduction measures?

The words of W. Edwards Deming took on real meaning: "The most important things we need to manage can't be measured."

Slide Locks

In the mid- and late-1980s, GM and the United Auto Workers (UAW) made reduction of SIFs a major goal. During this time the organizations became aware of a significant design problem on new transfer presses that stamped sheet metal parts such as vehicle hoods and side panels. The parts were indexed to the next station using a cam-actuated transfer mechanism. When the machine was shut down and locked out for maintenance, it was possible for the transfer mechanism to move forward as much as 8 in. if it was in a particular location on the cam. This unforeseen hazard was due to gravity and the design of the transfer cam. Going forward, part of LOTO became securing the transfer with chains to protect against potential crushing injuries.

This extra step was cumbersome and inefficient. It was proposed that devices to pin the slide could provide a means of automatically locking the slide such that inadvertent motion could not occur. These slide locks were an outgrowth of the 1970s best practice for securing vertical machine heads. Ultimately, this concept spread throughout the automotive industry.

A letter from the company's administrator of safety and ergonomics to all safety personnel addressed the issue of slide lock mechanisms for mechanical power presses (K. Lauck, personal communication, Jan. 24, 1989). The letter states:

> Properly designed automatic slide lock mechanisms satisfy the corporate and regulatory requirements for blocking the slide. Slide lock mechanisms can:
> - reduce the risk of injury associated with handling safety blocks;
> - provide an efficient convenient aid for shutting down and locking out a press for servicing;
> - provide a means of securing the slide at a variety of crank positions;
> - reduce the time for servicing presses;
> - enhance the overall safety of employees servicing presses.

FIGURE 4
DESIGN PROCESS MUST EVALUATE LOGISTICS

The logistics of a production cell required operators to step over and through a roller conveyor to place empty trays on a conveyor. In doing so, they caught their shins on the side of the conveyor.

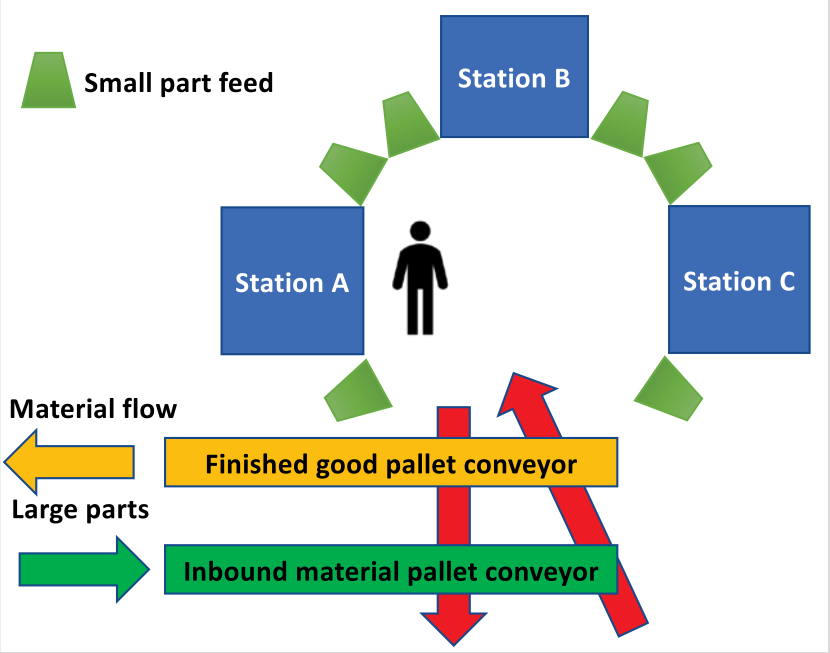
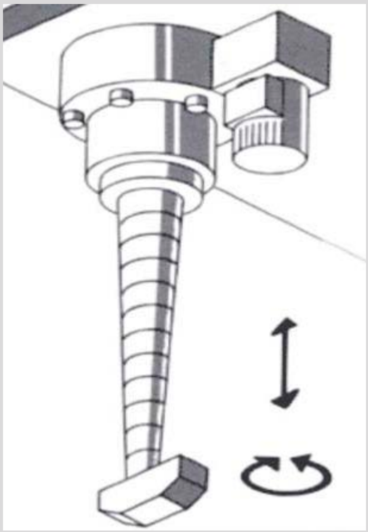


FIGURE 3
SLIDE LOCK



Slide locks are used for making the slide safe when working in the die space. These devices are used for both mechanical and hydraulic presses.

Figure 3 shows one type of slide lock. An electric motor and a gearbox are used to move a threaded nut up and down. The tie rod, which is in the parked position (fully extended), first performs a 90° rotation, then moves directly to the slide and prevents it from being lowered accidentally.

To prevent sticking, a hydraulic cushion ensures release of the tie rod, even under load. Due to the continuous variation in length of the tie rod, the press slide can be locked in any position.

In 2007, OSHA published CPL 02-01-043, Slide-Locks Enforcement Policy, Inspection Procedures and Performance Guidance Criteria. This directive notes:

> This instruction establishes OSHA's enforcement policy, inspection procedures and performance guideline criteria regarding slide-locks, i.e., when they are used for hazardous energy control purposes. . . . OSHA is . . . issuing this directive to further its goal of uniform enforcement of its standards.
>
> The appendix to this directive addresses a set of best practices related to the design, installation, use, inspection, testing and maintenance of slide-lock devices. This performance guideline was developed by a work group of practitioners (the Automotive Industry Action Group and representatives from the UAW) having expertise in power-press operation and safety design.

Lesson: *It takes a long time for PTD concepts to move into mainstream thinking.*

Joint Initiatives

The 1980s saw significant PTD-related efforts of the Joint UAW-GM Center for Health and Safety. During that time, both GM and UAW recognized the value of PTD concepts and strove to promote the concepts within and outside of the organization. Design-in safety was the theme of the 1986 Joint Health and Safety Conference.

Deming had a strong influence on joint safety initiatives. His background as a statistician led him to always question the current state of any system based on data. Only then could managers understand variability and issues causing that variation in the system. In the 1980s, the industry standard for measuring fatality rates was the number per 100,000 workers. While the metric may have had some value for comparing a company's performance to others in industry, it did nothing to help predict and mitigate future incidents (CDC, 1999).

Deming's influence and emphasis on the use of statistical process control (SPC) resulted in analysis of more than 30 years of fatality data (Note: SPC is now commonly referred to as six sigma). SPC showed that two common causes accounted for about half of the fatal incidents. (Note: Common and special causes are the two distinct origins of variation in a process, as defined in the statistical thinking and methods of Deming. Common causes, also called natural patterns, are the usual, historical, quantifiable variation in a system, while special causes are unusual, not previously observed, nonquantifiable variation.)

One common cause, caught in equipment, was long recognized by efforts to lock out machines. The second common cause, falls from height, accounted for nearly 20% of fatal incidents over 3 decades. GM and UAW recognized that processes and procedures could do little to reduce the risk of working at heights. Joint Center for Health and Safety undertook a multiyear effort to develop a program for engineers, supervisors and workers. Proper design of machines and facilities coupled with support and enforcement of supervision were recognized as the foundations for a suitable program. A degreed civil engineer from GM was loaned to the center to work collaboratively on developing a comprehensive program that began with good design. The fruits of this effort were borne out by a reduction in fatal incidents due to falls from height.

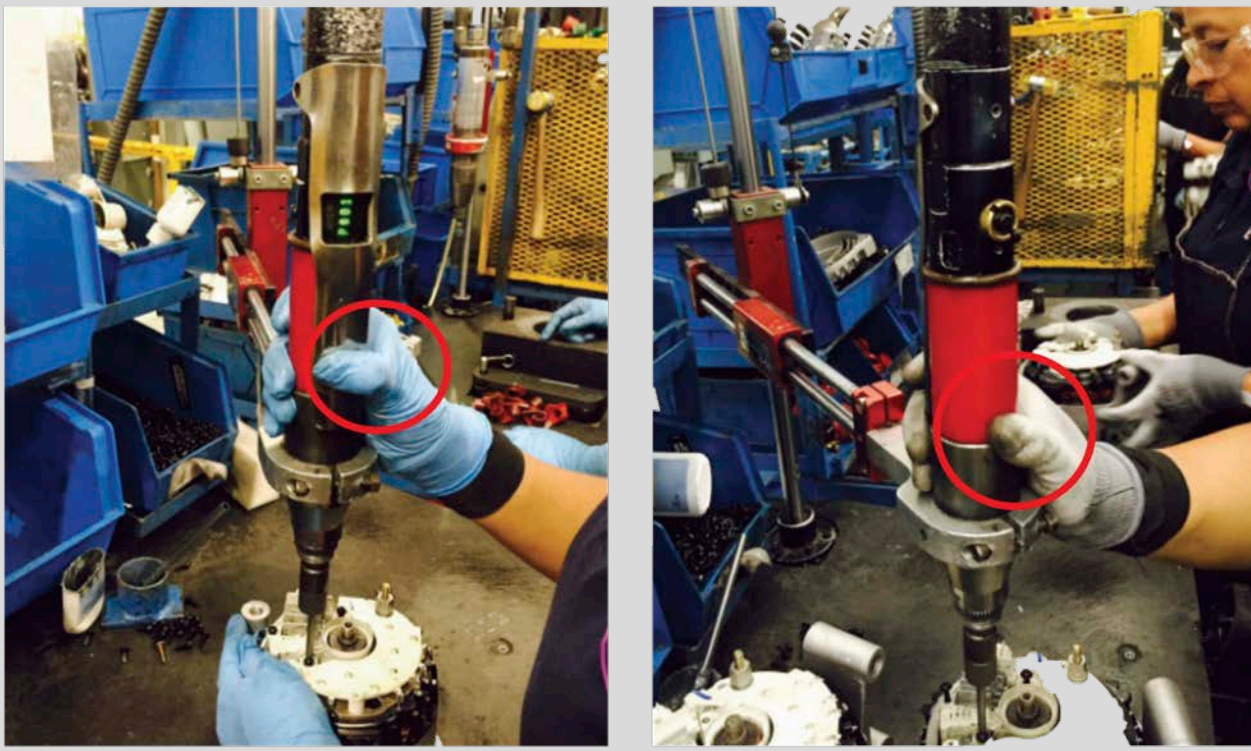
Lessons:

1) SPC identified a previously unrecognized common cause of fatalities. SPC is not risk assessment but it identified an issue that required attention. The risks of falling from height were known. Workers were seriously or fatally injured.

FIGURE 5
TOOL & INJURY EVALUATION

The electronic screwdriver activation button position was located in front of the operator. It required the operator to activate the button with the thumb, placing all the stress on the thumb. After evaluation, the screwdriver was turned 180° to allow the operator to use four fingers to activate it, thereby reducing the effort of the hand.

BEFORE **AFTER**



2) With leadership commitment, resources and focused attention of union and management, a comprehensive fall hazard program was developed to include engineers, supervisors and workers. The program used the hazard control hierarchy as the foundation of risk mitigation, where elimination of a fall hazard from good design was the best solution.

Other PTD Efforts in the Automotive Industry

In a three-machine assembly cell for a tier-one automotive supplier, the advanced manufacturing engineering (AME) team utilized the company's global machine and ergonomic specifications and guidance for ensuring that:

•the operator-machine interface was adequately protected for pinch points;

•ergonomic forces for the operator to load the parts, trigger the cycle and handle the finished assembly were within the acceptable ranges within force, frequency and duration;

•the alternative means of entry for the cells was adequately assessed and control measures were well defined.

In theory, this cell would have been a model for other multistep assembly operations. Within the first 2 months of operation, two broken and sprained ankles and several knee strains occurred, and employees working on this new model assembly cell expressed real dissatisfaction.

What went wrong? The management and AME teams were frustrated that this new cell could not meet production targets and that no one wanted to work on the line. The issue was so simple that no one saw it. The root cause of the issues was the interface with logistics. Operators had to step over and through a roller conveyor to place empty trays on a conveyor. In doing so, they caught their shins on the side of the conveyor. The need for operators to handle large bulky trays over their heads as they attempted to step over and through a conveyor line contributed to their being off-balance during performance of this task (Figure 4, p. 31).

Lesson: *The design process must include evaluations of:*

1) logistics, from raw material delivery to pallet changeouts to product palleting;

2) operator steps and paths for material handling (e.g., moving pallets, removing and attaching pallet straps).

Another tier-one supplier learned, the hard way, the PTD lesson that the devil is in the details. In a simple assembly operation, the operator bolted a cover to the housing. The workstation was one of several hundred in a manual assembly process for the rebuilding of automotive electrical components. The workstation was designed to ensure that:

•the operator was at an ergonomically efficient height to the workstation;

•ergonomic forces for the operator to handle the tool, load the parts, trigger the cycle and handle the finished assembly were within the acceptable ranges within force, frequency and duration;

•part bins were effectively placed with minimal ergonomic effort.

The low cost of this assembly cell setup allowed for it to be easily replicated. Although shift production targets were met, in charting productivity over the course of a shift, it became clear that by the third hour productivity was declining.

Workers did not complain about pain related to the job. The trigger to the screwdriver was activated by the thumb and required constant pressure during the assembly operation. Relocating the trigger fixed the problem (Figure 5).

Lessons: *PTD must:*

1) include an evaluation of the tools being used;

2) be an integral part of the injury evaluation process.

1990s

The 1990s was a decade with increased attention on the need for risk assessment. Safety professionals understood the concepts but did not yet have practical tools for use in the everyday world. A comment from an unknown source that stays with the author is, "If design-in safety is a vehicle, risk assessment is the engine that will power the vehicle."

Need would soon produce action. UAW-GM national negotiations conducted in 1993 produced a key agreement that would become important several years hence, when the concepts of task-based risk assessment (TaBRA) took shape. An outcome of the negotiations was formal recognition that the control of hazardous energy would include energy control that was broader than zero-energy lockout. The foundation of using properly designed control circuitry for dealing with the increased complexities of robotic operations and new manufacturing processes was now in place.

Lesson: *Necessity is the mother of invention. Safety professionals knew we needed the risk assessment tools that are so prevalent today but were not yet in existence in the early 1990s.*

About that time, Manuele's 1993 book, *On the Practice of Safety*, validated the beliefs driving early design-in safety or PTD efforts. His writings and vision made him a natural partner with UAW and GM personnel who held similar beliefs. Relevant excerpts from that book follow:

> At the ASSE Professional Development Conference in June of 1991, the keynote speaker informed attendees that 90% of accidents were caused by unsafe acts of employees. During sessions on behavior modification, similar statements were made. How pitifully unprofessional for safety practitioners to be so involved. Heinrich's 88-10-2 theory was held as the conventional wisdom years ago. It is a shallow myth. (p. 140)
>
> There is a need for us to establish and agree upon meanings for *hazards* and *risks* and use them consistently in our communications. (p. 141)
>
> I have adopted Lowrance's definitions of *risk*, taken from his book, *Of Acceptable Risk: Science and the Determination of Safety*, since it applies well to professional safety practice. "Risk is a measure of the probability and severity of adverse effects." (p. 183)
>
> As safety practice evolves, the required attention will be given to the avoidance of hazards in design and engineering processes. (p. 184)
>
> Every safety professional who writes a recommendation to eliminate or control a hazard makes a risk acceptability decision. (p. 187)
>
> Safety professionals must acquire knowledge of risk determination concepts to give validity to the proposals they make to reduce risk. (p. 187)

Lesson: *Manuele (1993) identified the need for safety professionals to understand risk and risk determination.*

In the early 1990s, the author wrote to the then-CEO at NSC encouraging the council to undertake an activity related to the design-in-safety system in place at GM at the time. In a discussion at a conference, recognizing Manuele's similar views about risk assessment and prevention through design, continued discussion soon led to action. Manuele approached the decision makers at the council regarding the proposal.

Following a feasibility study by an ad hoc committee, the council established the Institute for Safety Through Design (ISTD) in 1995. ISTD's definition of *safety through design* was "The integration of hazard analysis and risk assessment methods early in the design and engineering stages and taking the actions necessary so that risks of injury or damage are at an acceptable level."

ISTD hosted a 1996 symposium, "Integrating Safety Through Design." Jim Rucker, GM's executive director of industrial engineering and design-in safety department, opened the symposium with the words, "We are on a journey." The symposium was convened with the objective "to identify the safety, health and environmental knowledge an engineer should possess upon completion of a baccalaureate degree."

Lessons:

1) PTD practitioners are passionate. The energy, enthusiasm and passion the participants brought to this symposium and this new method of designing in safety was evidenced by the invitation, request and eventual pleading for the attendees to please stop discussions and eat lunch, an occurrence I had never seen before or since.

2) PTD requires collaboration of many different parties.

Much was accomplished by ISTD. It held seminars, workshops and symposia, issued proceedings and delivered presentations at safety conferences. NSC published a book, *Safety Through Design*, coedited by Wayne Christensen and Fred Manuele. In accord with its sunset provisions, the institute was disbanded in 2005.

GM's Design-In Safety Activity and ISTD participants all recognized that risk assessment was needed if the goals of PTD were to be realized. However, at this juncture in the mid-90s, there was no practical methodology for general industry risk assessment. From the author's perspective, perhaps the most important accomplishment of ISTD was creating a forum for like-minded individuals to meet and plan on how to move forward with risk assessment.

A major goal for the Design-In Safety Activity (later renamed Engineering for Health and Safety) was the development of a robotic safety specification. A method was needed to guide decisions on minor servicing tasks that could be performed

ACCEPTABLE RISK

Since the early 2000s, considerable progress has been made in the use of risk assessment and the application of feasible risk reduction measures using the hazard control hierarchy. Both the ANSI B11 and ANSI Z244.1 standards have done much to move the needle of progress. Importantly, the combination of these standards provides the necessary framework to identify alternative methods to traditional lockout to enable work to be performed safely and achieve acceptable risk. Those lessons and PTD examples from more industry sectors remain another story to be told.

using control reliable safeguarding in lieu of full lockout. With no method in hand, a team of company engineers, union representatives and a chief engineer from Hughes Corp. (a GM acquisition in the 1990s) worked directly with skilled trades on developing a simple method for risk assessment. With the many years of zero energy beliefs lingering in the background, the overriding mandate was that whatever came forth must be task based. In other words, the risk reduction method identified for a given task must allow a given task to be performed with acceptable risk, a term that would be formalized later in the world of voluntary standards.

TaBRA is the method that evolved from the factory floor. It asks a worker/subject matter expert to share his/her accumulated experiential learning to identify and mitigate hazards. In most cases, a small team may work through the process. The first step is to identify all steps of the task. After that, hazards are married to each step of the task, resulting in task-hazard pairs.

Feasible risk reduction to achieve acceptable risk is the goal. Risk reduction efforts are focused on task-hazard pairs that are high or medium risk with the goal of reducing them to low or negligible. The hierarchy of hazard controls is the preferred approach to mitigating risk. This hierarchy is comprised of six steps that are often referred to as the higher-order and lower-order controls.

- Higher-order controls include hazard elimination, substitution and engineering controls.
- Lower-order controls include warnings, administrative controls and PPE.

All engineering controls have some residual risk that is further mitigated using lower-order controls. TaBRA recognizes that some tasks require a greater focus on lower-order controls because higher-order controls are not feasible (e.g., diagnostic work on live 480-V primary panels, teach for a robot, tasks requiring employee intervention with power on).

The TaBRA process typically produces more information than observation or a traditional job safety analysis (JSA) because steps such as “obtain work order from computer,” “put the machine in manual” and “observe operation” are captured to ensure that the worker gets into the real-world cadence of performing the specific task being analyzed. This natural cadence of performing every step is useful to identify variables when something goes wrong during the task (e.g., parts or tools dropped). Discussion may disclose a potentially serious hazard with high risk that might not otherwise be identified.

TaBRA should complement traditional JSAs and standardized work instructions. TaBRA is useful for maintenance tasks where no standard work procedure exists and for high-risk jobs and situations where there are questions about the appropriate level of safeguarding or operational waste. The process recognizes several important factors:

1) Zero risk does not exist.

2) Risk reduction measures/safeguarding must recognize the realities of the real world, for example:

- Power may be required;
- Work may have to be performed at elevation or in a confined space;
- Operator intervention may be required during machine/process operation.

Demonstrating that beliefs die hard, a group of company robotics engineers refused to accept that it was proper to design robots allowing power on the end effector of a gripper robot when skilled workers were doing service and maintenance. The team involved with developing TaBRA recognized that the gripper could only be adjusted with power on, but the engineers were concerned that they could be held legally liable if someone suffered a pinched finger.

The issue was resolved after a skilled worker (of necessity) bypassed light screens and safeguards to adjust a gripper robot at an assembly plant. The worker experienced a serious near-hit when the robot arm activated. From the worker, the team learned:

- The task of adjusting the gripper cannot be done under full lockout because power is needed at the gripper to make the adjustment.
- The chance of getting a finger caught is remote to unlikely because of tools, hand position and hearing a solenoid click if the gripper activated.
- Forcing the worker to bypass safeguards made it such that impact from the robot arm was now possible with potential for a serious or fatal injury.
- If the finger was pinched, the severity was much less than being struck by the robot arm.

Lessons:

1) JSAs have always provided value and continue to do so. TaBRA is a complementary tool that should be used when questions arise about the steps of a task, whether power is required or unplanned maintenance tasks.

2) Although TaBRA had not yet evolved to the current state, the method won out because no other feasible approach existed for the worker to perform the task. Feasibility of risk reduction was linked directly to a given task using informal risk assessment.

3) Risk often comes from the unknown variables associated with a task. Understanding those variables requires the input of experienced workers.

Importantly, TaBRA received recognition from OSHA (1999). In a standard interpretation letter the agency noted:

> However, an MPS [Note: MPS was GM’s term for control reliable safeguarding], which meets the above referenced ANSI consensus standards on control reliability and control component failure protection [ANSI B11], would provide alternative safeguarding measures, which constitute effective employee protection. Thus, such an MPS may be used to protect employees who are performing minor tool changes and adjustments, and other minor servicing activities, which take place during normal production operations, provided that each element of the §1910.147(a)(2)(ii) exception is met. In other words, the MPS system may be used in cases in which minor tool changes and adjustments, and other minor servicing activities, are performed during normal production operations, **and** are routine, repetitive and integral to the use of the equipment for production. It is important, as you have stated, to apply this safeguarding technique (MPS) through a hazard analysis process (TaBRA) on a case-by-case basis in order to assure that it, in fact, provides effective employee protection.

The task-based methodology was also introduced into the series of ANSI B11, Machinery Safety Standards as well as ANSI B155.1, Standard for Packaging Machinery.

ANSI B11 Technical Report 3 (TR3) is an informative document to the family of B11 standards that provided the body of work that would ultimately find itself being adopted into the national standards themselves. The importance of the acceptance of the TaBRA methodology was captured in a 2002 article on ANSI B11.TR3 in a series of quotes referring to the report:

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"The greatest stride forward in the field of safety in the past 25 years" *—Fred Manuele, P.E., CSP, author and ASSE Fellow*

". . . fills the gap where no consensus standard exists. We know how important this document will be in promoting safety in the workplace." *—Richard Sauger, OSHA Standards Development Group*

". . . a document that is of great importance in the U.S." *—Jim Howe, Assistant Safety Director, UAW*

"Risk assessment has gone from a novel, untested concept to a practical method to improve safety through design. This is a great improvement over EN 1050." *—Bruce Main, P.E., CSP, Design Safety Engineering*

". . . critical in promoting safety through design." *—Wayne Christensen, director, NSC Safety Through Design Program* (Andres, 2002)

In his 2004 book, *Risk Assessment: Basics and Benchmarks*, Main chronicled the types of risk assessment methods used in many different industry sectors and provided critical information linking risk assessment to:

- safety through design;
- acceptable risk;
- design reviews.

It is recognized that, in the broad scope of overall risk, not all hazards are associated with tasks. However, in general industry, tasks and their numerous variables account for the vast majority of risk that must be managed.

Lesson: *The task-based approach to risk assessment, and the migration of it through various standards and publications, laid a solid foundation for subsequent accomplishments in PTD.*

What Lies Ahead

Risk assessment is the key tool for identifying hazards and preventing harm before it occurs in a wide variety of machinery, equipment, products and processes. Safety practitioners should play a leading role in promoting the inclusion of elements in operational risk management systems, particularly for task and hazard identification and assessing risks.

Risk assessment works. The numerous industry standards that require documented risk assessments to be performed is evidence of the success. Further evidence comes from machinery and equipment users now requiring risk assessments prior to purchases. End users are driving risk assessments because they help prevent injuries and improve machinery effectiveness. This trend will likely continue.

The purposes of safety practitioners will be best served if they are able to participate in risk reduction efforts, but this requires some advanced familiarity with the hazard control hierarchy and constraints of feasibility. To be effective, risk reduction solutions must be technologically, economically and functionally feasible.

Even if safety practitioners are not comfortable selecting risk reduction measures, they can still drive the process and engage engineers to assist in completing the risk assessment. Facilitating the process with engineers, workers and union representatives not only produces better results but also provides greater confidence in the findings of the risk assessment and risk reduction.

We have seen safety personnel avoid engaging in risk assessments, preferring to be consumed in familiar day-to-day activities such as safety training, reporting and recordkeeping. This is unfortunate and likely limiting growth and professional advancement.

College students must learn the risk assessment process while in school, and more safety science degree programs should include courses or content on the risk assessment process. The risk assessment method chosen is less important than students being conversant in the process upon graduation. Several universities include risk assessments in engineering project courses with great success.

It is hoped that this narrow history of one engineer who made safety his career has carried the message that risk assessment and feasible risk reduction are best accomplished in the early stages of concept and design of any product or process. The best way to ensure that we keep moving forward is to embrace and deploy PTD efforts via endeavors such as:

- ANSI/ASSP Z590.3-2011(R2016), Prevention Through Design: Guidelines for Addressing Occupational Hazards and Risks in Design and Redesign Processes;
- Main's (2012) more recent book, *Risk Assessment: Challenges and Opportunities*;
- Active participation in PTD and ASSP's Risk Assessment Institute.

Lesson: *PTD should be a goal of organizations that desire to prevent and mitigate risks before they create exposure on the factory floor. Risk assessment is the foundation for those efforts.*

Echoing the words from the 1996 ISTD conference, PTD is indeed a journey. But it is a journey akin to a long-term group relay race. Risk assessment is the baton. As safety professionals, let's make sure we don't drop it. **PSJ**

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