EXECUTIVE SUMMARY

Leveraging Prevention Through Design

- Prevention through design encompasses all efforts to anticipate and design out worker hazards.
- A hierarchy of controls is fundamental to prevention through design.
- Occupational electrical fatalities in the U.S. have decreased, but more work needs to be done.
- Over the last 50 years, PtD has reduced electrical fatalities.
- Standards and hazard control measures don't stand alone; they support each other.
- Safety, reliability, and productivity are linked—investment in one is often an investment in the others.

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Leveraging Prevention Through Design

Overview

Today's electrical system designers and facility owners are challenged to comply with the everchanging safety standards and legal requirements enforced nationwide. These continually updated codes and standards provide more accurate, but more complex, methods of assessing and recognizing hazards. Worker safety is of the utmost importance, whether it is protection from electrical or other common workplace hazards. Prevention through design or PtD is an effective way to reduce electrical danger. This approach has been used successfully for decades to manufacture safer components and systems. Automatic sensing, system layout, and other approaches are proven ways to enhance safety, reliability, and productivity.

Context

Lanny Floyd and Marcelo Valdes discuss prevention through design and describe how this methodology can improve worker safety, electrical system reliability, and organizational productivity.

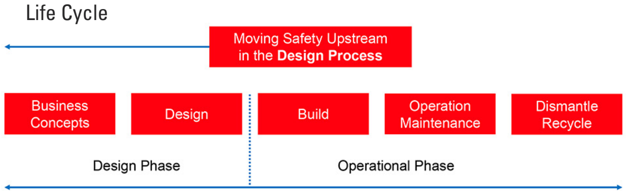
Key Takeaways

Prevention through design (PtD) encompasses all efforts to anticipate and design out worker hazards.

The focus of PtD is on workers who install or maintain different types of systems. PtD isn't new; its roots are in systems safety which emerged in the late 1930s and early 1940. In the United States, the National Institute of Occupational Safety and Health (NIOSH) launched a formal PtD Initiative in 2006.

PtD focuses on the full life cycle of a product, process, or facility, from conceptual design all the way to the dismantling or disposal phase of the life cycle. Redesign opportunities also exist throughout the operational phase. They can arise during renovations, expansions or modernizations, incident investigations, or disaster recovery.

Prevention through Design Applies to the Product or Process Life Cycle



Design decisions can reduce electrical risks for the entire life cycle, potentially decreasing worker dependence on safe work practices and personal protective equipment (PPE). PtD reduces the frequency or potential severity of electrical exposures. In some cases, it can eliminate risks entirely.

In 2006, the American Society of Safety Engineers sponsored the development of the ANSI Z590.3-2011 standard – Prevention through Design: Guidelines for Addressing Occupational Hazards and Risk in Design and Redesign Processes. This standard provides a framework, analysis tools, references, and examples. It was revised in 2016.

A hierarchy of controls is fundamental to prevention through design.

This concept has existed since the early days of system safety. Today, a hierarchy of hazard control measures has been captured in ANSI Z10. Elimination, substitution, and engineering controls can be applied during design and redesign processes. Warnings, administrative controls, and personal protective equipment are applied in the construction, operation, and demolition phases of the project life cycle.

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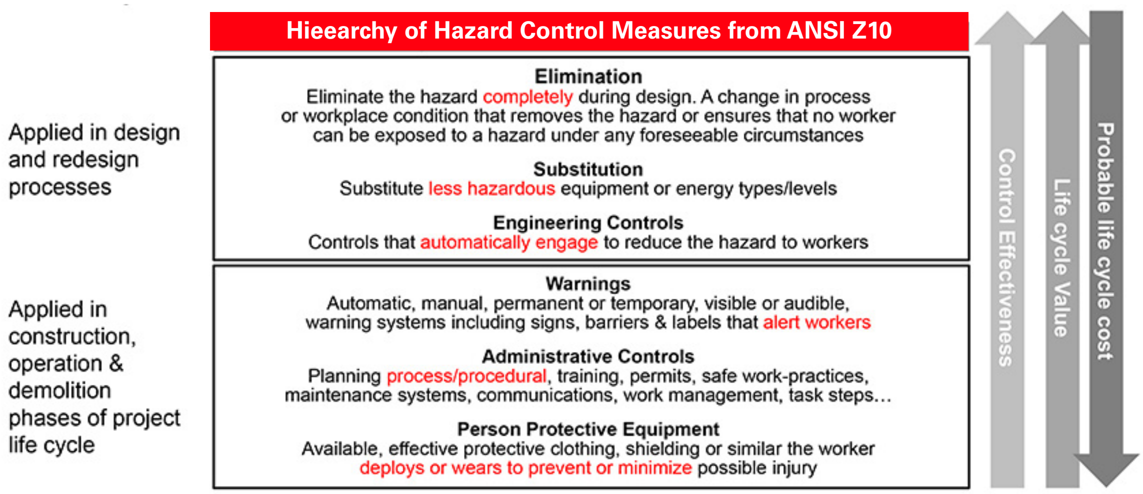


Occupational electrical fatalities in the U.S. have decreased, but more work needs to be done.

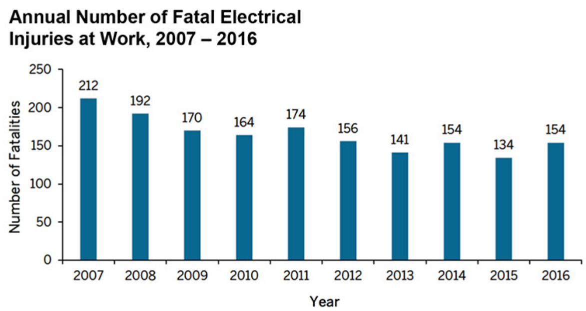
Between 1980 and 2010, the United States experienced a downward trend in occupational electrical fatalities. This is encouraging since the workforce has grown and the amount of electricity used in the workplace has also increased significantly. The decline in fatalities can be attributed to safer electrical equipment designs, safer work practices, better personal protective equipment, and worker education.

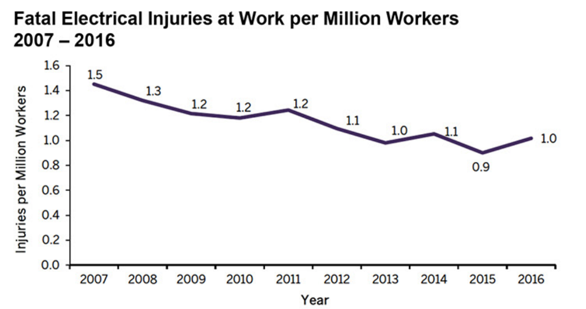
Between 2007 and 2016, however, the downward trend in electrical fatalities flattened. This raises the question of what can be done differently. Other countries have demonstrated extraordinary results in reducing electrical fatalities in the workplace. Almost all the Western European countries in the European Union have lower electrical fatality rates than the United States.

Between 2004 and 2010, close to half of occupational electrical fatalities (46%) involved contact with overhead powerlines.

Other causes of electrical fatalities included contact with wiring transformers and other electrical components (29%); contact with the current of a machine, tool, appliance, or light fixture (18%); and other accidents (7%). Each of these categories is associated with different types of electrical exposure. This means different PtD-based solutions will be needed to address them.

The Trend in Electrical Fatalities Has Flattened (2007 – 2016)





IEEE 1584 Revisions: Significant Changes on the Way for Arc Flash Calculation Analysis

Over the last 50 years, PtD has reduced electrical fatalities.

Examples of prevention through design include:

- **Plugs on electrical cords.** Plugs have been redesigned to reduce the likelihood of unintentional contact with the conductive prongs.
- **Power tools.** Old power tools were often manufactured with conductive metal cases and three wired cords. These cases could become energized due to a failure in the wiring insulation. In addition, if the equipment ground conductor broke, users were subjected to uncontrolled risk. Tools have been redesigned with non-conductive cases and two-wire cords. This is inherently safer because the system doesn't depend on the equipment ground to protect the person using the tool.
- **Electrical outlets.** Until 1962, the National Electrical Code requirements focused on two-wire systems. Then the code changed and equipment included a third wire equipment ground. The next evolution in outlet receptacle safety was ground fault circuit interrupter (GFCI) outlets.
- **Industrial switchboards.** These used to be open devices, with unguarded components, mounted on live front, unenclosed switchboards. All new designs now have enclosed parts and a dead front design. They also have remote control capability and remote diagnostic capability thanks to communication technologies embedded in the equipment.
- **Fluorescent lighting ballasts.** The National Electrical Code has bene updated to require touch-safe disconnect devices.
- **Fuse holders.** New touch-safe designs meet IP20 requirements for access. They are more effective in reducing the likelihood of a shock during routine maintenance.
- **Motor control centers.** Historically, people had to dress in PPE such as voltage-ready gloves and arc-flash protected gear when working on motor control centers. Communicating technologies with embedded sensing can reduce worker exposure to hazardous energy.

The hierarchy of controls used in PtD can be applied to many different types of electrical equipment. The examples below illustrate how the hierarchy can be used for overhead powerlines, cord-powered tools and appliances, and electrical equipment.

Applying the Prevention through Design Hierarchy of Controls

PtD and Overhead Power Lines

	Example Hazard Control Measures					
	Design Measures			Operational Measures		
Exposure Scenario	**Elimination**	**Substitution**	**Engineering Controls**	**Warnings**	**Administrative Controls**	**PPE**
Contact with overhead electric lines	Remove the line completely	Relocate lines underground	Barriers to prevent mobile equipment encroachment or passage beneath lines Raise overhead lines above standard requirements Install overhead lines away from roads, material handling areas & process equipment	Flags or other visual indicators on overhead lines. Proximity warning devices on all cranes & mobile rigging equipment.	Hazard awareness training. Permit system for mobile equipment movement & crane operation. No conductive ladders	Voltage Rated boots for ground personnel

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PtD and Cord Powered Tools and Appliances

Example Hazard Control Measures						
	Design Measures			Operational Measures		
Exposure Scenario	**Elimination**	**Substitution**	**Engineering Controls**	**Warnings**	**Administrative Controls**	**PPE**
Contact with electrical energy when using temporary wiring, portable tools, appliances & light fixtures	Use air powered tools — Discard obsolete or defective tools and appliances	Double insulated tools — Battery powered tools <50V. (Risk with 120v chargers remains)	Install GFCI protection — AFCI if in very flammable environment	Post signs to inspect tools & cords before using	Hazard awareness training, tool & cord inspections	Hand, eye protection

PtD and Electrical Equipment

Example Hazard Control Measures						
	Design Measures			Operational Measures		
Exposure Scenario	**Elimination**	**Substitution**	**Engineering Controls**	**Warnings**	**Administrative Controls**	**PPE**
Contact with wiring, transformers, or other electrical components	Eliminate the electrical equipment (not usually practical)	Supply circuits <50V — Smaller Transformers — 480V → 208V — HRG vs. solidly grounded — IP20 touch safe components	All energized parts inside enclosures — Interlocks on all covers — Instantaneous protection below arcing current level — HRG GF fault location function	Install hazard warnings on equipment enclosures — Are labels confusing, clear as useful as they can be?	Hazard awareness training, safe work practices, LO/TO & Electrically Safe Working Condition, ERMS (Energy Reducing Maintenance Switches to reduce incident energy	Shock & arc flash PPE

"A Practical Guide for Applying the Hierarchy of Controls to Electrical Hazards", Floyd, H.L., *IEEE Transactions on Industry Applications*, Vol. 51, No. 5, September/October 2015

Standards and hazard control measures don't stand alone; they support each other.

Industry safety standards are more than construction minimums; they give guidance on how to prioritize design decisions.

- The NEC NFPA 70 is an installation standard that provides minimum requirements for "safe" installations.
- NFPA 70B defines minimum maintenance practices for electrical equipment.
- NFPA 70E drives safe behavior within a facility relating to the electrical system.

System designers know that NEC compliance is mandatory. However, compliance with 70B and 70E is just as important for workers who live with the equipment. It is important to utilize multiple levels of protection, such as engineering controls, barriers, administrative practices, and PPE.

> *As long as there's a human involved, we're potentially one mistake away from an error that can cause an incident, an injury, or worst case even a death. If you have a fairly good design, it should take multiple mistakes before a bad thing happens.*
>
> Marcelo E. Valdes

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Safety, reliability, and productivity are linked—investment in one is often an investment in the others.

Observations about electrical safety, system reliability, and company productivity:

- **Automatic sensing supports condition-based maintenance.** Many types of electrical equipment now include built-in sensors, such as thermal sensors, partial discharge sensors, vibration sensors, and voltage sensors. These provide 24/7 sensing which enables teams to shift from calendar-based maintenance to condition-based maintenance. Condition-based maintenance minimizes equipment interactions, which is safer for employees. It also reduces the need to shut systems down.
- **Separating functions in large, complex substations facilitates safety and maintenance.** In large substations, a best practice is to lay out electrical distribution equipment in ways that minimize the effect of shutdowns for maintenance, replacements, and repairs. This is good for safety and also for reliability because it reduces plant shutdowns. If a fault occurs, an isolated piece of equipment is easier to replace on a permanent or temporary basis. The safety and reliability benefits are interlinked.
- **• Opportunities exist to improve designs when doing repairs, retrofits, and upgrades.** There is less reason to do primary current injection in modern equipment for maintenance purposes than in the equipment of previous generations. Primary current injection is time consuming, expensive and can lower reliability due to human error. Modern electronics, sensing, communications and appropriate algorithms can provide the intelligence to perform condition based maintenance that is lower cost, increases reliability and possible increases safety.
- **Equipment failures are costly, with or without people involved.** Even without human injury involved, an equipment failure is expensive in many ways. In addition, equipment failures can be caused by human error. The fewer interactions humans have with electrical equipment, the better for both worker protection and plant productivity.

Many alternatives exist for system design and equipment selections. There is little excuse for doing things "the same old way."

Safety and productivity are linked. The more thought and action is invested up front, the more both can be improved in a cost-effective way.

Lanny Floyd

Other Important Point

- **IEEE Electrical Safety Workshop.** This international forum is focused on changing the electrical safety culture and advancing application of technology, work practices, codes, and regulations to prevent electrical incidents and injuries in the workplace. The Electrical Safety Workshop (ESW) 2019 will be held March 4 to 8 in Jacksonville, Florida. The ESW Central America will be held May 22 to 24, 2019 in San Jose, Costa Rica.

Biographies

H. Landis "Lanny" Floyd, PE, CSP, CESCP

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Lanny Floyd joined DuPont in 1969. For over 30 years, his responsibilities focused on electrical safety in the construction, operation and maintenance of DuPont facilities worldwide. He retired from DuPont in 2014 as Principal Consultant and Global Electrical Safety Competency Leader, having responsibility for improving management systems, competency renewal, work practices, and the application of technologies critical to electrical safety performance in all DuPont operations. In 2013 he was invited to join the graduate school of Advanced Safety Engineering and Management (ASEM) at the University of Alabama at Birmingham (UAB). At UAB, he has taught Introduction to Systems Safety and Prevention through Design, Engineering Ethics and Acceptable Risk, and Electrical Systems Safety which he developed and currently teaches.

Marcelo E. Valdes, P.E.

IEEE Fellow, Application Engineering Manager, Marketing, ABB

Mr. Valdes was with GE 41 years in field engineering, sales, product management, marketing, and application engineering. Since July 2018 he is with ABB's Electrical Products division. Mr. Valdes is past chair of various IEEE PES and IAS chapters in Northern California as well as past chair of the 2014 IEEE Electrical Safety Workshop (IEEE-ESW). Mr. Valdes chairs the IEEE 1683-2014 working group "IEEE P1683 Guide for Specification and Selection of Low Voltage Motor Control Centers with Enhanced Safety Features" and is active in various other IEEE working groups, mostly in electrical safety and electrical systems protection. Mr. Valdes has received recognition for his contribution from the Pulp & Paper Industry Committee; "2015 Pulp & Paper Industry Committee Meritorious Engineering Award" and from IEEE Electrical Safety Committee; "Excellence in Prevention Through Design Technical Award". He received the *IEEE IAS Applications Magazine* "First Prize Article Award" for the 2014 article "Assessing Solutions to Electrical Hazards: An Analytical Tool to Reduce Hazards in Electrical Facilities". Mr. Valdes has authored or co-authored over 35 technical papers for IEEE and other engineering forums. Marcelo participates in CSA Z462, the Canadian Electrical Safety Standard, NFPA 70, the NEC and NFPA70B NFPA's Electrical Maintenance Standard. He is the holder of 27 patents in the field electrical distribution and control. Mr. Valdes is an IEEE Fellow.