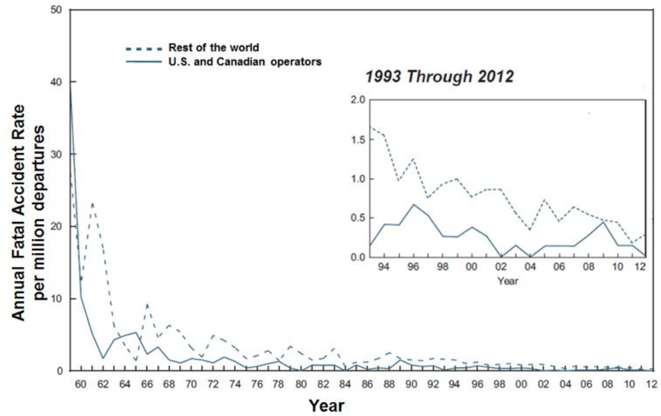
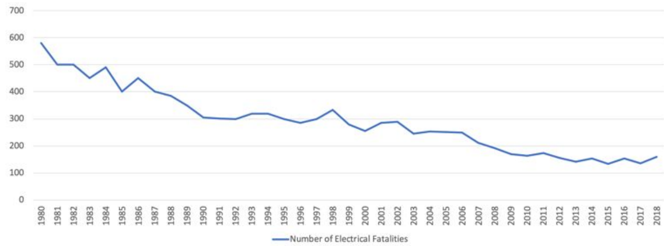
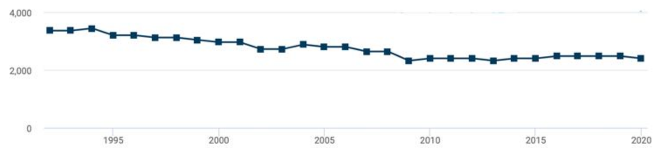
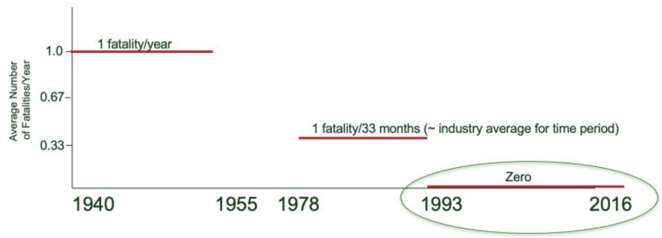

Rest of the world
U.S. and Canadian operators
1993 Through 2012
Annual Fatal Accident Rate per million departures
Year


700
600
500
400
300
200
100
0
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Number of Electrical Fatalities


4,000
2,000
0
1995
2000
2005
2010
2015
2020

| Event type | UK rate | US rate | Ratio |
|---|---|---|---|
| Contact with moving machinery | 0.06 | 0.20 | 3.3 |
| Struck by moving, including flying /falling object | 0.13 | 0.38 | 2.9 |
| Struck by moving vehicle | 0.11 | 0.43 | 3.9 |
| Strike against something fixed or stationary | 0.025 | 0.006 | 0.2 |
| Injured while handling, lifting or carrying | | | |
| Slips, trips or falls on the same level | 0.018 | 0.055 | 3.1 |
| Falls from a height of which: | | | |
| Up to 2 m | | | |
| Over 2 m | 0.17 | 0.50 | 2.9 |
| Height not stated | | | |
| Trapped by something collapsing / overturning | 0.06 | 0.07 | 1.2 |
| Drowning or asphyxiation | 0.028 | 0.055 | 2.0 |
| Exposure to, or contact with, a harmful substance | 0.012 | 0.13 | 10.8 |
| Exposure to fire | 0.011 | 0.053 | 4.8 |
| Exposure to an explosion | 0.013 | 0.051 | 3.9 |
| Contact with electricity or electrical discharge | 0.037 | 0.14 | 3.8 |
| Injured by an animal | 0.015 | 0.025 | 1.7 |


Average Number of Fatalities/Year
1.0
0.67
0.33
1 fatality/year
1 fatality/33 months (~ industry average for time period)
Zero
1940
1955
1978
1993
2016

# REFLECTIONS ON A 50 YEAR JOURNEY IN ELECTRICAL SAFETY


Paper No. PCIC-(do not insert number)

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***Abstract*** – For more than 50 years, I have explored advancements in technology, safe work practices, management systems, and human and organizational performance as they relate to electrical safety. During this journey, I have seen annual electrocution fatalities decrease by more than 80% in the U.S. However, other industrialized countries have demonstrated significantly better results in reducing electrical fatalities, which suggests that a significant reduction in the U.S. is possible. This paper discusses the limitations of compliance-based safety management systems that have evolved in the U.S. over the past 50 years and how systems safety concepts can complement and improve the effectiveness of compliance-based electrical safety programs.

*Index Terms* — electrical safety, safety management, systems safety, risk management, compliance.

## I. INTRODUCTION

For more than 30 of my 45+ year career with a company known as a leader in occupational and process safety, I explored opportunities to reduce the risk of severe and fatal injuries from electrical energy. Through my association with professional organizations and media companies, including the *Institute of Electrical and Electronics Engineers*, *National Fire Protection Association, American Society of Safety Engineers, Society for Maintenance and Reliability Professionals, Plant Engineering Magazine*, *ReliabilityWeb, and Electrical Safety Foundation International,* I sought opportunities to promote advancing concepts in electrical safety management. I have documented much of what I learned in this journey in my published papers and articles.

I have had the privilege of collaborating with hundreds of people to effectively advance the electrical safety culture to prevent injuries and fatalities. I am greatly indebted to colleagues who shared their wisdom, encouragement, experiences, and passion for advancing the practice of electrical safety, beginning in 1984 with our work to create *IEEE Standard 902, Guide to Operation Maintenance and Safety of Industrial and Commercial Power Systems,* members of my employer's Corporate Electrical Safety Team, which I worked to establish in the late1980s and chaired from 1992 to 2014, the leadership team for the IEEE IAS Electrical Safety Workshop established in 1991, and to the co-authors of my published papers and articles.

## II. BEFORE REGULATIONS AND STANDARDS

In the last decade of the 20th century and the first two decades of the 21st century, occupational electrical safety in most organizations in North America centered on conformance with electrical safety specific government regulations and industry consensus standards. Before 1990, one would not likely hear the questions, "What does OSHA require?" or "what guidance do industry consensus standards provide?. These resources were yet to be published. Before 1990, the technical committees of the IAS Industrial and Commercial Power Systems (I&CPS) Department had evolved as centers of excellence for standards and guidance for industrial power system engineering. The IEEE Color Book standards [1], first developed in the 1960s, were the shining jewel of this era. I attended my first IEEE conference in 1984, the IAS Industrial & Commercial Power Systems Technical Conference. It was there that I became involved in the Maintenance, Operations, and Safety (MOS) Subcommittee. The MOS Subcommittee had three initiatives underway: advocacy for an OSHA regulation on electrical safety requirements for general industry, expansion of a recently published NFPA standard to incorporate electrical safe work practices, and creation of a new IEEE standard that would provide recommendations on maintenance, operation, and safety of industrial and commercial power systems. In the absence of regulations and standards, subcommittee members provided leadership in hazard identification, risk assessment, and application of engineering designs and safe work practices to reduce the risk of injuries from hazardous electrical energy. In 1969, Lee published one of the first IEEE papers on industrial electrical safety [2]. Jordan advocated for novel methods to protect workers from arc flash burns [3]. Whittington and McClung demonstrated advancements in applying engineering designs to enhance power system reliability and worker safety [4] [5]. McClung and Gallagher published a reference book [6] to establish an industrial operations electrical safety program. In 1989, the MOS Subcommittee held a ½ day symposium on the prevention of arc flash injuries at the IAS Annual Meeting. The symposium was the first industry forum to bring together thought leaders on arc flash hazards in industrial power systems. For several decades before the first electrical safety regulations and industry standards, the groundbreaking collaborative work of the pioneering electrical safety leaders in the MOS Subcommittee laid the foundation for electrical safety federal regulations and industry standards that were to come.

## III. LEARNING FROM SYSTEMS SAFETY

On March 28, 1979, an accident began unfolding at the Three Mile Island nuclear generating plant 50 miles upwind of my home. The accident helped shape my views on where opportunities may lie in advancing electrical safety. I became curious about what safety management methods were used to ensure a technological mishap with potentially catastrophic consequences greater than anything in history, such as a nuclear reactor meltdown, could be prevented. My curiosity introduced me to systems safety.

*"Systems Safety: The application of engineering and management principles, criteria, and techniques to achieve acceptable mishap risk, within the constraints of operational effectiveness and suitability, time, and costs, throughout all phases of the system life cycle."*

International Systems Safety Society

Systems safety has its roots in the 1940s, with the rapidly expanding military and commercial aviation industries [7]. Designers, manufacturers, and pilots were pushing the envelope in technology. As airplanes became more sophisticated, the cost of mishaps escalated. The aviation industry recognized that the practice of analyzing mishaps after the fact was becoming unacceptable in terms of human safety and financial loss. In his paper, "Using Systems Safety Techniques to Perform Hazard Analysis," Kolak noted, "The costs associated with damaging expensive fighter jets and the development of nuclear energy (where a single system failure was unacceptable) contributed to the concept that hazards must be anticipated and controlled before even a single loss occurs" [8]. The extraordinary improvement in commercial aviation safety shown in Fig. 1 is primarily attributed to the development and application of systems safety [9]. The question in my mind was how the methods to control the extraordinary potential catastrophic consequences of 20th-century technology advancement could be applied to managing the safety of workers exposed to hazardous electrical energy [10]. In other words, how could I look through the lens of systems safety to see opportunities to reduce the risk of electrical incidents and injuries?

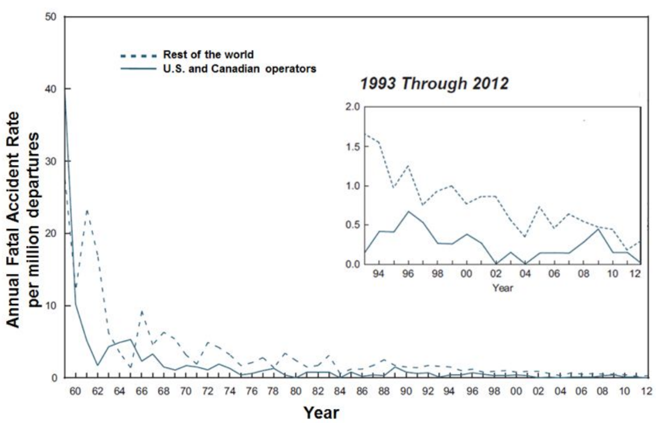


Fig. 1. The trend in fatal accidents in commercial aviation 1958 - 2012

## IV. A CULTURE OF COMPLIANCE

As shown in Fig. 2, over the past 40 years, there has been significant improvement in reducing occupational fatalities from exposure to electrical hazards [11]. However, the downward decline has been flat for the past ten years. The flattening of the downward trend is not unique to fatalities from exposure to hazardous electrical energy. Fig. 3 shows the trend in all occupational fatalities in the U.S. has also flattened [12].

These two charts indicate that the underlying causes of the flattened trend in electrical fatalities are likely not unique to electrical safety. The question I had was, "Is there an opportunity to change the electrical safety culture and have an even more significant reduction in deaths? Compliance is about adherence to regulations and rules. For electrical safety in the U.S., compliance involves asking questions such as "what does OSHA require?" and "What do industry consensus standards require?" Both OSHA regulations and industry consensus standards provide minimum requirements for worker protection. Compliance with minimum requirements may result in residual or unidentified risk that could be further reduced.

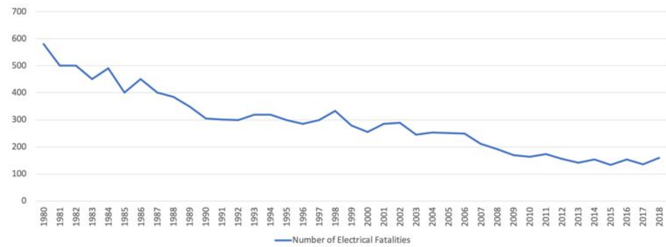


Fig. 2. The trend in Occupational Fatalities from Exposure to Electrical Hazards in the U.S.

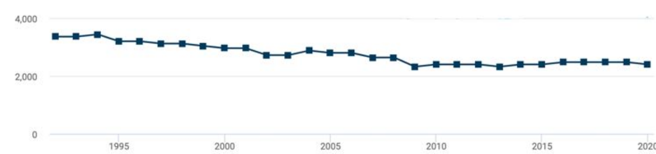

Fig. 3. The trend in Occupational Fatalities from all causes in the U.S.

Exploring electrical safety through the lens of systems safety involves understanding hazard identification, risk assessment, and risk reduction to supplement the results in injury prevention afforded by a compliance-based approach. After achieving compliance with safe work practices, applying risk management techniques includes exploring answers to questions such as "How can the risk controls fail? What are the consequences if one or more controls fail? Are the potential results acceptable? These questions are fundamental to systems safety. In the context of possible exposure to hazardous electrical energy, asking and answering these questions can help see beyond compliance with minimum requirements to how hidden hazards can be identified and residual risk can be reduced further.

## V. APPLYING SYSTEMS SAFETY CONCEPTS

### *A. The IAS Petroleum and Chemical Industry Committee (PCIC)*

In 1991 the PCIC Chair called me to ask if I would work with Don Vardeman to organize a new subcommittee, the PCIC Safety Subcommittee. The initial scope of the new subcommittee was to organize three papers for the annual conference that would help PCIC conference attendees achieve compliance with the new OSHA regulations for electrical safety in general industry. I had never attended a PCIC conference, but I was aware of its reputation for advancing the application of electrical technologies. Don and I concluded that compliance with minimum regulatory requirements should not be the objective. We wanted to raise the bar higher. Three papers annually would not be sufficient to achieve excellence in electrical safety performance. When the new Safety Subcommittee met for the first time at the 1992 PCIC Conference in Toronto, Don and I proposed a standalone conference on electrical safety to change the electrical safety culture. The first PCIC Electrical Safety Workshop was held in March 1992. In 2022, we celebrated the 30th anniversary of the PCIC Electrical Safety Workshop, now called the IAS Electrical Safety Workshop (ESW), sponsored by the IAS Electrical Safety Committee, which has its roots in the PCIC. The ESW has provided the forum to link system safety concepts to occupational electrical safety. Papers at the annual ESW have included advancements in hazard identification, risk assessment, risk control evaluation, the hierarchy of risk controls, prevention through design, human and organizational performance, and safety management systems.

## VI. AN EVOLUTION IN SAFETY MANAGEMENT

### *A. Outside the U.S.*

In 1994, the United Kingdom began requiring construction companies, project owners, and architects to address safety and health during the design phase of projects. Companies there responded with positive changes in management practices to comply with the regulations. Australia developed the Australian National Occupational Health and Safety (OHS) Strategy 2002–2012, which set eliminating hazards at the design stage as one of the five national priorities [13]. In 2008, the European Union launched a two-year campaign focused on expanding the application of risk management in occupational safety. In announcing the campaign, it included this statement: *"Risk assessment is the cornerstone of the European approach to prevent occupational accidents and ill health. If the risk assessment process – the start of the health and safety management approach- is not done well or not at all, the appropriate preventative measure are unlikely to be identified or put in place*" [14].

### *B. The U.K. Leaps Forward*

Mendleoff and Staatsky studied occupational fatalities in the U.S. and United Kingdom (U.K.) and showed that the overall occupational fatality rate in the U.K. was approximately 1/3 that of the U.S. As shown in Fig 4, the fatality rate from exposure to electrical energy was about 1/4 that of the U.S. One factor contributing to this difference is the safety management culture in the U.K. places more emphasis and resources on risk assessment and application of a hierarchy of controls than the compliance approach common in the U.S. [15].

### *C. The NIOSH Prevention through Design National Initiative*

In 2007, the U.S. National Institute for Occupational Safety and Health (NIOSH) announced the National Initiative on Prevention through Design. The initiative is based on applying risk management concepts to identify opportunities to reduce risk beyond compliance with existing regulations and standards.

| Event type | UK rate | US rate | Ratio |
|---|---|---|---|
| Contact with moving machinery | 0.06 | 0.20 | 3.3 |
| Struck by moving, including flying /falling object | 0.13 | 0.38 | 2.9 |
| Struck by moving vehicle | 0.11 | 0.43 | 3.9 |
| Strike against something fixed or stationary | 0.025 | 0.006 | 0.2 |
| Injured while handling, lifting or carrying | | | |
| Slips, trips or falls on the same level | 0.018 | 0.055 | 3.1 |
| Falls from a height of which: | | | |
| Up to 2 m | | | |
| Over 2 m | 0.17 | 0.50 | 2.9 |
| Height not stated | | | |
| Trapped by something collapsing / overturning | 0.06 | 0.07 | 1.2 |
| Drowning or asphyxiation | 0.028 | 0.055 | 2.0 |
| Exposure to, or contact with, a harmful substance | 0.012 | 0.13 | 10.8 |
| Exposure to fire | 0.011 | 0.053 | 4.8 |
| Exposure to an explosion | 0.013 | 0.051 | 3.9 |
| Contact with electricity or electrical discharge | 0.037 | 0.14 | 3.8 |
| Injured by an animal | 0.015 | 0.025 | 1.7 |

Fig 4 A Comparison of Occupational Fatality Rates between U.S. and U.K.

### *D. One Company's Results*

In 1989 my employer's senior management made a highly visible commitment to reducing the risk of injuries from electrical hazards to employees and contractors. Goals for sustainable improvement were established, financial support provided, and dedicated people empowered to reduce the likelihood of electrical incidents. We began crafting a focused application of the company's safety management expertise in highly hazardous processes to the unique hazards of electrical energy.

In 1992, I led the development of the paper *Creating a Continuous Improvement Environment for Electrical Safety* [16], which was based on integrating advanced concepts in risk management into our existing electrical safety program. This paper, presented at the 1992 PCIC Conference in San Antonio, outlined a long-term strategy for establishing a culture for continuous improvement in electrical safety. The culture and continuous improvement strategy nurtured for more than 25 years resulted in significant progress in reducing the severity and frequency of electrical injuries in the company. Most dramatic is the impact on the frequency of fatalities from electrical energy. As shown in Fig. 5, before 1993, fatalities from electrical energy were occurring on average every 33 months [17]. The chart represents a global workforce of employees and contractors that ranged from 80,000 to 120,000. The fatality frequency was industry average for the period. From 1993 to 2016, there were zero fatalities from exposure to electrical energy in company facilities, demonstrating that significant and sustainable improvement is achievable.


Fig 5. Improvement in occupational fatalities from exposure to electrical energy in the company's global operations. Employee and contractor workforce during the period was ~ 100,000.

### *E. OSHA Signals a Shift*

In 2010, the assistant secretary of the U.S. Department of Labor, Dr. David Michaels, issued this statement to the OSHA staff, *"Ensuring that American workplaces are safe will require a paradigm shift, with employers going beyond simply attempting to meet OSHA standards, to implementing risk-based workplace injury and illness prevention programs."* Although OSHA has not proposed any regulatory requirements to facilitate this shift, resources are available to help make this shift [18].

## VII. CONCLUSION AND RECOMMENDATIONS

So, what have I learned during this 50-year journey? The electrical hazards have not gone away. If anything, the potential for exposure to hazardous electrical energy has increased due to the growth in applying electrical technologies for energy, control, and communications in industrial applications. The evolution in occupational electrical safety regulations and standards in the U.S. has contributed to a significant reduction in occupational electrical injuries. However, the approach taken in the U.S. has created a widely held paradigm that compliance will be sufficient. Other countries have demonstrated that compliance combined with advanced safety concepts to more effectively identify hazards, assess risks, and evaluate risk control effectiveness can impact further reductions in injuries and fatalities from exposure to electrical hazards. Early IEEE IAS electrical safety leaders exhibited exceptional competency in hazard identification and application of risk management techniques. They were likely influenced by the events and concerns that hadled to the development of systems safety.

Significant further reduction in occupational electrical injuries and fatalities will require a culture shift in safety management. Compliance-based programs will need to shift from compliance only to incorporate risk management and other concepts derived from systems safety. Electrical safety leaders will need to commit to continual learning of the most effective approaches to safety management. Adding risk management components to compliance involves in depth understanding of hazard identification, risk assessment, and risk reduction to supplement the results in injury prevention afforded by a compliance-based approach. In addition to the resources listed in References, a bibliography of resources to draw upon include:

- ANSI Z10 - 2019 *Occupational Health and Safety Management Systems* [19]
- ISO 45001 - 2018 *Occupational Safety and Health Management Systems* [20]
- *Advanced Safety Management 3rd ed*, by Fred Manual [21]
- *Hazard Analysis Techniques for System Safety, 2nd ed*., by Clifton Ericson [22]
- *Risk Management Tools for Safety Professionals,* by Bruce Lyon and Georgi Popov [23}
- *System Safety Engineering and Risk Assessment,* by Nicholas J. Barr [24]

Significant improvement in preventing injuries and fatalities from exposure to electrical energy is possible and achievable. For more than 35 years, I have used the lens of systems safety to highlight ways to address the residual risk left unmitigated by a compliance-only approach to electrical safety. We can change how we think about compliance and the opportunities to integrate the lessons of systems safety into existing electrical safety regulations, standards, and programs.

The journey continues…

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## IX. VITA


H. Landis "Lanny" Floyd II (A'72–M'73–SM'91–F'00–LF'15) received a Bachelor of Science degree in electrical engineering from Virginia Polytechnic Institute and State University, Blacksburg, VA, USA, in 1973. His 45+ year career with DuPont, Wilmington, DE, USA, focused on electrical system reliability and electrical safety in the design, construction, operation, and maintenance of DuPont facilities worldwide. He retired in 2014 as Principal Consultant Electrical Safety and Technology and Global Electrical Safety Competency Leader. He is currently an Adjunct Faculty Member with the Engineering Graduate School of Advanced Safety Engineering and Management, The University of Alabama at Birmingham, Birmingham, AL, USA, and owner of Electrical Safety Group Inc., Elkton, MD, USA. He has published or presented more than 100 technical papers, magazine articles, tutorials, and workshop presentations on occupational electrical safety. Mr. Floyd is a professional member of the American Society of Safety Professionals, a Certified Safety Professional, a Certified Electrical Safety Compliance Professional, a Certified Utility Safety Professional, a Certified Maintenance and Reliability Professional, a Certified Reliability Leader, and a registered Professional Engineer in Delaware, Pennsylvania, Michigan, and Texas.