Safety Science 77 (2015) 143–151

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Control measures of electrical hazards: An analysis of construction industry

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ARTICLE INFO

Article history:
Received 23 December 2014
Received in revised form 12 February 2015
Accepted 1 April 2015

Keywords:
Hierarchy of controls
Injury prevention
Fatality investigation
FACE
Electrocution
Narrative text analysis
Tag cloud

ABSTRACT

The construction industry has adopted control measures of electrical hazards for decades, however construction workers are still electrocuted in the workplace every year. This problem leads to a need for assessing the quality of control measures. The goal of this study is to assess the control measures of electrical hazards using a perspective of hierarchy of controls (HOC). HOC counts control measures of five levels in descending effectiveness, which are Elimination, Substitution, Engineering, Administration, and Personal protective equipment. This study uses mixed methods of narrative text analysis and statistical analysis in examining 486 NIOSH recommended controls from fatality investigations. Findings reveal that behavioral controls remain prevalent in electrical hazard mitigation even though the knowledge of construction safety and health has increased in the past decades. This study also finds that effectiveness of controls is not statistically different by construction type nor occupation. Proposing a solution, the authors suggest that construction managers strictly stick to HOC rules by giving priority to higher level of controls and highly recommend that the U.S. construction industry leverage its prevention strategy by embracing more technological innovations and incentivizing prevention through design.
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1. Introduction

Literature shows that electrical-accident-related occupational injuries are disproportionate in construction compared to any other production sectors (Suárez-Cebador et al., 2014; Zhao et al., 2014). In the United States, the Occupational Safety and Health Administration (OSHA) named electrical hazards as one of the fatal four hazards to construction safety and health. Electrical hazards have been studied and corresponding mitigating measures have also been adopted for decades; however, construction workers still get electrocuted in the workplace every year. Data from the U.S. Bureau of Labor Statistics (BLS 2014) show that 51.1% of nationwide electrical fatalities occurred at construction sites in 2013. Such a disproportionate proportion keeps attracting attention to electrical hazards.

Electrical hazards are well known and believed to be controllable (Floyd and Liggett, 2010; Kleiner et al., 2008) and therefore a need arises for assessing effectiveness of existing control measures. However, little to no research has shed light on such assessment of control measures of electrical hazards in construction. To bridge this gap, the present study attempts to address the problem of electrocution with a goal of ultimately minimizing workers' exposure to hazards.

In risk mitigation practice, performance evaluation often uses a hierarchy of controls (HOC) standard to estimate a protection's effectiveness (Manuele, 2006; Wakefield et al., 2014). As Fig. 1 illustrates, HOC categorizes control measures into five primary levels in descending sort of effectiveness. The five levels (in a top-down order) are Elimination, Substitution, Engineering, Administration, and Personal protective equipment (PPE). Elimination is the first-level (most effective) hazard control that can remove the hazard all together. Elimination can be obtained by changing a work process in a way that will entirely get rid of a hazard; for example, disconnecting electrical circuits with electricity source. Substitution is the second-level control that exchanges something non-hazardous (or less-hazardous) to workers in place of a hazard. For example, a battery-powered (cordless) tool is a possible substitution for a corded power tool because it can mitigate hazards from electrical cords. Engineering is the third-level control that uses safeguarding technology to place a barrier to keep a hazard from reaching workers. For example, using non-conductive ladders in construction may help to isolate workers from power lines. Administration is the fourth-level control that changes workplace schedules, policies, or procedures. For example, implementing the lockout/tagout procedure may

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http://dx.doi.org/10.1016/j.ssci.2015.04.001
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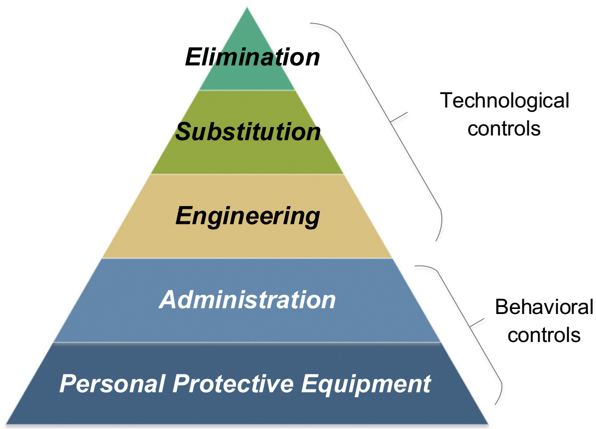

Fig. 1. Hierarchy of controls.

decrease probability of a worker being shocked. PPE is the fifth-level control that directly places protective equipment on workers' bodies. PPE examples include helmets, respirators, gloves, sleeves, goggles, and ear plugs.

The basic tenant of HOC is that control measures at a higher level are potentially more effective and protective while require more effort for implementation. The top three levels of control (shown in Fig. 1) are classified as technological controls in that they act on changing the physical work environment; while the bottom two levels represent behavioral controls in that they seek to change the way people work. The U.S. Centers for Disease Control and Prevention (2014) explains the hierarchy as follows:

- *Elimination* and *Substitution* are the most effective at reducing hazards. They tend to be the most difficult to implement in an existing process while may be less expensive and less difficult for a process at the design stage.
- *Engineering controls*, if well designed, are highly effective in protecting workers and are typically independent of worker interactions. The initial cost of engineering controls is often high while the long-term operating cost is frequently low, or can even provide a cost savings in some instances.
- *Administrative controls* and *Personal Protective Equipment* (*PPE*) are frequently used with existing processes but have proven to be less effective than other measures. The initial cost may be relatively low while the long-term cost to sustain can be high. These measures require significant effort by the affected workers and do not well control hazards.

The strategy of learning from failures is based on the idea that risk mitigation measures often arise from accidents. Such an effort for risk mitigation is the National Institute of Occupational Safety and Health's (NIOSH) investigations of Fatality Assessment and Control Evaluation (FACE). Each FACE investigation contains non-routinely-analyzed elements in its report that allows for identification of factors that contribute to a fatal incident (Bunn et al., 2008). From the perspective of research, FACE has unique merit in the recommendations for prevention provided at end of each investigation. NIOSH safety professionals who wrote the reports suggest corresponding control measures in these recommendations based on their investigations. As a result, the NIOSH recommendations are considered to be a good resource for research of accident analysis and prevention. Kunadharaju et al. (2011) examined NIOSH recommendations from firefighter fatality investigations and generalized accident causes and corrective actions. Zhao et al. (2014) analyzed 132 electrocution reports and listed

Table 1
NIOSH recommendations for electrocution prevention (Zhao et al., 2014).

NIOSH Recommendation	Pct. (%)
Adequate safety training and periodic specialized electrical safety training programs should be implemented to enhance the electrical hazard cognition and the avoidance of unsafe conditions in workplace	62.9
Well-designed non-conductive personal protective equipment, communication equipment and supporting equipment should be provided and enforced to workers in workplace	47.7
An electrical hazard survey should be conducted at jobsite to identify potential electrical hazards and intervention measures before work	47.7
Compliance with safety procedures that required by existing federal and state standards and regulations should be ensured, such as the proper grounding, minimum clearance and lock-out/tag-out procedures	42.4
Power lines should be de-energized or insulated before all works start	34.1
On-site safety procedures, safety meeting and safety inspection should be enforced at construction site on a routine base	33.3
Electrical safety procedures and preventions should be thoroughly considered and improved at the construction planning stage	17.4
Guarding co-workers, warning signs and the supervisory guidance should be ensured on site	13.6

the top-cited NIOSH recommendations for electrocution prevention (see Table 1). Based on that finding, Zhao et al. (2014) recommended an enhancement of hazard awareness through safety training as a central part of prevention strategies. Nevertheless, previous studies did not evaluate the quality of resulting control measures, which may influence the reliability of implementation and performance.

FACE reports are narrative text in nature, which allows researchers to extract desired information using a method of narrative text analysis (NTA). Compared to coded surveillance data, the narrative text is believed to have added value (McKenzie et al., 2010) in the following three aspects: (a) the identification of cases through alternative classification schema; (b) the identification of sequential chain-of-event information; and (c) the identification of systematic errors. As a result, many researchers have studied narrative text data in pursuit of occupational safety and health (OSH) in construction (Kemmlert and Lundholm, 2001; Smith et al., 2006) and other industries (Bentley et al., 2005; Fordyce et al., 2007; Lincoln et al., 2004).

Overall, the present work attempts to assess control measures of electrical hazards through both qualitative and quantitative analyses on FACE reports. Specific aims of this study are to identify (a) the effectiveness of adopted control measures; (b) the specific prevention strategies; (c) the discrepancies of control measures among construction types, occupations, and electrical conditions; and (4) the trends of change over time.

2. Material

FACE reports prove to be an eligible data source for OSH research. FACE reports have contributed to the formulation and dissemination of diverse strategies for OSH injury control (Higgins et al., 2001). This data source contains uncommon yet important information in the narrative texts, although they contain similar inclusion criteria with coded surveillance data sources, e.g., the Census of Fatal Occupational Injuries (Hammond et al., 2012). As a result, many prior studies have selected FACE reports as data source. For example, Cohen et al. (2006) examined FACE reports and concluded accident characteristics and resulting strategies needed to protect workers. Further, Kunadharaju et al. (2011)

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